Assessing Drought for the Period 1955-2021 in Heraklion-Crete (S. Greece) Urban Environment

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Abstract

The urban environment is characterized by unique climatic characteristics that can highly affect the growth and survival of vegetation. This is critical for cities located in the Mediterranean basin, as it is considered a climate change hot-spot with frequent and long lasting drought episodes. In this work, a drought assessment was performed for the city of Heraklion, by investigating the values of four drought indices (SPI, RDI, aSPI and eRDI) for the period 1955-2022. The results confirm the good performance of all examined indices to detect extreme and severe droughts, however there were differences for the identification of moderate droughts. In 2015-2016 the most severe drought in the city occurred, whereas a significant decreasing trend in the indices values was identified for the dry semester of the year, implying that more frequent and severe droughts are expected to occur in the future, with severe impacts on urban green infrastructures and on the local urban climate dynamics.

Keywords

Drought, SPI, RDI, SDI, aSPI, eRDI, trends, urban environment, Greece, LIFE GrIn project

1. Introduction

Drought is a major risk for the Mediterranean basin, highly affecting plant growth [1]. This is critical considering the ecological importance of the basin [2] in association with the highly variable Mediterranean climate, the high risk introduced by climate change and the low adaptive capacity of many Mediterranean areas especially at the eastern part of the basin [3-6].

The climate in Greece is characterized by frequent droughts and is constantly changing to more arid conditions especially in the coastal areas and in the islands [7, 8]. Mountainous sites are also affected, but on a smaller degree, by warming temperatures, increased evapotranspiration and reduced precipitation especially in the southern parts of the country [9-15]. These unfavorable, changes, for the natural vegetation, are accompanied by long lasting droughts in many Greek regions [16].

The island of Crete and more specifically Herakion city, is located in the Aegean Sea and is the southernmost region of Europe. The regional climate is rapidly changing to sub-arid especially during the recent decade [13, 17, 18]. This transition will most likely lead to changes of the local vegetation types and dynamics, highly affecting the island's enhanced biodiversity, variety of habitats and presence of endemic species. The continuous monitoring of the local climate and the evaluation of the possible

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risks is necessary in order to adopt measures to protect the natural ecosystems and to preserve the urban green infrastructures.

Drought is mainly a meteorological phenomenon which is usually approached by specific indices. The most commonly used index is the Standardised Precipitation Index (SPI) proposed by McKee et al. [19]. In recent years a great variety of new indices has been proposed in drought assessment research, including, among others, the widely used Reconnaissance Drought Index (RDI) [20]. The need to investigate many different drought indices depends on the objectives of each scientific study. This imposes a need for modifying original indices in order to approach specific scientific issues. In this context, SPI and RDI have been repeatedly modified. The agricultural Standardised Precipitation Index (aSPI) [21] and the effective Reconnaissance Drought Index (eRDI) were recently proposed as more appropriate indices to investigate agricultural drought [1, 22]. In both cases, the modified indices are based on the effective part of precipitation that can be used by plants instead of its total sum.

This work aims to assess the drought episodes that occurred in Heraklion during the time period 1955-2021 by applying the SPI, aSPI, RDI and eRDI indices on different timesteps. Also, a trend analysis is performed to detect and quantify the trends' significance and magnitudes.

2. Materials and Methods

Heraklion city is located in Crete (S. Greece) and is characterized by its Mediterranean climate. According to Proutsos et al. [7], the climate in Heraklion is sub-humid based on UNEP's [23] aridity classification system, with aridity index (AI) 0.51 for the period 1955-2017, estimated by Thornthwaite's [24] water balance approach. Tsiros et al. [8] reported that the city's climate changed to more arid during the last century (AI values: 0.56 in 1900-1930, 0.54 in 1930-1960 and 0.52 in 1960-1997). The increasing aridity is occurring rapidly during the recent decade (2010s), indicating that the region is at the edge of the threshold to switch aridity zone from sub-humid to semi-arid [17]. Similarly, Proutsos et al. [13, 18] reported significant increasing trends in temperatureduring1955-2017 especially in summer and autumn, whereas the increase was more rapid in the recent years.

For this study, long-term dataseries (1955-2022) of monthly temperature and precipitation data were used. The data for the period 1955-2017were obtained by the meteorological station (ID: 16754, 35.34^o N, 25.18^o E, 39m a.s.l.) of the Hellenic National Meteorological Service, whereas recent data (2019-2021) were recorded by the near (35.31^o N, 25.14^o E) station of the Hellenic Organization "Demeter", established for the implementation of the LIFE-GrIn project.

The drought assessment was performed by employing four indices: a) SPI which requires precipitation data [19], b) aSPI, an agriculture-oriented index that requires effective precipitation data [21], c) RDI based on evapotranspiration and precipitation data [20] and d) eRDI based on evapotranspiration and effective precipitation data [22]. All indices were estimated for three timesteps: a) annual-hydrological year (12-month Oct.-Sep.), b) wet semester (6-month Oct.-Mar.) and c) dry semester (6-month Apr.-Sep.).

For the calculation of the drought indices, the DrinC software was used [25]. Effective precipitation was estimated with the empirical formula of Brouwer and Heibloem [26], suggested by FAO and potential evapotranspiration was computed by the Hargreaves-Samani method [27, 28], which gives reliable estimates [29, 30]. For the trends' detection and significance evaluation at different confidence levels the non-parametric Mann-Kendall test [31, 32] was applied, whereas the trends' magnitudes were determined by the Sen's slope method [33].

3. Results and Discussion

The results of the drought indices in the 12-month (Oct.-Sep.) timestep (Figure 1) reveal that all four indices behaved similarly in predicting the drought episodes. SPI, aSPI, RDI and eRDI 12-month values for Heraklion, indicate that 2015-2016 was the only year of extremely drought, since all indices values exceeded -2.00 (SPI=-2.9, aSPI=-3.2, RDI=-3.0 and eRDI=-3.3). The 12-month time series analysis also indicates three years (1958-1959, 1969-1970 and 1992-1993) of severe drought, detected by all indices. The above pattern confirms the good performance of the investigated drought indices to identify extreme and severe drought episodes on a 12-month timestep.

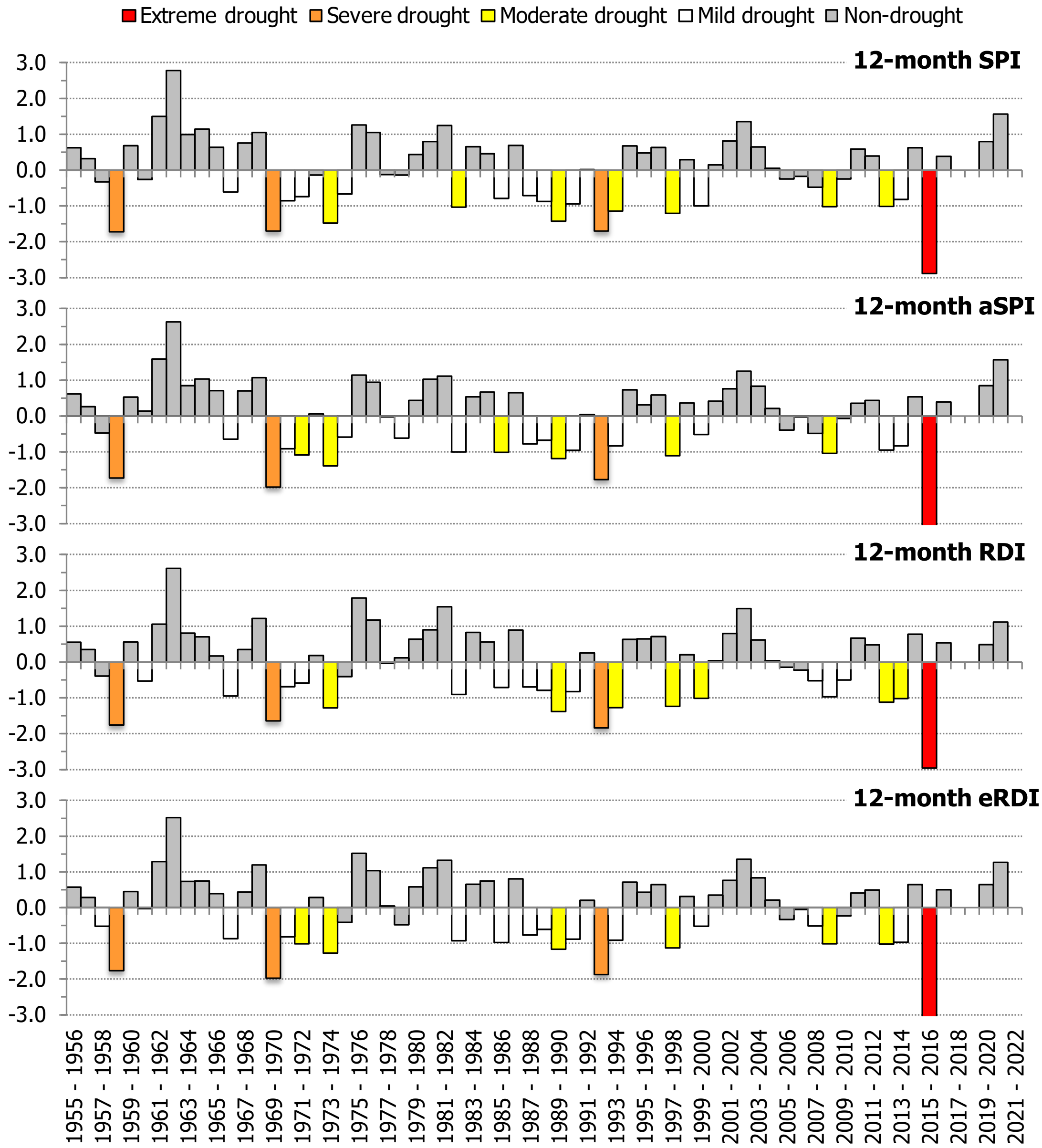

Figure 1: SPI, aSPI, RDI and eRDI drought indices values on a 12-month (October to September) timesep for the time-period 1955-2022 in Heraklion city.

The detection of moderate droughts appears to be less efficient and dependent on the drought index each time applied. Based on SPI 12-month values, seven years of moderate drought are recorded (1973-1974, 1982-1983, 1988-1989, 1993-1994, 1997-1998, 2008-2009 and 2012-2013), whereas six were detected either by the aSPI (1970-1971, 1973-1974, 1985-1986, 1989-1990, 1997-1998 and 2008-2009), RDI (1973-1974, 1989-1990, 1993-1994, 1997-1998, 1999-2000 and 2012-2013) or the eRDI (1971-1972, 1973-1974, 1989-1990, 1997-1998, 2008-2009 and 2012-2013).

In summary and based on the results of all indices twelve years were identified as years of moderate drought: 1970-1971, 1971-1972, 1973-1974, 1982-1983, 1985-1986, 1988-1989, 1989-1990, 1993-1994, 1997-1998, 1999-2000, 2008-2009and 2012-2013. However, only two of them (1973-1974 and 1997-1998) were detected by all four indices, three years by three indices (1989-1990 by aSPI, RDI, eRDI, 2008-2009 by SPI, aSPI, eRDI and 2012-2013 by SPI, RDI, eRDI), only one year by two indices (1993-1994 by SPI, RDI) and six by only one index (1970-1971 by aSPI, 1971-1972 by eRDI, 1982-1983 by SPI, 1985-1986 by aSPI, 1988-1989 by SPI and 1999-2000 by RDI). In all cases it appears that specific years can be considered as years of moderate drought for natural vegetation or agricultural production as indicated by the agriculture-oriented indices that incorporate the effect of the effective part of precipitation either uniquely (aSPI) or in association with the potential evapotranspiration (eRDI).

The six-month drought assessment for the wettest semester (Oct.-Mar.) indicates similar results with the 12-month timestep (Figure 2). This is rather expected for the Mediterranean climate of the region, since the main part of precipitation occurs during this period. Regardless of the drought index the 2015-2016 wet semester was extremely dry.

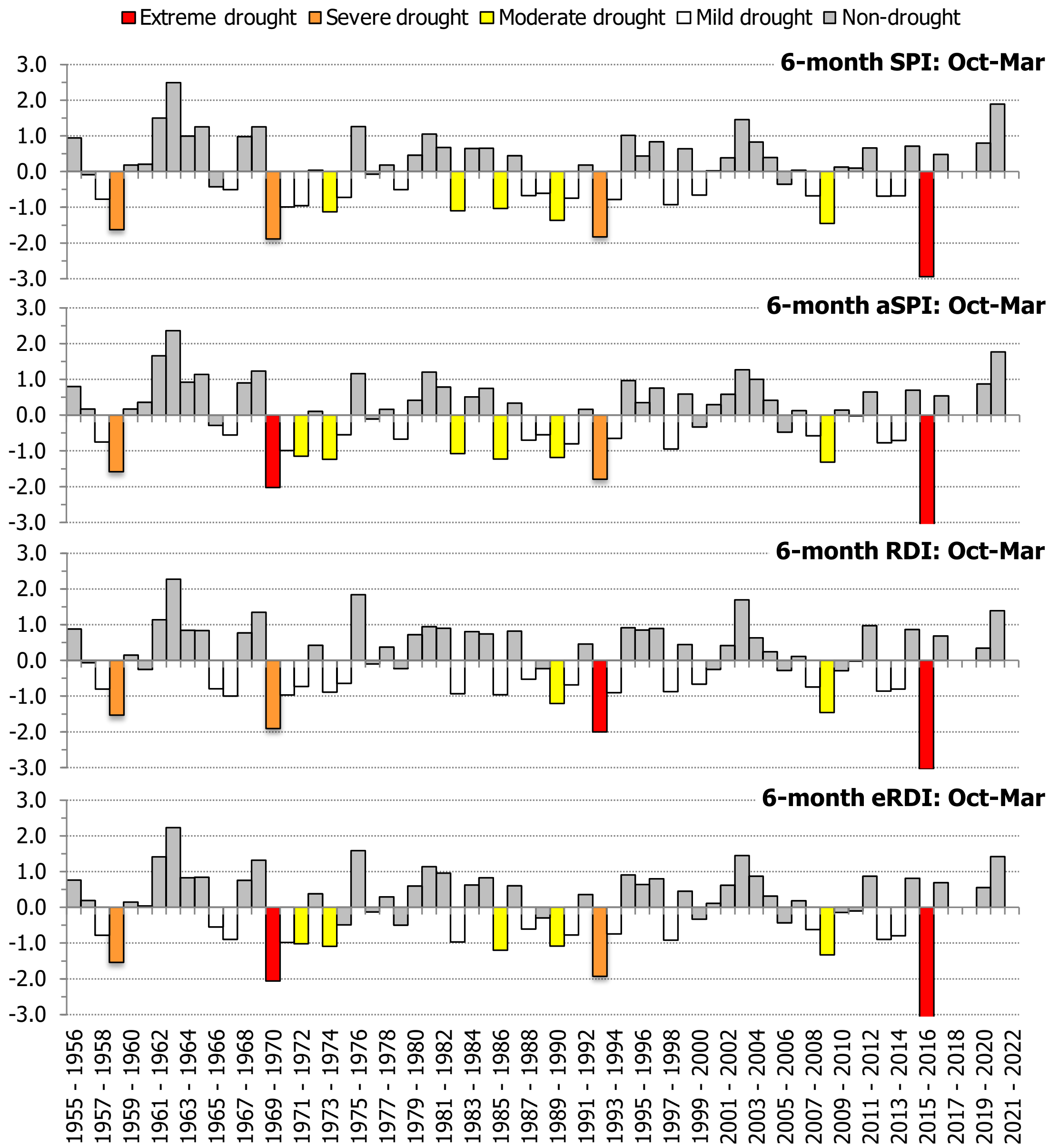

Figure 2: SPI, aSPI, RDI and eRDI drought indices values on a 6-month (October to March) timesep for the time-period 1955-2022 in Heraklion city.

There are, however, differences between the indices for other years. The 1992-1993 wet semester is also identified as extremely dry by the RDI but of severe drought (one class of order lower) by all other indices. In addition, agriculture-oriented aSPI and eRDI indices detected the extreme drought episode during the 1969-1970 wet period, when the original SPI and RDI detected extreme drought. It should be noted, however, that during the wet period all indices appear to perform well, since there are not differences higher than one class of order between years. Considering the values of all indices, the wet semester in 2015-2016 was historically the driest for Heraklion. Wet periods in 1992-1993 and 1969-

1970 were also extremely dry and in 1958-1959 severely dry. In addition, in nine years moderate drought wet periods were detected: 1970-1971, 1971-1972, 1973-1974, 1974-1975, 1982-1983, 1985-1986, 1989-1990, 1990-1991 and 2008-2009.

The results for the 6-month timestep concerning the dry semester of the year (Apr.-Sep.) are quite different from the above mentioned (Figure 3). Extreme droughts occurred during the 1960-1961 dry period, whereas in 1973-1974, 1993-1994 and 1998-1999 severe drought episodes were also detected. The 1960-1961 extreme drought in the dry period is identified by SPI and RDI indices, but the agricultural aSPI and eRDI indices classify it two classes lower (moderate drought). Similarly, in the dry periods of 1973-1974, 1993-1994 and 1998-1999 severe droughts were identified only by the original SPI and RDI, whereas the modified aSPI and eRDI recognized them as of one drought class lower (moderate drought). In addition, for the dry semester, seven years of moderate drought episodes were identified by SPI and RDI and ten by aSPI and eRDI.

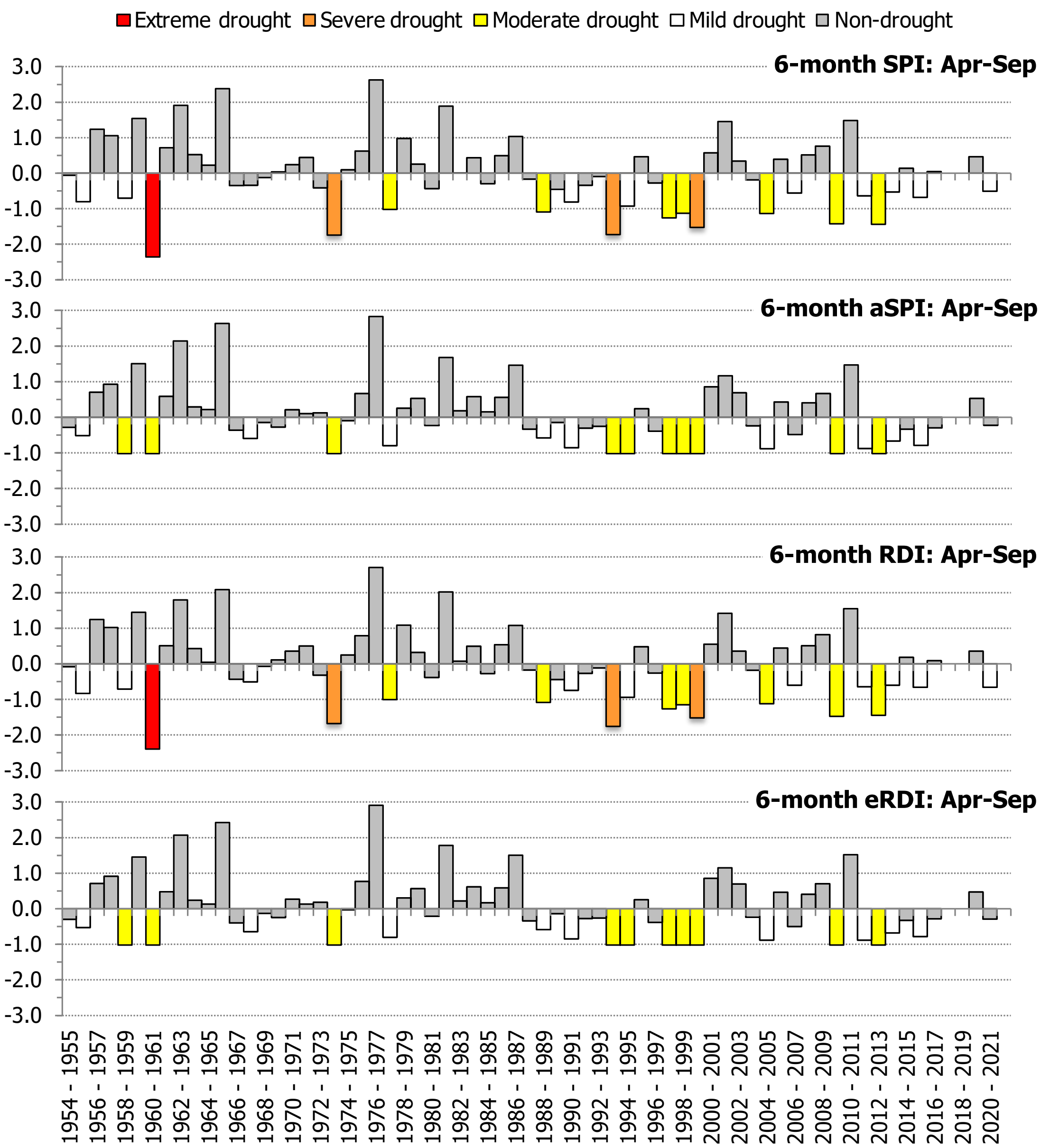

Figure 3: SPI, aSPI, RDI and eRDI drought indices values on a 6-month (April to September) timestep for the time-period 1955-2022 in Heraklion city.

The above patterns suggest that droughts are more frequent and strong in the recent years compared to the past. To evaluate the magnitude of these changes, a trend analysis was performed by applying the Mann-Kendal test (Table 2). The results confirm a significant ($p<0.10$) decreasing trend in the indices values for the dry semester of the year (Apr.-Sep.), which indicates that the local climate changes to drier conditions during the period of the year with the lower water availability for the plants. With respect to each drought index, the changing rates vary between -0.009 y^{-1} for aSPI and eRDI and -0.011 and -0.012 for RDI and SPI, respectively. The annual (Oct.-Sep.) and the wet semester (Oct.-Mar.) respective changes are not significant.

Table 1
Trend analysis Mann-Kendal test (Z) and average trend slope (Q) results for the SPI, aSPI, RDI and eRDI drought indices in Heraklion city (period 1955-2022) for 12-month (October to September) and 6-month (October to March and April to September) timesteps. The asterisk (*) indicate significance at $p<0.10$.

Drought index	Time step: 12 month (Oct – Sep)		6 month (Oct-Mar)		6 month (Apr-Sep)	
	Z	Q	Z	Q	Z	Q
SPI	-0.98	-0.005	-0.19	-0.001	-1.77*	-0.012*
aSPI	-0.68	-0.004	-0.16	-0.001	-1.70*	-0.009*
RDI	-0.86	-0.005	-0.24	-0.001	-1.65*	-0.011*
eRDI	-0.49	-0.003	-0.13	-0.001	-1.65*	-0.009*

4. Conclusions

The patterns of the changes in the values of the drought indices in Heraklion underline the need for assessing multiple indices to identify drought events in a region, whereas the timestep adopted each time is also important. The performance of all drought indices examined in this work for the urban environment of Heraklion-Greece is adequate, indicating that extreme and severe drought indices can be identified by applying either the original SPI and RDI or the modified and agricultural-oriented aSPI and eRDI indices, especially for the annual timesteps. In moderate droughts the performance of the indices is probably depending both on the orientation of each index and the site-specific characteristics. The trend analysis reveals decreasing and strong trends since 1955, for all drought indices at the dry semester of the year (Apr.-Sep.). This is expected to significantly affect the urban green infrastructures, imposing the need for the adoption of measures (species selection, changes in design and distribution of urban parks e.tc.) to ensure their conservation.

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