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ORIGINAL PAPER

Trends and impacts of temperature and fire regimes in South Africa's coastal national parks: implications for tourism

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Abstract

Climate change poses significant risks on coastal national park-based tourism through its effect on accessibility, comfort levels, and spatiotemporal changes of attractions. Wildfires and extreme temperatures have become issues of concern. Due to the widespread occurrence of fires in national parks along coastal areas and the noticeable changes in temperature regimes, more needs to be done to deepen understanding of their trends and impacts and devise appropriate management regimes. This study analyses the trends and impacts of fires and temperature-related variables in six coastal South African national parks, namely Agulhas, Garden Route, West Coast, Table Mountain, Namaqua, and Addo Elephant National Park. The triangulation and convergence model of the mixed-methods research design was adopted as the inquiry strategy. Data on statistical weather variables from the South African Weather Services and the National Aeronautics and Space Administration were used to calculate temperature trends using Mann–Kendall trend tests and homogeneity analysis. Data collection included questionnaire surveys, key informant interviews, field observations, and document analysis. The study observed statistically significant ($p < 0.05$) changes in temperature-related variables in all coastal national parks. There is also an increase in the intensity and spatial spread of fires, resulting in increased fire damage over time. Despite the current efforts of the coastal parks to manage wildfires and the changing climatic patterns, the fire and temperature regimes are threatening the biophysical environment with resultant effects on tourism and the economic viability of the national parks. The need to reengineer the fire suppression mechanisms and temperature-resilient tourism facilities has been observed.

Keywords Coastal national parks · South Africa · Temperature · Wildfire · Climate change · Tourism

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1 Introduction

The world's climate system is changing, as indicated by the increase in the frequency of slow onset and extreme events. There is a continuing increase in average temperatures, changes in precipitation trends, increased frequency and severity of cyclones, floods, droughts and heat waves, rise in sea level, ocean acidification, desertification, fires, and ecosystem degradation (IPCC 2021). The changes are expected to alter landscapes and conservation areas, including national parks (Dube and Nhamo 2020), especially those located near coastal areas (Coldrey and Turpie 2020). National Parks comprise important ecosystems preserved for recreational activities and conservation of the natural environment and cultural heritage, among other purposes (Liu 2016). However, the critical functions of national parks are threatened by changes in the climate system. The increased frequency and severity of fires and temperature regimes have great potential to exacerbate the fragility of park-based tourism enterprises.

Scientists agree that continued use of fossil fuels is highly likely to exacerbate the climate crisis with consequent impacts on natural resources, potentially making the most valuable parks inaccessible for tourism activities and inhabitable for wildlife (Coldrey et al. 2022; Michalak et al. 2022). The impacts of climate change on national parks are predicted to negatively affect southern African economies, as nature-based tourism contributes significantly to national incomes (Dube and Nhamo 2020).

Coastal areas are affected by climate change in several ways. Mgadle et al. (2022) notes that coastal areas are vulnerable to sea level rise, frequent and high-intensity storms, and warmer temperatures. The increase in atmospheric carbon dioxide has resulted in a surge in the amount of carbon sequestered by oceans, resulting in ocean acidification (Asha et al. 2023). Climate change-driven acidity, temperature increases, and precipitation vagaries have significant impacts on coastal ecosystems (USEPA 2017). From the coastal ecosystems, including those in national parks, temperature-sensitive species are affected, resulting in abundance shifts and consequently a change in species composition. The ultimate effect of these climate-induced ecological changes is on biological diversity (Chapungu and Nhamo 2016; Chapungu 2017; Chapungu et al. 2020). Changes in biological diversity destabilize ecological integrity and sustainability of species of fauna and flora with dire impacts on tourism in national parks (Liu 2016; Coldrey et al. 2022). National parks are renowned for their rich biodiversity, considered a major tourism draw card' (Dube and Nhamo 2020). To this end, the rich biodiversity hosted in national parks remains under threat and the effects will be felt in the tourism industry.

Temperature and fire regimes are important climatic variables for coastal national parks. Temperatures are necessary for a number of ecological processes that promote vegetation growth, nutrient cycling, and functional integrity of ecosystems (García et al. 2018). On the other hand, fires play an important role in ecosystems by generating open habitats that enable the evolution and growth of shade-intolerant species (Pausas and Keeley 2019). At ecosystem level, fires further enhance habitat heterogeneity by creating spaces and increasing niches that enhance evolutionary processes (Pausas and Keeley 2019). Hence, both temperatures and fires are necessary ingredients in natural ecosystems, including national parks. However, when temperature and fire regimes go beyond ecological and species tolerance levels, they become destructive. For example, high temperatures are a threat to the functional integrity of the Earth's ecosystems (García et al. 2018). As such, undesirable biotic and abiotic changes in ecosystems have been observed when the thermal tolerance of species and ecosystems are exceeded (Grimm et al. 2013; Chapungu et al. 2020). The increased frequency and severity of fires has resulted in the burning of important biomass, which promote functional integrity of ecosystems. Fires may also lead to the displacement of faunal species, alteration of reproductive cycles of wildlife, and habitat fragmentation, among others (Keeley 2009).

Ecosystems vary in their sensitivity to temperature and fire regimes due to the complexity of biological interactions, abiotic disparities, geographical intricacies, and other disturbances, including human impact (Malhi et al. 2020). Coastal national parks in South Africa comprise special ecosystems that vary in support of a diversity of species that have been key to tourism. In view of the effect of temperature (García et al. 2018) and fire regimes (Keeley 2009) on ecosystem functional integrity, as well as studies that indicate that the climate system in national parks is changing (Dube and Nhamo 2020; Chikodzi et al. 2022), the need to examine the trends and impacts of temperature and wildfire regimes on coastal national parks and tourism potential cannot be overemphasized. Therefore, this article seeks to investigate trends and impacts of temperature and wildfire regimes in six South African coastal national parks and tourism potential. The research questions for the study are as follows:

1. What are the trends in temperature and fire regimes in coastal national parks over time?
2. What are the impacts of temperatures and fires on coastal national park resources?
3. What are the implications of temperature and fire regimes on tourism?

Knowledge could be useful in the establishment of species- and park-specific adaptation and resilience management regimes to offset the possible adverse impacts of unfavourable trends of the selected climatic variables.

2 Review of the literature

2.1 Trends in temperature and wildfires in national parks

Several studies have confirmed that global surface temperatures have increased by more than 1 °C since the industrial revolution (Hansen et al. 2012; Huntingford et al. 2015; IPCC 2021). Several national parks specific studies on temperature trends have shown that temperatures in national parks are increasing over time. For example, van Wilgen et al. (2016) documented that the Kgalagadi Transfrontier Park in South Africa experienced an increase in temperatures by 1.9 °C on average since 1960. Dube and Nhamo (2020) observed an increase in temperatures in Kruger National Park, another park in South Africa. The worst-case scenario computations of climatic variables in the USA revealed that national parks were projected to experience a temperature increase of between 3 and 9 °C in the next 80 years (Haiken 2018). Other studies from the US reflect that national parks are warming faster than other places due to their location in areas that are highly vulnerable to climate change, such as high-altitude areas, remote, arid, and semi-arid environments (Ahmed 2018).

The widespread global warming reported in various studies (Hilaire et al. 2019; Deutch 2020; El-Sayed and Kamel 2020; IPCC 2021) has not spared national parks in all biomes around the world. In view of the differences in biophysical conditions between biomes, the impacts of temperature rise would differ from one biome to another (Ahmed 2018). Additionally, impacts and trends of coastal and inland national parks could possibly differ as a consequence of the influence of oceans on earth's atmospheric processes affecting coastal regions.

The high temperature regimes recorded in national parks have also been associated with an increase in the frequency and intensity of wildfires (Kruger et al. 2000; Keeley 2009; Kraaij et al. 2017). In South Africa, Forsyth et al. (2010) observed an increase in the occurrence and a change in the behaviour of wildfires was observed. In Kruger National Park, the frequency of fire was observed that fire frequency had increased (Van Wilgen et al. 2004; Chamane 2012; Smith et al. 2013). The increase in fire occurrence was attributed to the increase in temperatures and the decrease in rainfall, especially in the savanna biome (Kusangaya and Sithole 2015). Kavhu and Ndaimani (2022) observed a significant ($p = 0.000258$; $\alpha = 0.05$) relationship between annual average temperatures and the frequency of wildfires in Hwange National Park in Zimbabwe. The same trend and dynamics were observed in other biomes (Kopper 2022). For coastal regions with a Mediterranean climate, further studies are needed to determine the trends and dynamics.

Kopper (2022) reports an increase in fire frequency in the western national parks of the US. In Zimbabwe's Hwange National Park, (Kavhu and Ndaimani 2022) and (Kusangaya and Sithole 2015) observed an increase in burnt areas over time, signalling an increase in fire frequency, intensity, and spatial behaviour. In Gonarezhou National Park, another national park in Zimbabwe, wildfire frequency has been reported to have increased over time (Gandiwa and Kativu 2009). What emerges is that, in view of the relationship between dry climate and fire frequency and intensity, national parks in all biomes of the world are threatened by veld fires, which expose their ecosystems to fire-related disasters. It is necessary to examine trends and impacts in specific ecosystems to understand and develop adaptation and mitigation options.

2.2 Impacts of changes in the temperature and wildfire regime in national parks

Climate change, in its various manifestations, threatens the integrity of natural ecosystems (Chapungu et al. 2020; El-Sayed and Kamel 2020). Specifically, changes in rainfall patterns, temperature regimes, fire behaviour, and drought frequency, among others, have modified ecosystems through changes in biodiversity (Oberle et al. 2019), habitat fragmentation (Chapungu et al. 2014), species phenology and abundance among others. National parks comprise important ecosystems preserved for recreational activities and the conservation of the natural environment, and cultural heritage among other purposes (Liu 2016). However, the important functions of national parks are being threatened by changes in the climate system.

Changes in temperature patterns and fire regimes have contributed significantly to the alteration of functions and services provided by national parks. Liu (2016) noted that temperature increases in some glacier national parks led to the melting of glaciers, with resultant effects on vegetation changes, natural habitat destruction, and extinction of some species. Glacier National Park in Montana is reported to have lost more than 115 glaciers, with more glaciers expected to follow the same trend (Hall and Fagre 2003; Florentine 2019). In Tanzania, high temperatures resulted in the disappearance of glaciers, influencing drastic environmental and wildlife changes at Amboseli National Park (Wasike 2021). In the US, the Joshua National Park is predicted to be on course to lose all Joshua trees due to temperature increase (Haiken 2018).

The general effect of unplanned fires is negative, as observed by various studies (Forsyth and van Wilgen 2008; Kusangaya and Sithole 2015; Nieman et al. 2021; Kavhu and

Ndaimani 2022). In Gonarezhou National Park, the frequency of fires has affected the structure and composition variables of the forest, including tree height, dead plants, the basal area and shrub density (Gandiwa and Kativu 2009). In the Western Cape province of South Africa, fires have resulted in the loss of some animal species, including tortoises and other small species (Kruger et al. 2000). The next section focusses on the materials and methods used in the document.

3 Methodology

3.1 Study area

The study was carried out in six coastal national parks that span three provinces of South Africa, namely Addo Elephant National Park in the eastern Cape, Garden Route National Park (East and West Cape Provinces), Agulhas National Park, Table Mountain National Park, West Coast National Park (West Cape Province) and Namaqua National Park (North Cape Province) (Fig. 1). Addo Elephant Park is located in a transition zone of two different climatic regimes. Given its vastness, some areas are in the summer rainfall season, while others are in areas that experience winter rainfall, and yet other areas experience rainfall throughout the year. The amounts of rainfall vary from 350 to about 900 mm per year (South African National Parks 2015). Temperatures in the park region vary between 15 and 45 °C in January and can reach as low as 5 °C and 18 °C. Addo Elephant National Park is one of the most diverse parks in South Africa, comprising six out of the seven biomes found in the country.

The Garden Route National Park stretches over two provinces of the Eastern Cape and Western Cape and is a segmented national park with towns, farms and other nonprotected areas in between it. Some of the sections of the park include Tsitsikamma National Park,

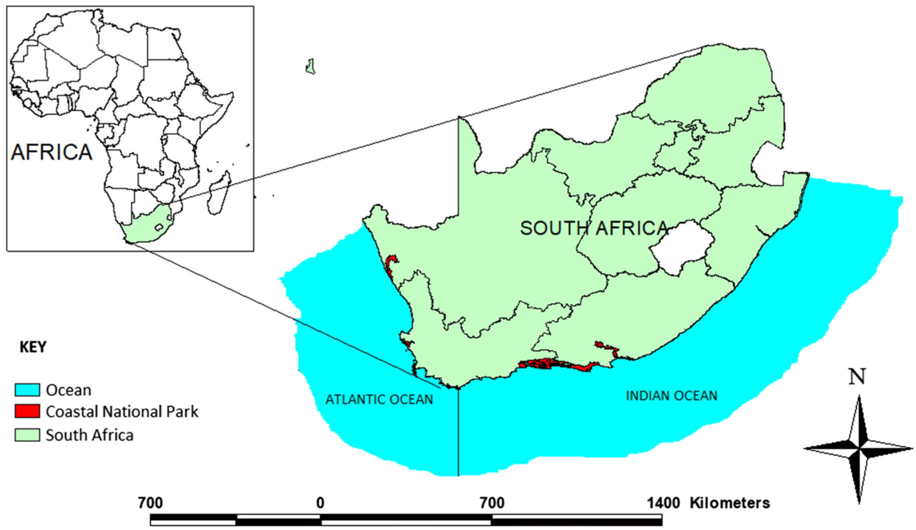

Fig. 1 Study area map *Source* Authors

the wilderness section, and the Knysna lake area. The three sections of the park have different biomes and ecosystems given the distance between them.

Agulhas National Park is part of the protected areas of the Cape Floral region and is part of the World Heritage Site of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The park is considered to fall under Mediterranean climatic conditions with a predominantly winter rainfall season. Rainfall is reported to range between 400 and 600 mm (South African National Parks 2015).

The weather of Table Mountain National Park is influenced by the Indian and Atlantic Oceans. The climate in the park is quite varied within a short distance due to the topography of the area and the oceanic influences. The park shares space with the city and the Cape Town habitat.

The West Coast National Park is located in Langebaan and stretches all the way to Saldanha Bay. The climate of the park is considered semi-arid, Mediterranean, and rainfall falls in winter. The annual average rainfall is about 265 mm (SANParks 2013). Lastly, Namaqua National Park also lies on the Atlantic Ocean coastline and is part of the Succulent Karoo biome and is located in the northern Cape Province.

4 Research design

The triangulation and convergence model of the mixed-methods research approach was adopted for the inquiry procedure. The design uses different but complementary data on the same topic to gain a deep understanding of the research problem (Tashakkori and Creswell 2007). Figure 2 shows the research design used in this study.

4.1 Data collection

Following the procedures shown in Fig. 2, the questionnaire survey method was used to collect data from national parks employees ($n = 150$) and tourists ($n = 870$). The tourist perception survey tool sought to gather tourists' views on the climatic threats facing national parks, how these threats can affect tourists' experiences in national parks and what tourists

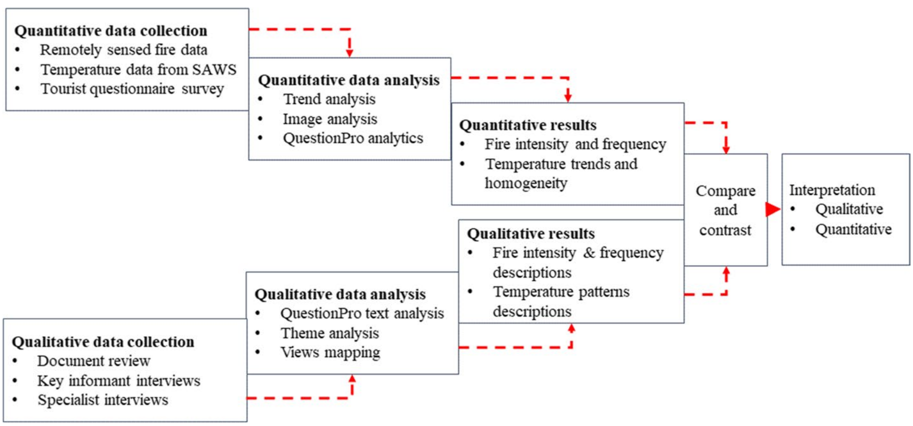

Fig. 2 The triangulation-convergence model adopted for the study

thought could be some of the solutions to the threats facing coastal national parks in South Africa. The survey was administered by the researchers using a QuestionPro preloaded questionnaire on mobile devices. Each survey took an average of 12 min to complete.

Furthermore, the study used interviews to collect data from employees located in the respective national parks ($n = 150$). The interviewees included park managers, park rangers, tourism managers, climate change experts, park scientists, and ecologists. Data collection was carried out between September 2020 and December 2021. This period covers all the climatic seasons of the national parks to allow one to capture the perceptions of tourists who visit in different seasons. These data sets were augmented by archival and secondary data sources such as annual reports, science bulletins, and park management plans. On average, each interview took 45 min. The inclusion criteria for the interviews were that the interviewee must have more than five years of experience working in the park. An interview guide was used that had questions that focused on climatic trends for the parks, experienced extreme weather events, the perceived and observed impacts of such events on flora and fauna and tourism operations and activities. Some of the questions were as follows:

1. May you provide a brief description of the weather events in this park over the past years, as far as you can remember?
2. What aspects of this park have been affected by specific weather events? Explain in detail how the specific impacts occurred.

Quantitative meteorological data spanning more than three decades were downloaded from NASAPOWER (https://power.larc.nasa.gov/data-access-viewer/). Of interest were data for temperature-related variables. The data were used to determine the trends of temperature-related variables over time and compute the statistical significance of such trends. The purpose of this procedure was to understand whether temperatures in coastal national parks are changing significantly or not.

Remote sensing techniques were also used to collect data on fire frequency and intensity. Only Table Mountain and Garden Route National Parks were selected for evaluation using remote sensing because they have recently recorded large fires that warrant research attention. For Garden Route National Park, the analysis was performed for the period between 2016 and 2020, while for Table Mountain, the analysis period was for the period between 2017 and 2022. The spectral unmixing procedure was adopted to observe the ground cover materials of the components and obtain their abundances. The use of spectral unmixing was premised on its dexterity to show fractions and proportions of each end-member within a mixed pixel (Miao et al. 2006; Kusangaya and Sithole 2015).

The spectral unmixing procedure computes each spectrum as a combination of a finite number of spectrally discrete signatures, whose coefficients range between 0 and 1 and adding up to 1 (Kusangaya and Sithole 2015). This linear mixture model can be mathematically described for a pixel in band i, with the observed pixel reflectance R_i as a linear equation:

$$R_i = \sum_{i,j=1}^{n} fj\, aij + \varepsilon_i \tag{1}$$

where fj is the j-th fraction of the end member in a pixel, j is the total number of end members in the scene, aij is the pure reflectance from the jth end members in the ith pixel, and ε_i is an error term.

Only two distinct signatures or land classifications were used: burned areas and non-burnt areas. The minimum noise fraction (MNF) was used to reduce the image dimension from which the distinct spectral signatures were selected. According to (Kusangaya and Sithole 2015), the MNF segregates and equalizes 'the noise in the data and reduces the computational requirements for subsequent processing'.

4.2 Data analysis

Exploratory and confirmatory data analysis was performed using various quantitative and qualitative research procedures. Closed questions in the surveys were analysed using QuestionPro Analytics. This is an in-built function of QuestionPro that permits simple and more complex statistical analysis according to the user needs. The open-ended questions were analysed using QuestionPro Text analytics. The interview data were transcribed by experts and went through the process of content and thematic analysis based on the research questions that were established in this study.

Quantitative meteorological data were explored to determine trends in temperature-related variables, specifically maximum monthly mean temperatures (MMMaxT). To determine the months with high temperatures and a high likelihood of fire occurrence, temperature and fire occurrence scores were calculated for a period of more than 30 years for each park, as shown in Fig. 3.

Trend tests were performed to determine changes in temperature-related variables for the six coastal national parks. The Mann–Kendall trend test was then used for trend analysis. The time series data were subjected to prewhitening using the autoregressive moving average (ARIMA) model before it was used for trend testing. The Mann–Kendall test statistic is calculated using Equation:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(Xj - Xk) \tag{2}$$

where S is the Kendall score. $Sgn\ (x) = (1 \text{ if } x > 0, 0 \text{ if } x = 0, -1 \text{ if } x < 0)$.

The variance of S is calculated from Eq. 3

$$\text{Var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p-1}^{g} \text{tp}\ (\text{tp}-1)(2\text{tp}+5)\right] \tag{3}$$

where n is the number of groups tied and tp is the number of observations in the pth group. After computing the variance, the Z value (Z_{MK}) is calculated as follows:

$$\begin{aligned} Z_{\text{MK}} &= \frac{s-1}{\sqrt{VAR(S)}} \text{ if } S > 0 \\ &= 0 \text{ if S } = 0. \\ &= \frac{s+1}{\sqrt{\text{VAR}(S)}} \text{if S } < 0 \end{aligned} \tag{4}$$

A positive MK statistic Z_{MK} denotes a positive change in the variable trend, while a negative Z_{MK} indicates a decreasing trend. Values greater than 1.96 and smaller than 1.96 indicate significant changes at 95% confidence level" (Chapungu and Nhamo 2021: 4).

Fig. 3 Monthly mean maximum temperatures (MMMaxT) (1980–2021) and the estimated fire occurrence score (5 = Very High, 4 = High, 3 = Medium, 2 = Low, 1 = very low)

5 Results

5.1 Temperature regimes in South African coastal parks

The results show that coastal national parks in South Africa are experiencing an increase in maximum monthly temperatures. Table 1 shows the trend and homogeneity characteristics for the six national parks in the study. There is a significant ($p < 0.05$) increase ($p < 0.05$) in monthly mean maximum temperatures in all the national parks of coastal in the study. There is no homogeneity in the temperature patterns, which shows that the temperature regimes for the parks have changed significantly at some point. Only Namakwa National Park has shown no significant trends in both temperature trends and homogeneity, but

Table 1 Mean monthly maximum temperature (MMMaxT) trends and homogeneity characteristics. *Source* Authors, data from South African Weather Services

Coastal park	Mann Kendall p value	Pettit's p value	Description of changes
Table Mountain	0.0001	0.000	There is a significant change in MMMaxT and there is a date where there was a significant change in MMMaxT
Agulhas	0.000	0.000	There is a significant change in MMMaxT and there is a date where there was a significant change in MMMaxT
Garden Route	0.0001	0.0001	There is a significant change in mean monthly maximum temperatures and there is a date where there was a significant change in MMMaxT
West coast	0.0001	0.038	There is a significant change in MMMaxT and there is a date where there was a significant change in MMMaxT
Addo elephant	0.0001	0.021	There is a significant change in mean monthly maximum temperatures and there is a date where there was a significant change in MMMaxT
Namaqua	0.002	0.039	There is a significant change in mean monthly maximum temperatures and there is a date where there was a significant change in MMMT

significant interannual variability can be observed in the trend. Figure 4 shows the trends for the monthly mean maximum temperatures for the six national parks.

As shown in Fig. 4, climate change in coastal national parks is a reality as indicated by the temperature trends within the parks. The trend shows that the temperatures are increasing and the climate is warming. We also noted that post 1992, there is high interannual variability, which could be driven by the large-scale climate drivers such as the El Nino Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), and Southern Annular Modes (SAM), among others. Some large-scale drivers have a strong effect on the year-to-year

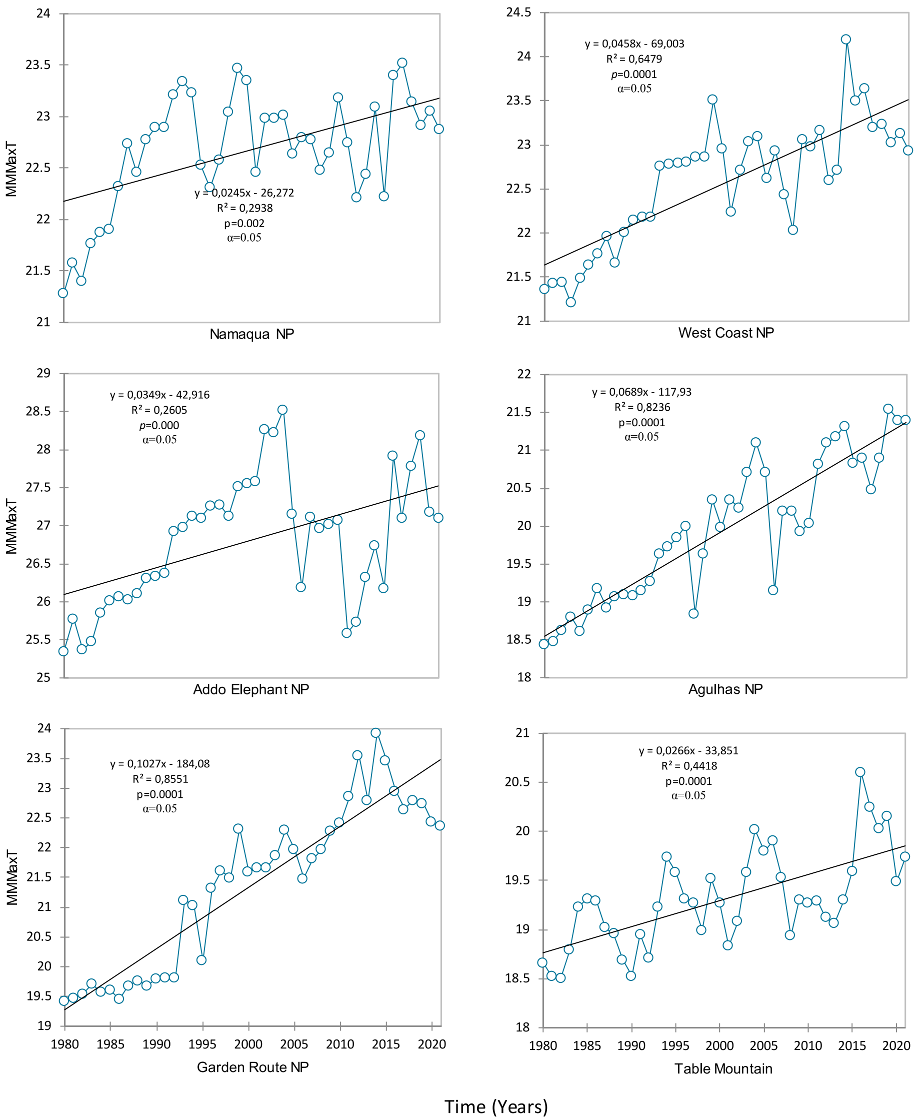

Fig. 4 Mean Monthly Maximum Temperature (MMMaxT) trends for selected Coastal National Parks in South Africa

variability of temperature and rainfall. For example, ENSO has a major influence in South African coastal national parks in DJF when it is highly prone to forest fires, as shown in Fig. 3. However, the overall 40 year trend for mean monthly maximum temperatures shows significantly increasing temperatures.

The data from the key informant interview and the tourist survey confirm the temperature trends observed in the statistical data. In Table Mountain National Park, for example, maximum temperatures were indicated as one of the most notable environmental changes experienced by tourists and park employees. Key informants indicated that in the early 1970s, cold snowing winters were experienced in the park, but they have since disappeared due to rising temperatures and the shift in seasonal temperature patterns influenced by climate change. In Garden Route National Park, temperatures were also highlighted as a major concern for tourism activities and various other impacts affecting the park, including the creation of fuel for wildfires.

All coastal parks have indicated effects of climate change that are related to an increase in maximum monthly temperatures. Table 2 shows the perceptions of tourists who participated in the study about the impacts of climate change related to the increase in temperature in the national parks of the study.

As shown in Table 2, tourists are of the opinion that the decline in vegetation experienced in coastal national parks is linked to the changing climate, characterized by an increase in the maximum monthly temperatures. This view has been confirmed through key informant interviews, who revealed that changes in environmental conditions, particularly the temperature and rainfall regimes, are the driving force behind the proliferation of invasive species and biodiversity losses. Consequently, there is a decline in vegetation and the resultant environmental degradation.

Other impacts related to high temperatures include a reduction in the animal population. Park managers and rangers explained that high temperatures have an effect on fertility, sperm quality, and production, resulting in low animal population. This has consequences on tourism productivity. It also emerged that some species alter their reproductive systems in response to changing environmental conditions, for example, some species postpone reproduction due to high temperatures'.

High temperatures have sucked dry the water points in coastal national parks, creating water scarcity challenges as observed in Addo Elephant national park. Attractions have also been defaced by the alternating extremes of high temperatures, cold spells, and the occasional high rainfall events in the coastal parks.

5.2 Fire regimes in coastal national parks

The increase in temperatures in coastal national parks is predicted to increase the risk of wildfires, both natural and human-induced. Fires have been reported to have increased in frequency and intensity over time. The occurrence of fires has resulted in massive damage to property in national parks, as well as wildlife resources, and environmental damage. However, the trend of fires in coastal national parks, in terms of their frequency and intensity, varies from one park to the other depending on the type of dominant vegetation in the park, fire management policy, and the influence of berg winds. Key informant interviews revealed a plethora of causes of fires in the national parks under study, including prescribed burning (especially in the case of Table Mountain National Park), access policy, escaped barbecue fires, powerlines, flares, lighting, arson, and falling rocks, among others. However, the link between wildfires and dry

Table 2 Tourist perceptions regarding the impacts related to temperature increase. *Source* Authors, fieldwork data

Perception	Percentage (%) of tourists with the corresponding perception						
	Table mountain % ($n=562$)	Namaqua % ($n=444$)	West coast % ($n=492$)	Garden route % ($n=517$)	Agulhas % (n = 524)	Addo elephant % (645)	Total % ($n=871$)
Decline in vegetation Species	21($n=118$)	7 ($n=31$)	14 ($n=69$)	21 ($n=109$)	13 ($n=68$)	16 ($n=103$)	57 ($n=498$)
Reduced animal population	14 ($n=79$)	6 ($n=27$)	11 ($n=54$)	17 ($n=88$)	11 ($n=58$)	16 ($n=103$)	47 ($n=409$)
Reduced bird population	9 ($n=51$)	4 ($n=18$)	7 ($n=34$)	11 ($n=57$)	6 ($n=31$)	9 ($n=58$)	29 ($n=249$)
Drying up of natural drinking points	7 ($n=39$)	8 ($n=36$)	7 ($n=34$)	8 ($n=41$)	8 (=42)	18 ($n=116$)	35 ($n=308$)
Destruction of attraction infrastructure	6 ($n=34$)	5 ($n=22$	5 ($n=25$)	5 ($n=26$)	2 ($n=10$)	5 ($n=32$)	17 ($n=149$)
Destruction of heritage features	7 ($n=39$)	4 ($n=13$)	3 ($n=15$)	5 ($n=26$)	3 ($n=16$)	5 ($n=32$)	16 ($n=141$)

climates has been noted in the interviews conducted. Additionally, changing wind patterns have also been identified as a contributing factor to current fire regimes, especially the berg winds (katabatic winds that are hot and dry) in Garden Route National Park. It emerged during key informant interviews that the winds have become stronger and more destructive. They also make it difficult to suppress fires as they improve the weather and size of the fires, as well as spreading raging fires to distant areas. These berg winds are hot and dry and originate in the semi-arid interior Karoo region.

The warm Agulhas current has been contributing to the temperature regimes along the eastern coast, contributing in influencing the fire weather for the Garden Route National Park. In addition to increasing temperatures, the fire regimes in coastal national parks have been influenced by the fire management structures and policies of the individual parks. In Table Mountain, for example, the fire management policy identifies the need for periodic fires to enable beneficial ecological processes resulting from periodic burning. Therefore, deliberate burning sometimes takes place. However, in most circumstances, the size of the fire will be larger than anticipated, resulting in extensive fire damage.

In both the Table Mountain and Garden Route National Parks, there has been a drastic reduction in the number of days per year that are ideal for controlled burning, hence some places have gone for years without burning. This creates massive accumulation of biolitter which can easily ignite and burn uncontrollably resulting in mega fires that are difficult if not impossible to suppress using available firefighting techniques. There is an extensive urban wildland boundary around Table Mountain, which complicates nonecological fire control and suppression, putting houses and infrastructure at risk. Recent fires in the park have left a trail of destruction.

Key informant interviews also revealed that fire regimes in coastal national parks have been enhanced by the presence of invasive species that are prone to fire. Invasive species occur as a result of previous land uses that replaced native fynbos vegetation replacing it with exotic pine trees. Invasive species have also been influenced by changing climate regimes dominated by increases in near-surface temperatures and frequent and severe droughts. Therefore, the new climates create a conducive environment for the proliferation of invasive species that have a high affinity for fires. Consequently, fires have increased in terms of their frequency, intensity, size, and destructiveness.

Most of the fires occurring in parks like Tsitsikamma, Knysna, and Table Mountain usually originate from outside the park, and the fires spread into the park even in the presence of fire breaks. The parks are surrounded by land uses that are mainly forestry of exotic trees that are vulnerable to fires. The situation is further complicated in some places such as the Tokai Section of Table Mountain, where attempts by SANParks to harvest exotic trees and replace them with native fynbos vegetation have been met with objections and lawsuits from local community organizations. This has led to further improvement of fire risk in the areas. In addition, the park is mostly open access, which makes it difficult to monitor the activities of visitors in the park.

The MODIS Terra thermal anomalies data show variations in fire intensity and frequency over time. The high variability in fire behaviour is influenced by interannual variability of environmental conditions, specifically temperature changes. Fires preceded by drought periods have been observed to cover large areas compared to periods when there is no drought. Table 3 shows the fire occurrences and the damaged area. There has been a gradual increase in the overall size of the burnt area as shown by the fire scars.

Table 3 Major fire events in coastal national parks and their impacts. *Source* Authors, Compilation from fieldwork interview data and various secondary data sources

National park	Recent major fire events	Major impacts
Garden route	Tuesday, 22 September 2020	Infrastructural damage
	Monday, 29 October 2018	18 houses destroyed, 75 people displaced, loss of life, 5000 hectares of fynbos destroyed, access roads were closed, Outeniqua hiking trail was closed
	Tuesday, 06 June 2017	Staff members lost their homes, 500 houses destroyed, 7 people died, 700 were displaced from their homes
	Thursday, 11 August 2016	4 homes were destroyed, 15,000 hectares of land were damaged
Table mountain	Sunday, 18 April 2021	650 hectares of Rhodes Memorial area was burnt, 11 buildings were destroyed, a library with historical archival information, biodiversity loss, a lawsuit by Cape Town University against SANParks
	Thursday, 09 June 2022	Visibility effects on motorists
	Saturday, 17 March 2018	Disruption of tourism activities
	Tuesday, 17 January 2017	Two residential structures, a guard house and an office were damaged
West coast	Thursday, 15 January 2015	6000 hectares burnt, affecting biodiversity
Agulhas	Saturday, 26 December 2009	60% of the park was burnt, habitat destruction, introduction of new alien species
Addo elephant	Friday, 15 August 2008	7000 hectares of fynbos and grassland vegetation, Disruption of tourism activities

5.3 Major fire events and impacts in coastal national parks

Some of the coastal national parks, specifically, Table Mountain, Garden Route, Agulhas, Addo Elephant, and the West Coast, have experienced wildfires that resulted in environmental and economic losses. However, there is a marked variation in the frequency and severity with which wildfires occur in these national parks. Table Mountain and the Garden Route, for example, experienced more frequent and damaging fires compared to other parks. Table 3 shows the major fire events in coastal national parks and their impacts. As shown in the table, between 2016 and 2022, Table Mountain and Garden Route had more than four fire events each, resulting in significant losses and damage, while other national parks experienced one or two events. This was confirmed by a key informant who said:

> Garden Route and Table Mountain are our problem parks when it comes to fire management issues.... the fires are fierce and more frequent compared to other parks.....

Forsyth and Van Wilgen (2007) reported about 373 fires recorded in Table Mountain between 1970 and 2007. About 244 of these fires were reported to be of unknown origin, but they have been associated with weather regimes. Kraaij et al. (2017) observed that climate change-related invasion by invasive species has contributed to fire intensity in Garden Route National Park. Replacement of natural fynbos vegetation with pine plantations has exacerbated the frequency and intensity of fires. Although some past wildfires were very intense and destroyed large areas, for example, 5000 hectares in Table Mountain in 2009, park management staff noted that the intensity of fires and the level of damage are increasing over time. A Park Manager at Table Mountain had said:

> ...... We need to increase the game with respect to fire management before we completely fail to control the fires because they actually increase in frequency and intensity over time.

The frequency of incidence of fires has increased over time; for example, the burnt areas in Fynbos vegetation has become more than four times greater than in the past, especially in the 1980s. Fire frequency has increased in fynbos and Renonsterveld vegetation over time. With a constantly drying climate, there is a high likelihood that fires continue to increase in frequency. In Garden Route National Park, wildfires have affected all aspects of life, including socioeconomic activities. Life and property such as houses and related assets have been lost. Economic losses to the tune of millions of Rands have been incurred. The loss of biodiversity and destruction of sensitive environments have been reported, despite the fact that fires are sometimes used as a land and ecosystem management tool, especially in fynbos vegetation whose regenerative capacity is dependent on fire. A key informant summarized the impacts of fire as follows:

> ... Wildfires are a serious threat to the park. Whenever they occur, we experience losses from all ends, including lives, biodiversity, and infrastructure... In 2016, close to 15000 hectares of the park were damaged by fires. Damage usually results in a lot of financial losses…"

Figure 5 shows the impact of fires on vegetation health and cover in the Garden Route, as indicated by the enhanced vegetation index evaluated after the major 2017 fire outbreak. A sharp decrease in EVI reflects the impact of fires on vegetation cover

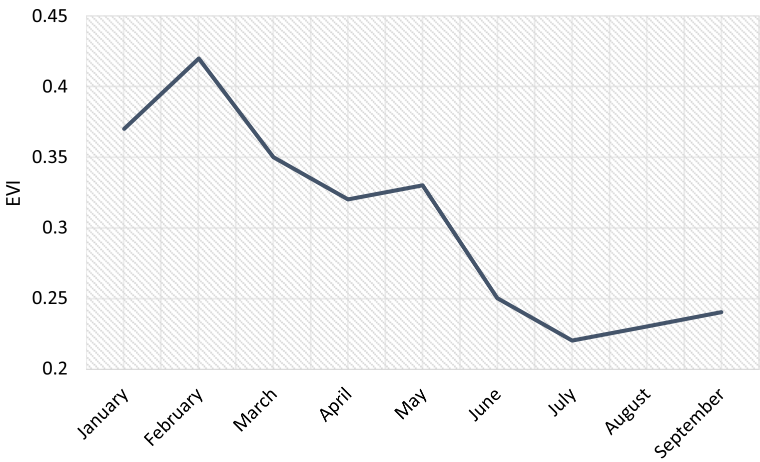

Fig. 5 Enhanced Vegetation index for Garden route after a major fire in June 2017. *Source* Authors, data from Frost et al. (2018)

and health. The impact on vegetation brings further indirect impacts on the biophysical components of the national park, including exposing soil to several agents of erosion, biodiversity loss, extinction of important species, changes in the phenology of species, and the sprouting of new invasive species, among other impacts. The feedback loop between a series of frequent droughts and increasing temperatures will erode the capacity of the natural environment to recover from these shocks further accelerating land degradation and increasing vulnerability of these parks even to minor exposure to other hazards.

6 Discussion

6.1 Trends in temperature and implications for tourism in coastal national parks

The emerging findings confirm the findings of other scholars. For example, van Wilgen et al. (2016) noted that it is not only in the arid regions where temperatures are increasing. The mean maximum temperatures at Cape Point in Table Mountain National Park in South Africa were observed to have increased by an average of 1.25 °C since 1960. Along with increasing temperatures, national parks in the southern parts of South Africa, including Bontebok, Garden Route, and Addo Elephant, also reflect a drying trend (Kraaij et al. 2018). High interannual variability, as shown in Fig. 4, especially in the post-1992 period, has been noted in an earlier study by Zampieri et al. (2023). This could be driven by large-scale climate drivers such as the ENSO (Zampieri et al. 2023). ENSO has a strong effect on year-to-year variability of temperature. This may influence perceptions about temperature and fire trends among respondents to this study.

The synergetic relationship between warming and drying in national parks was projected to have catastrophic consequences for individuals and groups of species. The most vulnerable are those that are endemic, with limited natural distributions and adaptation capabilities.

The increase in temperatures and the trends of fires have implications for coastal parks and tourism. Coastal regions are delicate and biologically diverse environments that are extremely vulnerable to the effects of natural processes and human activities. It is imperative that coastal management regimes minimize impacts to avoid further degradation of these habitats to improve the perpetuity of ecological services. The results of the current study indicate that the national parks along the Indian and Atlantic coasts of South Africa are experiencing an increase in temperature and wildfire events over time. The magnitude of loss and damage to property has also increased due to the increasing intensity of the fire. Climate is getting warmer, which exacerbates the vulnerability of coastal areas to climate-related challenges. Consequently, biodiversity losses and resource depletion are expected, among other impacts. This creates degraded coastal areas with no capacity to support local economies and inbound tourism.

Our results confirm the assertions of various scholars that the trends and dynamics of temperatures and fires have implications on ecosystem functions (Biggs et al. 2020), service delivery (Culhane et al. 2018), and climate stabilization (Duncan et al. 2019), which then compromise the achievement of sustainable development goals (SDGs). Specifically, SDG 15 and 14.

The coastal management policy framework for South Africa reflects the commitment to develop an ocean-based economy in a sustainable way. Therefore, it becomes critical to protect the underlying marine and coastal biodiversity, as well as ecological processes (Harris et al. 2022). National parks along the coasts become strategic hubs for launching management strategies that promote coastal and marine integrity, which are the engine of a thriving tourism industry. Minimizing adverse impacts on the environment is one of the strategic coastal area issues listed in the National Coastal Access Strategy for South Africa (South African National Parks 2015). Thus, the control of human activities and natural processes, which accentuate coastal environmental problems, needs to be prioritized.

6.2 Fire trends and implications for tourism in coastal national parks

Historical trends reflect the inevitability of fire occurrences, especially in the Table Mountain and Garden Route National Parks. This has implications on fire management approaches in coastal national parks. Instead of investing resources in thwarting fire occurrence, wildfire can be manipulated to achieve coastal management goals. This calls for prior understanding of the trends, seasons, and characteristics of the fires. This understanding provides an opportunity to appropriately determine strategies to maximize the benefits that come with wildfires and avert associated losses. Coastal ecosystem challenges such as bush encroachment and invasions can be managed through planning around the frequently occurring fires (Nieman et al. 2021). Relatively high-intensity fires may be useful in addressing bush encroachment and suppressing the proliferation of invasive species.

Combined with climate-induced sea level rise and the increasing intensity of coastal storms, high-intensity fires and the increasing temperature regimes have affected coastal biodiversity and ecosystem structure. High-intensity fires, for example, have the propensity to increase the mortality rates of large trees (Smit et al. 2013), while increasing temperatures have modified the ecological niche for several species.

Our results have shown that frequent and intense fires have had a significant impact on houses and other infrastructure along the coast, with severe economic and social costs. The future is uncertain with regard to fire patterns, but there is evidence that climate change (Philippenko et al. 2021) and the occurrence of Berg winds, especially in the Western Cape

Province, exacerbates fire spatial spread and the risk of infrastructural damage. Given the nonexistence of a mechanism to control the impact of Berg winds, and reluctance in building climate resilience in coastal areas, managers are faced with serious challenges in controlling future fires when they occur. To manage the threat of fires in coastal areas, a cocktail of fire management measures need to be put in place, including investing in firefighting infrastructure, constructing fire breaks, implement controlled burning, and strict enforcement of wildfire related regulations (Forsyth and Bridget 2004). Philippenko et al. (2021) noted that building environmental awareness in communities is one strategy that can be used to address climate change impacts. This strategy, if adopted for coastal areas, would help build resilience to the increase in temperature and related impacts.

7 Conclusions

The study shows that the maximum monthly temperatures in the coastal parks of South Africa are increasing significantly. The study also notes that the frequency, intensity and spatial spread of fires are gradually increasing over time in the coastal national parks, although the degree of change varies between national parks. The combination of extreme temperatures and fires has caused a deluge of ecological and economic impacts within the coastal national parks. The ecological impacts prompt a litany of spillover effects that affect the integrity of national park ecosystems and threaten the sustainability of these conservation areas. Some of the impacts include biodiversity loss, invasion by invasive species, species extinction, and phenological changes in biological species. A loss in ecological integrity constitutes a loss in economic value. The main economic threat is the loss of tourism business when these national parks surrender their integrity to the changing climate and the raging fires.

Warmer temperatures in coastal parks due to climate change will result in more fire events as they contribute to creating the fuel for fire occurrence. This will make it increasingly difficult in the future to manage fires in coastal parks because the higher the intensity and frequency of fires, the more sophisticated the methods of managing them. This also implies that the strategies to put out these fires will also have to change. Firefighting methods must be continuously reviewed to put into context changing environmental conditions. Fire suppression mechanisms must be advanced through the resourcing and training of park management teams. There is also a need to strengthen collaborations between SANParks and surrounding landowners in firefighting, especially the sharing of equipment and technical knowledge during fire incidences.

The causes of fires are not always known. Monitoring coastal parks through remote sensing devices may go a long way toward improving our understanding of the causes. Arson-related fire occurrences may be detected and the legislation must be strengthened to include heavy penalties in the event of arson.

It should be noted that SANParks is making commendable efforts to contain the spread of fires through monitoring patrols, controlled burning, and enforcing legislation, among others. Efforts are also being made to make the coastal parks attractive to tourists despite the increasing temperatures, which make the parks uncomfortable and affect tourism activities. With additional resources and continuous staff training, it is possible to maintain the integrity and promote the sustainability of coastal parks in the face of climate change. We recommend further research and development of new strategies to manage fires and build resilience of attractions to increasing temperature and fire occurrence.

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Declarations

Conflict of 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.

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