Effects of climate change on flowering times of *Narcissus bulbocodium* L. in Portugal

Patrícia Alegria[1], Alfredo Rocha[2,3], Paulo Silveira[1,3,*]

Abstract — Global temperatures are increasing at an unprecedented rate, promoting important shifts on plant communities and contributing to the global loss of biodiversity. Of the biological responses to global warming, changes in the timing of phenological events such as flowering are among the most sensitive and important, both from a biological and economical point of view. The most reliable data sources to monitor life-cycle events are datasets systematically compiled by phenological stations. Although these are relatively abundant in Central and Northern Europe, they are scarce in Portugal. The lack of phenological observations can, however, be filled up by biological collections in herbariums and museums. These specimens are potential sources of long-term data to detect changes in flowering phenology, as long as some correction procedure is applied to overcome differences in sampling locations. In this study, we examined herbarium specimens of *Narcissus bulbocodium* L., an early flowering species with a short flowering period, collected between 1882 and 2006 and, more or less, equally distributed by the whole of the Portuguese territory. The main objective of this work is to find a model that can be used to correct for the geographical differences among the collection sites, allowing for the use of the abundant specimens held in the Portuguese herbaria for the study of the effect of the rise of temperature on plant phenology.

Keywords — climate change, flowering times, herbarium specimens, *Narcissus bulbocodium*, phenology, Portugal

1 Introduction

Global warming is already affecting natural processes around the world. Examples of observed changes include melting of glaciers, thawing of permafrost, earlier break-up of ice on rivers and lakes, species are moving their ranges towards the poles and up mountain slopes, lengthening of growing seasons, earlier flowering of plants, emergence of insects and egg-laying in birds and some species are, even, going extinct [1], [2]. Some of the above mentioned effects, i.e. periodic events in the life cycles of animals or plants, as influenced by the environment, especially seasonal variations in temperature and precipitation, are studied by Phenology [3].

The phenological changes from year to year may be a sensitive and easily observable indicator of environmental changes, and have a wide range of consequences for ecological processes, agriculture, forestry, human health, and the global economy. The wealth of historical phenological records allows scientists to examine trends from the past and make cautious predictions about what may happen to species in the future [4]. The seasonal onset of warmer temperatures triggers a suite of physiological responses in plants species, such as leaf bud-burst and the initiation of flowering. These species are prime candidates on which to base monitoring programs to elucidate the effect of climate change on natural systems [5]. In recent years, phenology studies have been conducted in many plant taxa from a broad range of biogeographic regions, including Asia [6], Australia [5], [7], North America [8]-[10] and Europe [11]-[15].

The first phenological network in Europe is linked with the name of Carl von Linné, who made his observations in Sweden [16]. The International Phenological Garden (IPG) is nowadays a unique system in Europe, which was founded by F. Schnelle and E. Volkert in 1957 [16]. The current network ranges across 28° of latitude from Scandinavia to Macedonia and across 37° of longitude, from Ireland to Finland in the North and from Portugal to Macedonia in the South. It consists of 89 stations in 19 European countries (updated in 2010). Since 2000, the observation programme includes 8 phenophases of 21 plant species [17].

Not included in the IPG network, in 1942, the Spanish *Instituto Nacional de Meteorología* (INM) created its own phenological network in Spain to gather information about plant and animal phenology. This network relies on volunteer observers that record several phenological events according to standardized observational methods and

1. *Patrícia Alegria is with the Department of Biology, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal. E-mail: paalegria@ua.pt*
2. *Alfredo Rocha is with the Department of Physics and Centre for Environmental and Marine Studies, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal. E-mail: alfredo.rocha@ua.pt*
3. *Paulo Silveira is with the Department of Biology and Centre for Environmental and Marine Studies, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal. E-mail: psilveira@ua.pt*

a selected species list. Consequently, the monitoring of phenological events is widespread throughout Spain [18].

On the contrary, phenological observations in Portugal are rather scarce. The study of phenology in Portugal began in 1759, by Domingos Vandelli under request by Carl von Linné, however nobody knows the results [19]. From 1876 to 1903 regular observations were conducted by Filipe de Figueiredo from the Institute of Agriculture that resulted in a manual of phenology [19]. In 1956, phenological observations where started at the *Instituto Geofisico do Porto*. In 1968, this station was the first Portuguese phenological observatory to integrate the IPG network. However, at present, this observatory is deactivated [17], [19].

At present, mainland Portugal has only one active phenological station, in Évora, which was incorporated into the IPG network in 2004 [17].

Therefore, phenological studies in Portugal are practically nonexistent. However, other kinds of data sources can be used. Data collated from historical records have been used expansively to investigate the impacts of climate change on plant species [5] such as herbarium specimens [5], [8]-[10], [20] and photographic archives [6], [21]. Herbarium plant specimens, i.e. plants, or plant parts, dried, fixed in cardboards, properly labeled, cataloged and arranged according to botanical classification [22: 15] are unique amongst these sources of information in that they capture an individual plant's phenological state at the time and location of collection, and therefore may represent a substitute for field observation [20]. If used carefully, i.e. using some kind of correction for the different climatic conditions associated with sampling locations, this information can be used in order to detect changes in the timing of life-cycle events. Lavoie and Lachance [8] used the date of disappearance of snow cover to make the aboce mentioned correction, however this cannot be applied to mainland Portugal.

Therefore, the main objective of this work is to find a model that can be used to correct for the geographical differences among the collection sites, allowing for the use of the abundant specimens held in the Portuguese herbaria for the study of the effect of the rise of temperature on plant phenology.

Our first attempt uses the Hopkins's Bioclimatic Law, which states that there is a relationship between phenological events of plants and animals with the various elements which make up the climate of the region such as elevation, latitude and longitude and that spring advances 4 days for each 1° latitude, 5° longitude and 400 feet of altitude [23].

We selected as a model species *N. bulbocodium*, because this species is well adapted to different climates and environments is very frequent and widespread in the Portuguese territory and its flowering period is short and early in the year. Furthermore, since it is a geophyte, there is a higher probability that its phenological behavior might reflect climatic changes. Finally, in recent decades, it has been abundantly collected and deposited in Portuguese herbaria, permitting availability of data for this study.

2 Materials and Methods

2.1 Study area

Mainland Portugal is located in the extreme southwest Europe, at the Iberian Peninsula, roughly between 37° to 42°N and 6,5° to 9,5°W, a territory that extends about 580 km N to S and 220 km E to W (Fig. 1).The region is characterized by altitudes ranging from 0 to 2000m. North and Central Portugal have significant areas that exceed 1000 m [24]. This territory is part of the Mediterranean biogeographical region except the North Coast, inserted in the Atlantic region [25].

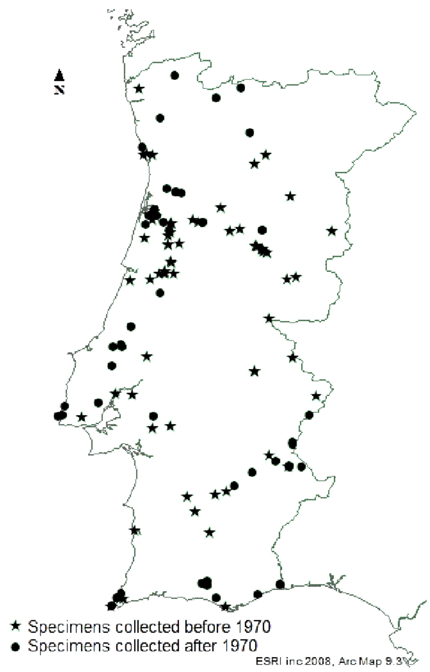

Fig. 1. Geographic distribution of used herbarium specimens of *N. bulbocodium* in the study area.

2.2 Climate data

According to the international classification by Köppen, the climate of mainland Portugal is divided in two regions: a temperate climate with a wet winter and dry and hot summer (mostly North West) and another temperate climate with a wet winter and dry but moderately hot summer (mostly South East) [26]. Observed precipitation in the North West region is relatively high, reaching, in some places, a mean annual accumulated rainfall exceeding 3000 mm. In several areas of the South East, by the contrary, the accumulated annual precipitation does not exceed an average of 500 mm. The average annual temperature varies between 7°C in the highlands of central and northern regions and 18°C in the south coast [24], [26]

2.3 Species data

Belonging to the family Amaryllidaceae, *Narcissus bulbocodium* L. (petticoat daffodil) is an endemic species of the South and West of France, Iberian Peninsula, and North Africa. It is a species that occurs throughout the Portuguese mainland. It is an herbaceous plant, bulbous, with 8-35 cm. It has large flowers, solitary, of a light yellow color. Occurs in meadows, high altitude grasslands, sand-hills, and clearings of heath, fields of rock-roses and deciduous and perennial woods dominated by *Quercus* species. The flowering period is short and early in the year, beginning in February and ending in May or June [27]. Currently, this species is protected by Habitats Directive 92/43/EEC, Annex V, considered a species of community interest [28].

2.4 Herbarium data

After consulting the main Portuguese herbaria, we selected a total of 122 specimens of *N. bulbocodium*. From the University of Coimbra (COI) we selected 34 specimens, 27 from the University of Aveiro (AVE), 15 from the National Museum of Natural History, University of Lisbon (LISU), 14 from the Institute of Agronomy of the Technical University of Lisbon (LISI), 13 from the National Agronomic Station (LISE), 9 from the University of Oporto (PO), 5 from the University of Algarve (ALGU) and also 5 from the National Station for Plant Breeding (ELVE). All specimens collected on the Portuguese mainland, at peak flowering, with complete date of harvest where selected. We rejected the hybrids and specimens with fruit, or flower and fruit. In order to use only specimens with exact information concerning the latitude, longitude and altitude of the place of collection we established a criterion based on Hopkins's Bioclimatic Law, admitting, at most, an error of 1 day. That is, all specimens whose geographic coordinates and altitude could be determined with and error smaller than 27,83 km of latitude, 106,25 km longitude and 30,48 m in altitude, were included in the selection, excluding those who exceed this error. Taking into account the criterion mentioned above, we determined the altitude and geographical coordinates (degrees, minutes, seconds) using the software Google Earth 2010 (version 5.2.1.1588). Using the software ArcMap 9.3 (ESRI) the geographic distribution of the studied specimens was analyzed, to check if they were well distributed by the Portuguese territory and between two time periods: 1882-1970 and 1971-2006.

2.3 Meteorological data

Due to the difficulty in obtaining weather records for the period from 1882 to 2006, along the Portuguese territory, we used only records from the meteorological station of the Geophysical Institute of Lisbon [29]. For this study, according to the peak flowering of *N. bulbocodium*, we calculated the average of the first four months of each year (January, February, March and April), corresponding to the year of collection. Due to the lack of meteorological data, specimens collected in 1982 where not used. Considering that the temperature decreases an average of 6,5°C per 1000 m of altitude a proportional correction was introduced to determine an estimated mean temperature for each collecting point based on its altitude.

2.5 Analysis

For each specimen, a Julian Day Number (JDN) was computed based on its collecting date. Considering that the specimens used where collected at different locations, a correction was introduced, based on Hopkins's Bioclimatic Law [23] i.e., to the calculated JDN, 4 days where added/subtracted for each 1° latitude, 5° longitude and 400 feet (121,92 m) altitude. The JDN of all *N. bulbocodium* collecting sites was by this way converted as if they have all been collected in the Geodetic Center of Portugal (39°41'40,20619"N; 8°7'50,06228"W; 580 m altitude). Data analysis in the study, statistical calculations and the correlations and their regressions were performed using the software Microsoft Excel 2010 (version 14.05128.5000).

3 RESULTS

The climate in Lisbon has become progressively warmer since the XIXth century. The mean annual temperature recorded at the Meteorological station of the Geophysical Institute of Lisbon, from 1864 to 2008 (Fig. 2), rose by approximately 1,8 degrees Celsius in 144 years (y = -0,0125x -7,9105; r^2 = 0,5713; P <0,0001). Also there was an increase of 1,8°C in the mean January to April temperature (Fig. 2) for the same interval of time (y = -0,0128x - 12,211; r^2 = 0,3973; P <0,0001).

A great climatic variability was observed, however, along the years. In the mean annual temperature, three high peaks reaching 17.7 °C, where observed, in 1955, 1995 and 1997. The lower peak (14,6 °C) was observed in 1889. In the January to April mean temperatures a high peak was observed in 1997, reaching 15,4 °C, and two lower peaks where observed in 1888 and 1934 with a temperature of 10,5 °C.

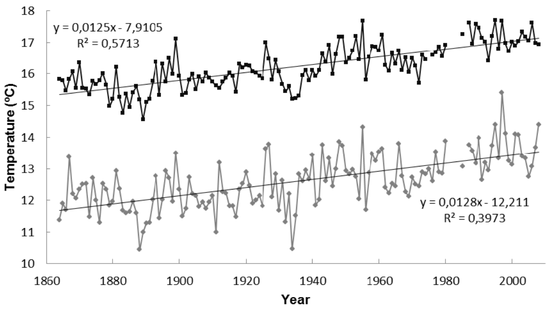

Fig. 2. Lisbon temperatures from 1864 to 2008 as reported by Meteorological station of the Geophysical Institute of Lisbon. The top series represents mean annual temperatures. The bottom series represents mean temperatures in January, February, March and April. The lines are the best fit lines for the series.

According to the applied correction using Hopkins's Bioclimatic Law, an advancement of 1,5 days per decade in flowering time of *N. bulbocodium* was observed (Fig. 3). This has resulted in an total advancement of 18,8 days since 1882. However, the relationship between flowering date and year was not significant (y = -0,1483x + 364,61; r^2 = 0,0106; P = 0,260037; n= 122).

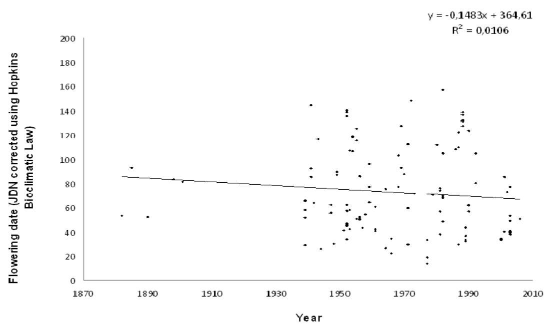

Fig. 3. Relationship between the day number that a flowering herbarium specimen of *N. bulbocodium* was collected (corrected using Hopkins Bioclimatic Law) and year.

On the contrary, the relationship between flowering date of herbarium specimens (JDN) corrected by Hopkins's Bioclimatic Law and the average temperature in January-April (Fig. 4), in the period from 1882 to 2006, was significant (y = -8,5904x + 170,73; r^2 = 0,4401; P <0,0001; n= 122), reaching an advancement in flowering time of 8,6 days per 1 °C.

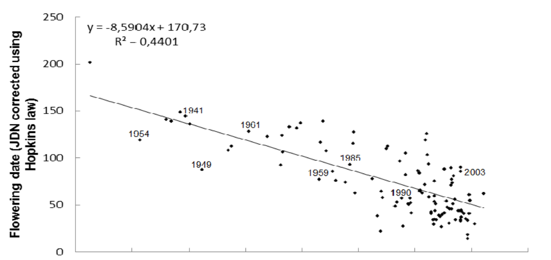

Fig. 4. Relationship between the day number that a flowering herbarium specimen of *N. bulbocodium* was collected (corrected using Hopkins Bioclimatic Law) and mean temperature of the first four months of the year, Jan-Apr. The line is the best fit line for the series.

4 Discussion

The present study showed that mean annual temperatures and mean January to April temperatures has risen, in Lisbon, by 1,8°C in 144 years, i.e. 0,125°C per decade. This corroborates well with what has been reported by IPCC for the global rise of temperature (0,13°C per decade from 1956 to 2005) [30] and with the reported mean temperature increase for Portugal, in the period 1941 to 2005, of 0,11ºC per decade [32].

Has expected, this rise in temperature caused an advancement in the flowering dates of *N. bulbocodium* across the Portuguese territory, estimated in 1,5 days per decade, resulting in a total advancement of 18,8 days since 1882.

Although the relationship between flowering date and year was not significant, it is within the range reported by Khanduri's study [12]. This author, reviewing the published literature, reported and average advancement of 1.9 days per decade, ranging from 0,2 to 4,5 days per decade, depending on the author, species and geographical and time scope of the study under analysis [12].

The dispersion of the records was, however, high (Fig. 3), probably due to the climatic variability between different years and collection sites, resulting in a non significant relationship between flowering date and year. The relationship between flowering date of herbarium specimens (JDN) corrected by Hopkins's Bioclimatic Law and the average temperature in January-April (Fig. 4), was, however, highly significant. This suggest that the relationship between flowering dates and year was not significant mostly due to climatic variability between years, and not due to differences between collection sites, therefore indicating that we can use Hopkins's Bioclimatic Law to correct for the geographical differences between collection sites across large areas.

The fact that the used herbarium specimens where acceptably distributed in a North-South and East-West gradient in the study area before and after 1970 (Fig 1.) is important to demonstrate that there where no biases .introduced in the analysis due to asymmetric sampling.

A small amount of specimens collected before 1939 was used in the analysis due to the general lack of an indication of day of collection in the specimens from the XIXth century. Also, specimens from the period 1900 to 1938 are practically inexistent in the Portuguese herbaria. However, the abundant specimens collected after 1939 (inclusive) allowed a robust analysis, especially of the relationship between flowering dates and mean January to April temperatures. In fact, we found that flowering date of *N. bulbocodium* advanced 8,6 days per 1°C in the period from 1882 to 2006. This is within the range of values reported in other studies. For example, Robbirt et al. [20] reported an advancement of 5,7 to 6,7 days per 1°C rise in temperature, for *Ophris sphegodes*; Gallagher et al. [5] reported an advancement varying from 4,35 to 11,97 days per 1°C on Australian alpine species and Primack et al. [10] reported a mean advancement of 3,9 days per 1°C in a study including 229 species in Boston.

In this study we considered corrections of altitude, longitude and latitude, based on Hopkins Bioclimatic Law, but other variables such as rain and humidity may also influence flowering times. Furthermore, errors related to the spatial accuracy of coordinates resulting from misrepresentation of the original location of the collection or lack of details regarding slope, aspect and soil type in the label of the collection might have contributed to the high dispersion of the records and non-significance of the regression concerning the relationship between flowering times and year.

N. bulbocodium, as a spring-flowering plant, with a short and early flowering period [27], falls into a group identified as having flowering phenologies that are likely to be particularly sensitive to temperatures early in the year [20]. This fact is important for the phenological study and is supported by the results of this study.

The earlier onset of flowering can have consequences not only for the individual plants and populations affected, but also to the maintenance of diversity at the community level. Understanding the response of primary producers within communities provides scope for investigating the effect of climate change on biotic interactions with species at other trophic levels [5]. For most species of plants and animals, biological collections are the only source of long-term phenological data. It is estimated that some 2,5 billion specimens of flora and fauna are held in biological collections worldwide [31]. With appropriate validation, the exploitation of this resource will have increasing relevance and value as we seek to understand and predict the consequences of continuing climate change [20].

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