Applied Biological Research 27(3): 416-424; (2025)
DOI: 10.48165/abr.2025.27.01.41

INTER-ANNUAL VARIATIONS IN PHENOLOGICAL EVENTS OF WILLOW (*Salix alba*) AND DEVELOPMENTAL STAGES OF GYPSY MOTH (*Lymantria obfuscate*), USING DEGREE DAY MODELS

Javeed Ahmad Mugloo[1], Oyais Ahmad Wagay[2]*, Barkat Hussain[3], Nazir A. Pala[4], Gowhar Nabi Parray[5] and Jauhar Rafeeq[6]

[1,2,5]*Krishi Vigyan Kendra (KVK)/Extension Training Centre, SKUAST-K, Malangpora, Pulwama - 192 301, Jammu & Kashmir (India)*
[3]*Division of Entomology, Faculty of Horticulture, S.K. University of Agricultural Sciences & Technology of Kashmir (SKUAST-K), Shalimar, Srinagar - 190 025, Jammu & Kashmir (India)*
[4]*Faculty of Forestry, SKUAST-K, Benhama, Ganderbal - 191 201, Jammu & Kashmir (India)*
[6]*KVK Gurez (Bandipora II), SKUAST-K, Gurez - 193 503, Jammu & Kashmir (India)*
*e-mail: *owaiswagay777@gmail.com*

(Received 26 April, 2025; accepted 2 September, 2025)

ABSTRACT

Climate variability plays a crucial role in regulating the phenological patterns of plants and the developmental dynamics of associated insects. This study examined the phenology of willow (*Salix alba*) and the developmental stages of the gypsy moth (*Lymantria obfuscata*) over two consecutive years (2022–2023) using Julian dates and accumulated degree days (DD). Significant inter-annual variations were observed in both the plant and insect development. In 2022, vegetative bud burst occurred earlier (Julian day 53, 0.55 DD) than in 2023 (Julian day 60, 3.86 DD), with similar delays observed in flowering and late-season events. Increased DD requirements in 2023 suggest climatic influences on phenological timing. Gypsy moth development also shifted temporally. In 2022, key stages such as egg hatching and adult emergence occurred earlier and at lower DD thresholds as compared to 2023. Adult emergence was recorded at Julian day 158 (945.30 DD) in 2022 and at day 165 (492.22 DD) in 2023, indicating altered developmental dynamics. Population peaks differed between years, with a mid-June peak in 2022 (40 individuals, 608.65 DD) and a delayed, smaller peak in 2023 (35 individuals, 593.88 DD). These findings highlight the influence of temperature on plant–insect synchrony and demonstrate the value of degree day models for predicting phenological responses under changing environmental conditions.

Keywords: Climatic variation, degree days, gypsy moth, *Lymantria obfuscata*, phenology, plant-insect synchrony, *Salix alba*

INTRODUCTION

Salix alba L.**,** commonly known as white willow, silver willow or golden willow, belongs to the family Salicaceae. The genus *Salix* comprises of over 450 species which span across diverse ecological zones from tropical to cold-temperate regions (Helfenstein *et al.,* 2014). *S. alba* thrives at altitudes varying from sea level to 2400 m masl, predominantly near water bodies with a typical lifespan of 20-30 years (Praciak *et al.,* 2013). India hosts approximately 33 species of *Salix*, with 23 species found in Kashmir valley alone, 15 of which extend to alpine or subalpine regions (Dhar and Kachroo, 1983). Of special interest are the three varieties of *S. alba*: var. *alba*, var. *vitellina* (golden willow), valued for its ornamental appeal, and var. *caerulea* (cricket-bat willow), renowned for its commercial significance

(Gupta *et al.,* 2014). Beyond their ecological and economic importance, willows play a pivotal role in supporting biodiversity and mitigating the environmental stressors (Oliveira *et al.,* 2024).

Plant phenological development is predominantly shaped by meteorological factors such as temperature, solar radiation and precipitation, which significantly influence vegetative and reproductive growth, yield and fruit characteristics (Moriondo *et al.,* 2015; Orlandi *et al.,* 2020). Temperature, in particular, acts as the primary driver, enabling the development of predictive models for phenological stages across species and geographic regions (Chuine *et al.,* 2013). Accurate phenological data are critical for optimizing agricultural practices, including irrigation, fertilization, harvesting and pest control (Didevarasl *et al.,* 2025). Phenological models like linear growing degree day (GDD) model and curvilinear alternatives like the Wang and Engel model, have been employed to predict flowering and fruit-setting events (Parker *et al.,* 2011; Orlandi *et al.,* 2020). These models underscore the dependence of plant and pest phenology on temperature, offering insights into the genetic and environmental factors shaping their responses (Mosseler and Papadopol, 1989).

The Indian gypsy moth (*Lymantria obfuscata* Walker, 1865**)** is a significant pest of *Salix alba* and other forest and fruit trees in the Kashmir Valley. The larva of this pest exhibit voracious nocturnal feeding habits, primarily targeting tender leaves, while adult males are active fliers and females are wingless (Roonwal, 1979). Integrated pest management strategies, including pheromone-baited traps, have proven effective in monitoring and controlling populations (Munshi *et al.,* 2008). This study embarks on an in-depth exploration of the phenology and occurrence of major insect pests in *S. alba*, employing the degree day (DD) model as a pivotal analytical framework. The DD model, rooted in the concept of accumulated temperature, provides a nuanced perspective on the developmental patterns of insect pests, offering valuable insights into their life cycles and seasonal dynamics (Crimmins *et al.,* 2020). Phenology is the study of periodic recurring biological events in plant life cycles and their interactions with weather and climate (Schwartz, 2013). By integrating phenological observations with pest occurrence data, this research was aimed to elucidate the intricate interactions between *S. alba* and its insect adversaries. The findings may contribute to the sustainable pest management strategies, enhancing the ecological resilience and economic viability of *Salix alba* plantations. This study also underscores the broader implications of climate change on plant-pest dynamics, offering valuable insights into adaptive strategies for mitigating its impacts on agroforestry.

MATERIALS AND METHODS

Study sites and sampling design

The study was conducted to record the phenological stages of *Salix alba* at three randomly selected sites in Ganderbal district, Kashmir, India. Six mature trees were chosen at each site. On each tree, four primary branches oriented in the cardinal directions (North, South, East and West) were selected and marked with durable metal tags for consistent observation. Weekly observations were made from February to October to monitor and document the phenological stages across the study sites.

Degree-day model

The accumulation of degree days (DD) was calculated by the method of McMaster and Wilhelm (1997):

$$DD = \frac{Tmax + Tmin}{2} - MTT$$

Where DD are the degree-days, T_{max} and T_{min} are the daily maximum and minimum temperatures, respectively and MTT is the minimum threshold temperature.

The observations in the study focused on the timing of various phenological stages, their corresponding temperatures, and the emergence of insect pests during each stage. The phenological stages systematically recorded were as follows: (i) Vegetative bud burst, marked by the emergence of green tissue or leaf tips from stems or stools; (ii) Formation of axillary buds, characterized by the appearance of axillary buds as the petiole bent away from the stem; and (iii) Stem colouration, reflecting seasonal changes in stem colour influenced by sun exposure and branch position (Jenderek *et al.,* 2020). The development of (iv) sylleptic branches involved the initiation and growth of these branches, while (v) differentiation of generative buds was observed when larger generative buds became distinct from smaller vegetative buds during the 'green bud' stage (Saska and Kuzovkina, 2010). The (vi) colouration of generative bud scales indicated a transition of bud scales to reddish, brownish, or yellowish hues, referred to as the 'bud blush.' (vii) Generative bud swelling signalled the initial expansion of inflorescences, followed by (viii) generative bud burst, where bud scales split open to expose 50% of catkins (Kutsokon and Khoma, 2025). (ix) Catkin formation involved the visible extension of inflorescences beyond the bud scales, with bract hairs imparting a 'furry' appearance, leading to (x) inflorescence expansion, where 95% inflorescences reached their full length, termed the 'post-peak' stage (Marchenko and Kuzovkina, 2023). (xi) Flowering initiation was marked by the appearance of sporadic flowers with distinguishable stamens or stigmas on 10% flowers, progressing to (xii) blooming, when 50% inflorescences displayed pollen-bearing stamens or receptive stigmas (Wagay *et al.,* 2024). The later stages included (xiii) inflorescence wilting, where 50% inflorescences showed wilting, and (xiv) inflorescence dropping, marked by the detachment of 50% inflorescences from male plants. In female plants, (xv) capsule fruits final size was noted with the swelling of pistils to their maximum size, followed by (xvi) seed dispersal, involving capsule bursting and the release of cottony seed masses (Gage and Cooper, 2005). Vegetative stages such as (xvii) shoot tip abortion, where shoot elongation terminated due to apex abortion and (xviii) leaf discolouration, where 50% of leaves changed colour, were also recorded (Poethig, 2013). Finally, (xix) leaf drop occurred when 50% leaves detached from the plant, and (xx) skeletonization, characterized by damage to leaves from insects, disease, or chemical injury, concluded the phenological observations (Ekholm *et al.,* 2022).

Data analysis

The data generated on phenological stages, corresponding temperatures and pest occurrences were statistically analyzed using both R software and SPSS software, to correlate temperature fluctuations with the timing of developmental events. The degree-day model served as a predictive tool for phenological and pest emergence patterns.

RESULTS AND DISCUSSION

Phenological events timeline

The phenological stages of *S. alba* (Fig. 1) were monitored across the two consecutive years, 2022 and 2023 (Table 1), using Julian dates and accumulated degree days as metrics. Significant variations were observed between the two years in both the timing and degree day accumulation of phenological events. In 2022, vegetative bud burst occurred earlier at Julian day 53 with an accumulation of 0.55 degree days (DD), whereas in 2023, it was recorded at Julian day 60 with 3.86 DD. This delay in 2023 aligns with cooler early season temperatures, which likely slowed the accumulation of heat units required for bud burst. Chuine and Regniere (2017) emphasize that lower temperatures can significantly delay developmental stages by reducing the rate of physiological processes.

Flowering initiation remained consistent between the two years, both occurring at Julian day 64. However, the DD accumulation differed, with 1.10 in 2022 and 7.47 in 2023, suggesting a prolonged response to thermal conditions in the later year. The flowering peak and blooming stages exhibited significant delays in 2023. In 2022, the flowering peak was observed at Julian day 74 (23.02 DD) and blooming at day 75 (28.85 DD). In contrast, these stages were delayed in Julian days 81 and 82 in 2023, with degree day accumulations of 593.88 and 39.92, respectively. Such delays may indicate altered climatic conditions, such as cooler spring temperatures or extended growing seasons (Bita and Gerats, 2013). Subsequent phenological events, including stem coloration, development of sylleptic branches and differentiation of generative buds, consistently occurred later in 2023 as compared to

2022, accompanied by higher degree day accumulations. By the end of the growing season, stages such as leaf discoloration, leaf drop and skeletonization also occurred later in 2023 (Julian days 277, 295 and 303) as compared to 2022 (Julian days 274, 288 and 298), with degree day accumulations increasing correspondingly. These findings are consistent with the broader literature on the temperature-driven pheno-logical shifts. Menzel *et al.* (2006) reported that inter-annual temperature variability and extended growing seasons can delay the onset of autumnal senescence, particularly in

Fig. 1: The phenological stages of *Salix alba*

Table 1: The timeline of phenological events in *Salix alba* with Julian dates and degree days (2022 and 2023)

Phenological stages	2022		2023	
	Julian dates	Degree days	Julian dates	Degree days
Vegetative bud burst	53	0.55	60	3.86
Flowering initiation	64	1.1	64	7.47
Formation of axillary buds	65	1.65	66	9.96
Flowering peak	74	23.02	81	38.26
Blooming	75	28.85	82	39.92
Stem coloration	95	133.81	105	117.08
Development of sylleptic branches	106	204.06	114	142.05
Differentiation of generative buds	115	245.7	120	162.04
Coloration of generative bud scales	125	323.16	131	209.52
Generative bud swelling	135	388.41	138	263.12
Generative bud burst	145	456.99	150	352.53
Inflorescence dropping	146	463.93	151	356.42
Seeds disperse initiation	148	480.87	153	366.97
Catkin formation	152	514.48	159	418.06
Inflorescence expansion	161	608.64	165	492.22
Inflorescence wilting	181	856.7	187	814.43
Flowering completion	186	932.25	192	866.94
Capsule fruits final size	201	1131.15	205	1047.5
Peak seed disperse	203	1160.88	207	1075.83
Shoot tip abortion	225	1467.26	232	1444.98
Seeds disperse completion	227	1495.59	234	1479.42
Leaf discolouration	274	2072.55	277	2001.37
Leaf drop	288	2177.29	295	2087.49
Skeletonization	298	2211.75	303	2113.32

temperate deciduous species. Similar trends have been observed across Europe where warming-induced increases in GDD result in prolonged photosynthetic activity and delayed leaf coloration and abscission (Estrella and Menzel, 2006; Vitasse *et al.,* 2011). The observed delay in *S. alba* pheno-phases thus reflects the sensitivity of willow phenology to cumulative thermal conditions rather than calendar time alone.

Gypsy moth development stages

The phenology and thermal requirements of gypsy moth (*Lymantria obfuscate*) were compared across the two consecutive years (Fig. 2) which revealed marked inter-annual variation in the timing and degree-day (DD) accumulations associated with different developmental stages. In 2022, oviposition began on Julian day 54 with an accumulated 0.55 DD, and hatching occurred by day 59 at a similar thermal threshold. The larval stage commenced by day 75 after reaching 28.85 DD and progressed to pupation by day 146 with 463.93 DD. Adult emergence occurred around day 158 following the accumulation of approximately 945.30 DD. In contrast, during 2023, egg laying was delayed until day 60, coinciding with higher initial thermal accumulation (3.86 DD), and hatching was observed by day 66 at 9.96 DD. Larval development began later, on day 82 (39.92 DD), and pupation was achieved by day 150 (352.53 DD), while adult emergence occurred on day 165 with a total of 492.22 DD.

The later onset of all developmental stages in 2023, coupled with reduced cumulative DD values, suggests that cooler early-season temperatures slowed the rate of heat accumulation, thereby extending the duration of each stage. These findings are consistent with the concept that insect development is tightly regulated by temperature-dependent physiological processes, where insufficient thermal accumulation delays ontogenetic transitions (Regniere *et al.,* 2012; Chuine and Regniere, 2017). Temperature influences enzyme activity, metabolic rate and hormonal regulation, which in turn determine the pace of embryonic and larval development (Koch, 2015). The greater degree-day requirement observed for the egg stage in 2023 (3.86 DD vs. 0.55 DD in 2022) implies a slower post-diapause warming period, potentially affecting the timing of hatching and subsequent cohort synchrony, a pattern also prominent in *L. dispar* populations under fluctuating spring temperatures (Wei *et al.,* 2014).

The observed reduction in cumulative DD at adult emergence in 2023 (492 DD as compared to 945 DD in 2022) may reflect physiological plasticity or local thermal adaptation within *L. obfuscata* populations. Gray (2018) emphasized that developmental rates in *Lymantria* species post-diapause are both age- and temperature-dependent, often displaying nonlinear responses near the lower development

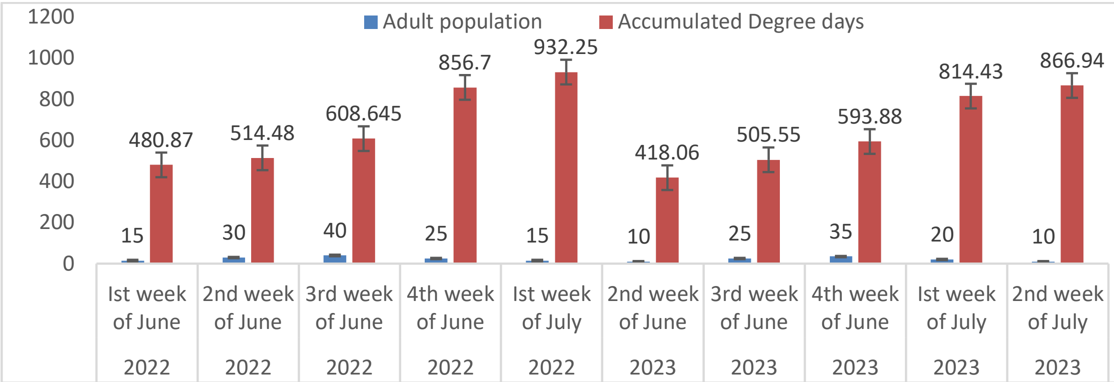

Fig. 2: Developmental stages of gypsy moth in relation to degree days (2022 & 2023)

developmental thresholds. This plasticity enables populations to survive in the regions with varying climatic conditions but can also lead to desynchronization between life stages and host phenology when temperature regimes deviate from the norm (Mallard *et al.,* 2020). Similarly, Hill *et al.* (2021) reported that inter-annual variation in temperature regimes can significantly alter the rate and synchrony of development in gypsy moth populations, leading to temporal asynchrony between life stages and host plant leaf-out, thereby influencing feeding success and survival. Moreover, the slower progression of larval and pupal stages in 2023 aligns with the findings of Harvey *et al.* (2020) who demonstrated that suboptimal temperatures during early larval instars can extend development and cascade into later life stages, ultimately influencing fecundity and survival. Similar developmental delays have been observed in *L. monacha* and *Malacosoma disstria* when exposed to low-temperature regimes (Gray *et al.,* 2001; Regniere and Nealis, 2007). Such inter-annual thermal variability, therefore, not only modulates the phenological timing of *L. obfuscata* but may also affect its voltinism, population dynamics and potential outbreak risk (Logan *et al.,* 2003; Van Asch and Visser, 2007).

The results underscore strong coupling between temperature, degree-day accumulation, and the phenological plasticity of *L. obfuscata*, consistent with previous research on *L. dispar* and related species (Gray, 2018; Hill *et al.,* 2021). These findings highlight the importance of integrating local temperature variability and degree-day modelling into predictive frameworks for pest emergence and management under changing climatic conditions in temperate ecosystems like Kashmir. Understanding such fine-scale phenological shifts is critical for forecasting pest pressure and optimizing intervention timing, as even modest temperature deviations can significantly alter the seasonal dynamics of outbreak-prone forest defoliators (Regniere *et al.,* 2012; Buckley, 2022).

Monitoring of adult gypsy moth population

Adult *L. obfuscata* moth populations were tracked biweekly during early summer of 2022 and 2023 (Fig. 3), alongside accumulated degree-days (DD), revealing clear differences in emergence timing, peak abundance and decline dynamics. In 2022, adults first appeared in early June, with approximately15 individuals recorded at 480.87 DD. The population climbed steadily to 30 individuals by mid-June (514.48 DD), peaking at 40 adults during the 3rd week of June (608.64 DD)**.** After this maximum, the population declined through late June (25 individuals at 856.70 DD) into early July (15 individuals at 932.25 DD). In contrast, 2023 presented a delayed and subdued phenological profile. Initial adult captures in mid-June revealed only 10 individuals at 418.06 DD. The number rose to 25 by 3rd week (505.55 DD) and reached a slightly lower peak of 35 individuals at 593.88 DD in late June**.** The descent was sharper: 20 individuals by early July (814.43 DD), followed by just 10 by mid-July (866.94 DD). The 2023 season displayed a clear delay in adult emergence, with peak emergence shifting approximately one week later as compared to the year 2022, and peak abundance slightly reduced. These delays coincide with the earlier pattern of cooler thermal accumulation and slower developmental progression across the earlier life stages, consistent with phenological theory in ectotherms where cooler temperatures prolong development and shift timing (Liebhold *et al.,* 2000). Interestingly, the cumulative DD corresponding to peak adult emergence was lower in 2023

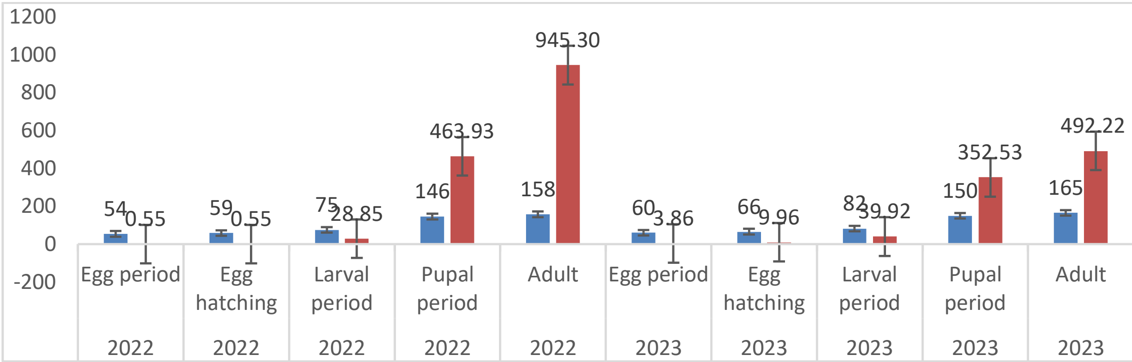

Fig. 3: Adult gypsy moth population on *Salix alba* and degree day accumulation (2022 & 2023)

(593.88 DD) than in 2022 (~ 609 DD). While degree-day models often predict adult flight within the established thresholds of 900 - 1300 DD in many regions (Olaya-Arenas *et al.,* 2024), our observations suggest either locally adjusted development thresholds or temporal distribution differences in cohorts, highlighting the need to calibrate regional degree-day models with real-time field data. Overall, the data indicated that phenological events and gypsy moth development stages experienced temporal shifts between 2022 and 2023, with 2023 generally showing delayed phenological stages and altered DD accumulations. The synchronization between plant phenology and gypsy moth development stages suggests potential implications for pest management strategies, as changes in phenological timing could affect the interaction dynamics between the host plants and the gypsy moth populations.

Conclusion: The study highlights significant inter-annual variations in phenological events of *Salix alba* and the developmental stages of gypsy moths, influenced by environmental conditions. In 2023, the phenological events such as vegetative bud burst, flowering and leaf drop occurred later in comparison to 2022, requiring higher degree day accumulations, likely due to cooler early-season temperatures. Similarly, gypsy moth development showed delayed transitions, with higher degree day thresholds for egg hatching, larval development and adult emergence in 2023. monitoring adult populations revealed a delayed and lower peak in 2023, indicating altered population dynamics. These findings emphasize the role of climate variability in shaping plant-insect interactions and highlight the importance of degree day models for predicting the phenological shifts and informing adaptive management strategies in forestry and pest control.

Acknowledgements: The authors are thankful to the Faculty of Forestry, SKUAST-K, Benhama and Division of Entomology, Faculty of Horticulture, SKUAST-Kashmir, Jammu & Kashmir (India), for their steadfast support, guidance and resources during my research work.

REFERENCES

Bita, C.E. and Gerats, T. 2013. Plant tolerance to high temperature in a changing environment: Scientific fundamentals and production of heat stress-tolerant crops. *Frontiers in Plant Science*, **4**: 273. [*https://doi.org/10.3389/fpls.2013.00273*].

Buckley, L.B. 2022. Temperature-sensitive development shapes insect phenological responses to climate change. *Current Opinion in Insect Science*, **52**: 100897. [*https://doi.org/10.1016/j.cois.2022.100897*].

Chuine, I., Garcia de Cortazar-Atauri, I., Kramer, K. and Hanninen, H. 2013. Plant development models. pp. 275-293. **In:** *Phenology: An Integrative Environmental Science* (ed. M.D. Schwartz). Springer, Dordrecht, The Netherlands. [*https://doi.org/10.1007/978-94-007-6925-0_15*].

Chuine, I. and Regniere, J. 2017. Process-based models of phenology for plants and animals. *Annual Review of Ecology, Evolution and Systematics,* **48**(1): 159-182.

Crimmins, T.M., Gerst, K.L., Huerta, D.G., Marsh, R.L., Posthumus, E.E., Rosemartin, A.H., *et al.,* 2020. Short-term forecasts of Insect phenology inform pest management. *Annals of the Entomological Society of America*, **113**(2): 139-148.

Dhar, U. and Kachroo, P. 1983. *Alpine Flora of Kashmir Himalaya.* Scientific Publishers, Jodhpur, Rajasthan, India.

Didevarasl, A., Costa-Saura, J.M., Spano, D., Deiana, P., Snyder, R.L., Rechid, D., *et al.,* 2025. The phenological phases of early and mid-late budbreak olive cultivars in a changing future climate over the Euro-Mediterranean region. *European Journal of Agronomy*, **168**: 127658. [*https://doi.org/10.1016/j.eja.2025.127658*].

Ekholm, A., Faticov, M., Tack, A.J.M. and Roslin, T. 2022. Herbivory in a changing climate – Effects of plant genotype and experimentally induced variation in plant phenology on two summer-active lepidopteran herbivores and one fungal pathogen. *Ecology and Evolution*, **12**(1): e8495. [*https://doi.org/10.1002/ece3.8495*].

Estrella, N. and Menzel, A. 2006. Responses of leaf colouring in four deciduous tree species to climate and weather in Germany. *Climate Research, **32***(3): 253-267.

Gage, E.A. and Cooper, D.J. 2005. Patterns of willow (*Salix* spp.) seed dispersal, seed entrapment, and seedling establishment in a heavily browsed montane riparian ecosystem. *Canadian Journal of Botany*, **83**(6): 678-687.

Gray, D.R. 2018. Age-dependent developmental response to temperature: An examination of the rarely tested phenomenon in two species (gypsy moth (*Lymantria dispar*) and winter moth (*Operophtera brumata*)). *Insects*, **9**(2): 41. [*https://doi.org/10.3390/insects9020041*].

Gray, D.R., Ravlin, F.W. and Braine, J.A. 2001. Diapause in the gypsy moth: A model of inhibition and development. *Journal of Insect Physiology, **47***(2): 173-184.

Gupta, A., Singh, N.B., Choudhary, P., Sharma, J.P. and Sankhayan, H.P. 2014. Advances in agricultural practices *International Journal of Agriculture, Environment and Biotechnology,* **7**(2): 299-304.

Harvey, J.A., Heinen, R., Gols, R. and Thakur, M.P. 2020. Climate change-mediated temperature extremes and insects: From outbreaks to breakdowns. *Global Change Biology*, **26**: 6685–6701.

Helfenstein, J., Bauer, L., Claluna, A., Bolliger, J. and Kienast, F. 2014. Landscape ecology meets landscape science. *Landscape Ecology,* **29**(7): 1109-1113.

Hill, G.M., Kawahara, A.Y., Daniels, J.C., Bateman, C.C. and Scheffers, B.R. 2021. Climate change effects on animal ecology: Butterflies and moths as a case study. *Biological Reviews*, **96**(5): 2113-2126.

Jenderek, M.M., Ambruzs, B.D., Holman, G.E., Carstens, J.D., Ellis, D.D. and Widrlechner, M.P. 2020. *Salix* dormant bud cryotolerance varies by taxon, harvest year, and stem-segment length. *Crop Science*, **60**(4): 1965-1973.

Koch, K. 2015. Influence of temperature and photoperiod on embryonic development in *Sympetrum striolatum* (Libellulidae*:* Odonata). *Physiological Entomology*, **40**(1)**:** 31-40.

Kutsokon, N. and Khoma, Y. 2025**.** Effects of drought stress on spring bud development in poplar and willow clones. *Dendrobiology,* **93***:* 86-97.

Liebhold, A., Elkinton, J., Williams, D. and Muzika, R. 2000. What causes outbreaks of the gypsy moth in North America? *Population Ecology,* **42**: 257-266.

Logan, J.A., Regniere, J. and Powell, J.A. 2003. Assessing the impacts of global warming on forest pest dynamics. *Frontiers in Ecology and the Environment*, **1**(3): 130-137.

Mallard, F., Nolte, V. and Schlotterer, C. 2020. The evolution of phenotypic plasticity in response to temperature stress*. Genome Biology and Evolution,* **12**(12): 2429-2440.

Marchenko, A.M. and Kuzovkina, Y.A. 2023. Notes on the taxonomy of *Salix vitellina* (Salicaceae). *Plants*, **12**(14): 2610. [*https://doi.org/10.3390/plants12142610*].

Mcmaster, G.S. and Wilhelm, W.W. 1997. Growing degree-days: One equation, two interpretations. *Agricultural and Forest Meteorology,* **87**: 291-300.

Menzel, A., Sparks, T.H., Estrella, N., Keuler, N. and Aasa, A. 2006. European plant phenology and climate change. *Global Change Biology,* **12**(1): 1-8.

Moriondo, M., Ferrise, R., Trombi, G., Brilli, L., Dibari, C. and Bindi, M. 2015. Modelling olive trees and 494 grapevines in a changing climate. *Environmental Modelling and Software,* **72***:* 387-401.

Mosseler, A. and Papadopol, C.S. 1989. Seasonal isolation as a reproductive barrier among sympatric *Salix* species. *Canadian Journal of Botany,* **67**: 2563-2570.

Munshi, N.A., Hussain, B., Malik, G.N., Yousuf, M. and Fatima, N. 2008. Efficacy of entomo-pathogenic fungus *Fusarium pallidoroseum* (Cooke) Sacc. against gypsy moth *Lymantria obfuscata* Walker. *Journal of Entomology,* **5**(1): 59-61.

Olaya-Arenas, P., Cho, C.Y.L., Olmstead, D., DiPaola, A., Crowther, S., Degni, J., *et al.,* 2024. Degree-day models for predicting adult *Delia platura* (Diptera: Anthomyiidae) spring flight and first emergence in New York state. *Journal of Economic Entomology,* **117**(5): 2181-2185.

Oliveira, N., Canellas, I., Fuertes, A., Pascual, S., González, I., Montes, F., *et al.,* 2024. Beyond biomass production: Enhancing biodiversity while capturing carbon in short rotation coppice poplar plantations. *Science of The Total Environment*, **933**: 172932. [*https://doi.org/10.1016/j.scitotenv.2024.172932*].

Orlandi, F., Ruga, L. and Fornaciari, M. 2020. Willow phenological modelling at different altitudes in central Italy. *Environmental Monitoring and Assessment*, **192**: 737. [*https://doi.org/10.1007/s10661-020-08702-7*].

Parker, A.K., Garcia de Cortazar-Atauri, I., Van Leeuwen, C. and Chuine, I. 2011. General phenological model to characterise the timing of flowering and veraison of *Vitis vinifera* L. *Australian Journal of Grape and Wine Research,* **17**(2): 206-216.

Poethig, R.S. 2013. Vegetative phase change and shoot maturation in plants. *Current Topics in Developmental Biology*, **105**: 125-152.

Praciak, A., Pasiecznik, N.M., Sheil, D., van Heist, M., Sassen, M., Correia, C.S., *et al.*, 2013. *The CABI Encyclopedia of Forest Trees.* CABI Publishing, Wallingford, Oxfordshire, UK.

Regniere, J. and Nealis, V.G. 2007. Ecological mechanisms of population change during outbreaks of the spruce budworm. *Ecological Entomology, **32***(5): 461-477.

Regniere, J., Powell, J., Bentz, B. and Nealis, V. 2012. Effects of temperature on development, survival and reproduction of insects: Experimental design, data analysis and modelling. *Journal of Insect Physiology,* **58**(5): 634-647.

Roonwal, M.L. 1979. Field-ecological studies on mass eruption, seasonal life-history, nocturnal feeding and activity rhythm, and protective behaviour and coloration in the sal defoliator, *Lymantria mathura* (Lepidoptera: Lymantriidae), in Sub-Himalayan forests. *Records of the Zoological Survey of India,* **75**: 209-223.

Saska, M.M. and Kuzovkina, Y.A. 2010. Phenological stages of willow (*Salix*). *Annals of Applied Biology,* **156**(3): 431-437.

Schwartz, M.D. (ed.). 2013. *Phenology: An Integrative Environmental Science* (2^{nd} edn.). Springer, Dordrecht, The Netherlands.

van Asch, M. and Visser, M.E. 2007. Phenology of forest caterpillars and their host trees: The importance of synchrony. *Annual Review of Entomology,* **52**: 37-55.

Vitasse, Y., Francois, C., Delpierre, N., Dufrene, E., Kremer, A., Chuine, I., *et al.,* 2011. Assessing the effects of climate change on the phenology of European temperate trees. *Agricultural and Forest Meteorology,* **151**(7): 969-980.

Wagay, O.A., Mugloo, J.A., Masoodi, T.H., Pala, N.A., Hussain, B., Khan, I., *et al.,* 2024. Exploring the floral biology of *Salix alba*: Insights into reproductive dynamics, pollen production and pollen morphology in Kashmir Himalayas. *International Journal of Environment and Climate Change*, **14**(7): 714-723.

Wei, J., Luo, Y.Q., Shi, J., Wang, D.P. and Shen, S.W. 2014. Impact of temperature on postdiapause and diapause of the Asian gypsy moth (*Lymantria dispar asiatica*). *Journal of Insect Science*, **14**: 5. [*https://doi.org/10.1093/jisesa/ieu119*].