Abstract The objectives of this paper are to: (1) present 10 years of phenological data for nine natural species growing in a Mediterranean-type climate, (2) present threshold temperatures that were derived for the computation of cumulative degree-days (CDD), and (3) evaluate the sensitivity of the nine natural species to weather variability. The study was conducted at the Phenological Research Garden of Oristano, Sardinia, Italy, during the period 1986–96. The observations were made on five typical Mediterranean species and four species that are typical of higher latitudes. The mean annual pattern of phenological events and the CDD from 1 January are given for each development stage. Temperature thresholds were evaluated by comparing the standard deviation about the mean number of days in the development period for each species. A good relationship between timing of phenophase occurrence and temperature was observed for the Mediterranean species, which were little affected by variations in rainfall. Phenological development of the non-native species was affected by springtime rainfall.

Key words Phenology · Climate change · Mediterranean species · Degree-days

Introduction

Phenological observations provide a method with which to investigate the relationship between climate variation and plant development, and they provide data for the design and testing of growth and development models. Temperature-driven heat-unit accumulation has a big influence on plant development, and therefore phenological observations of natural plant species can potentially be used to characterize climate. Recent studies on global climatic change have focused on the interpretation of the species response to past climate changes and how they might respond in the future (Fitter et al. 1995; Sparks and Carey 1995). The high natural variability of the Mediterranean climate and the emerging problems of water scarcity could significantly affect the Mediterranean region ecosystems.

Recently, studies were conducted to investigate the phenological behavior of various species in different Mediterranean climates (Arianoutsou and Diamantopoulos 1985; Correia et al. 1992; de Lillis and Fontanella 1992; Kummerow et al. 1981; Moll 1987; Montenegro et al. 1979; Mooney and Kummerow 1981; Mooney et al. 1974). However, there is limited information on the timing of the key development processes and the relationship between phenological stage occurrence and duration and intensity of drought period.

The prediction of crop and natural plant development is widely made using degree-days. Critical aspects of degree-day calculation are related to the methodology used,
Several studies have been directed toward improving the procedures for calculating the integral of the temperature curve, such as the triangle method and the sine-wave method and its modifications (Allen 1976; Baskerville and Emin 1969; DeGaetano and Knapp 1993; Yin et al. 1995). In addition, some scientists tested the accuracy of various forms of the basic equation for the computation of cumulative degree-days (CDD) in order to determine the most appropriate starting date of degree-day summation in relation to the choice of threshold temperature (Castonguay et al. 1984; Oger and Gilbert 1989; Yang et al. 1995). In addition, modifications were suggested to enhance the canonical equation for calculating degree-days such as incorporating an upper temperature threshold (McMaster and Smika 1988; Wang 1960) or functions for other environmental factors that affect phenology (e.g., water availability and light quality and quantity) (Caprio 1993; McMaster et al. 1992; Wilhelm and McMaster 1995).

The objectives of this paper are: (1) to show several years of phenological data for nine natural species growing in a Mediterranean-type climate, (2) to present threshold temperatures that were derived for the computation of CDD, and (3) to evaluate the sensitivity of the nine natural species to weather variations.

### Materials and methods

The study was conducted in a Phenological Research Garden located within the Experimental Farm at the University of Sassari in Oristano, Sardinia, Italy (39° 53’ N, 8° 37’ E, 11 m above sea level, 10 km from the sea) during the period 1986–1996. The Garden was