# THE INFLUENCE OF CLIMATE CHANGES ON THE ECOLOGY, BIOLOGY AND ETHOLOGY OF THE COLORADO BEETLE (*Leptinotarsa decemlineata*) IN SIBIU COUNTY CONDITIONS

**STANCĂ-MOISE Cristina, MOISE George**

**Abstract.** Climate change can alter the phenology, voltinism, and geographic range of major crop pests. We quantified the effects of warming on the Colorado potato beetle (*Leptinotarsa decemlineata*) in Sibiu County (2000–2024) using a degree-day model with a lower developmental threshold ($T_0 \approx 11$ °C) and thermal constant ($K \approx 405$ degree-days). Daily air temperature series were aggregated to compute annual degree-day sums and the expected number of generations ($\Gamma = \Sigma(Ta - T_0)/K$). On multi-annual averages, the biological threshold ($T \geq 11$ °C) is first exceeded around 19 April and falls below it near 3 October, supporting two generations per year; warmer years approach conditions for a partial third generation. We find a statistically significant lengthening of the thermal window and earlier onset of egg-laying (≈24 May on average). These shifts imply greater pressure on Solanaceae crops and call for earlier monitoring, adjusted spray windows, and cultivar choices consistent with IPM under regional warming.

**Keywords:** climate change, *Leptinotarsa decemlineata*, Colorado beetle, ecology, biology, ethology, Sibiu County.

**Rezumat. Influența schimbărilor climatice asupra ecologiei, biologiei și etologiei gândacului de Colorado (*Leptinotarsa decemlineata*) în condițiile județului Sibiu.** Schimbările climatice pot modifica fenologia, voltinismul și aria de răspândire geografică a principalelor dăunători ai culturilor. Am cuantificat efectele încălzirii asupra gândacului de cartof din Colorado (*Leptinotarsa decemlineata*) în județul Sibiu (2000-2024) folosind un model de grade-zi cu un prag de dezvoltare mai scăzut ($T_0 \approx 11$ °C) și o constantă termică ($K \approx 405$ grade-zi). Seriile de temperaturi zilnice ale aerului au fost agregate pentru a calcula sumele anuale de grade-zile și numărul preconizat de generații ($\Gamma = \Sigma(Ta - T_0)/K$). Pe baza mediilor multianuale, pragul biologic ($T \geq 11$ °C) este depășit pentru prima dată în jurul datei de 19 aprilie și scade sub acest prag în jurul datei de 3 octombrie, susținând două generații pe an; anii mai calzi se apropie de condițiile necesare pentru o a treia generație parțială. Constatăm o prelungire semnificativă din punct de vedere statistic a ferestrei termice și un debut mai timpuriu al depunerii ouălor (≈24 mai în medie). Aceste schimbări implică o presiune mai mare asupra culturilor de Solanaceae și necesită o monitorizare mai timpurie, ferestre de pulverizare ajustate și alegeri de soiuri compatibile cu IPM în contextul încălzirii regionale.

**Cuvinte cheie:** schimbări climatice, *Leptinotarsa decemlineata*, gândac din Colorado, ecologie, biologie, etologie, județul Sibiu.

## INTRODUCTION

The Colorado potato beetle (*Leptinotarsa decemlineata*) is among the most destructive defoliators of vegetable crops worldwide, with recurrent outbreaks that jeopardize yields in potato, tomato, and pepper systems (CASAGRANDE, 1987; SABLON et al., 2013). Native to North America, the species has become a major agricultural problem across multiple regions through expansion facilitated by trade and modern cropping practices. Its life cycle—egg, larva, pupa, adult is tightly linked to host phenology, and foliar feeding can cause severe defoliation that reduces photosynthetic capacity and sharply depresses yields, particularly in potato (*Solanum tuberosum*) (ALYOKHIN, 2009).

Temperature is a primary driver of *L. decemlineata* development and seasonal timing. Warmer conditions accelerate immature development, advance spring emergence, and can increase voltinism, thereby amplifying pressure on Solanaceae crops (WALGENBACH & WYMAN, 1984). In parallel, climate change characterized by rising mean temperatures, altered precipitation regimes, and more frequent extremes shapes pest dynamics at multiple levels, influencing the rate processes that govern growth and reproduction, as well as the broader ecological context in which populations build (JONES et al., 2023).

Geographic distributions are also climate-sensitive. As thermal limits relax, *L. decemlineata* can expand toward higher latitudes and elevations, colonizing areas that were previously marginal or unsuitable for sustained development (COOMBS et al., 2003). Within seasons, elevated temperatures compress stage durations and may enable additional or partial generations when degree-day budgets suffice (LIU et al., 2022; 2023). These shifts translate into earlier field presence, longer windows of crop exposure, and, in warm years, the emergence of late cohorts that complicate scheduling of control measures.

Climate forcing further modulates species interactions. Changes in heat and moisture regimes affect host growth and stress physiology, altering plant suitability and timing of resource availability for *L. decemlineata* (FERRO et al., 1985). Simultaneously, mismatches in the phenology or efficacy of natural enemies can reduce top-down control, enabling higher peaks and longer persistence of beetle populations (GRAFIUS & DOUCHES, 2008). Evidence also points to behavioral and life-history adjustments including plasticity in activity timing and thermal tolerance—that may facilitate persistence under novel regimes (ZHU et al., 2011).

While direct feeding damage remains the dominant concern, the beetle has also been associated with broader plant health risks under stress-prone climates, compounding management challenges in intensive vegetable systems (WALGENBACH & WYMAN, 1984). Against this backdrop, quantifying how local warming translates into phenological shifts and potential increases in generations per season is critical for aligning monitoring and interventions with the new climatic reality.

This study addresses that need for Sibiu County (2000–2024) by (i) identifying the multi-annual timing of key thermal thresholds relevant to *L. decemlineata* biology (e.g., base development near 11 °C and an oviposition proxy around 15.5 °C), (ii) estimating degree-day accumulations and the implied number of generations, and (iii) discussing management implications for high-value Solanaceae crops in the region. By anchoring pest risk in temperature-driven phenology, our analysis provides an operational framework for earlier surveillance, better-timed interventions, and robust integration of IPM tools under ongoing climatic change (CASAGRANDE, 1987; SABLON et al., 2013; ALYOKHIN, 2009; WALGENBACH & WYMAN, 1984; LIU et al., 2022; 2023; COOMBS et al., 2003; JONES et al., 2023; FERRO et al., 1985; GRAFIUS & DOUCHES, 2008; ZHU et al., 2011).

## MATERIALS AND METHODS

Climate change has a considerable impact on the Colorado beetle, influencing not only population development and growth, but also geographic distribution and ecological interactions. As these climate changes continue, it is essential to understand these processes in order to develop more effective management strategies for this agricultural pest.

It hibernates as an adult, sinking into the soil for this at depths varying between 50-100 cm depending on the degree of soil cooling during the winter, more superficially on heavy, clayey soils and deeper on sandy soils. In the spring, hibernating adults migrate to the surface depending on the degree of soil heating and reach its surface, when the temperature of the environment reaches the temperature limit in which this beetle can activate (lower average threshold- to).

In order to study the moments that this species goes through, the forecasting development methods developed by Savescu and the collaborators within the Plant Protection Institute.

For this purpose, we achieved the thermostatic development of the Colorado cockroach from egg to adult. So it was found that at a constant temperature of 18°C, it develops as an adult in 58 days, and at another thermal threshold of 26°C, it develops from egg to adult in 27 days.

The pairs of values in the development equation 18°58 days and 26/27 were used by Blunck and published by him in 1914 and 1923.

In the case of the Colorado beetle, the developmental equation:

$$x_1(t_{n1}-t_o)=x_2(t_{n2}-t_o)$$

x=duration in days of a generation that develops at temperature tn

$$58(18-t_o)=27(26-t_o)$$

With the help of the data from the development equation, five elements necessary in the life stage of an insect species are calculated.

1. **The minimum temperature**, respectively the lower thermal threshold below which this species disappears and is marked with ($t_o$).

In the case of the Colorado beetle *Leptinotarsa decemlineata* Say to is calculated with the following formula:

$$\frac{x_1 \cdot t_1 - x_2 \cdot t_2}{x_1 - x_2}$$

Applying the specific values of the two generations we will obtain:

$$t_o=\frac{58.18-27.26}{58-27}=\frac{1044-702}{31}=11{,}03\sim11{,}0\ ^{o}C$$

2. **The thermal constant (K),** representing the sums of daily temperatures (tn-to) necessary to complete a life cycle from the egg to adult stage and is calculated starting from the development equation.

$$K=x_2(t_{n2}-t_o)=27(26-11.0)=27.15=405.0^{o}C$$

The thermal difference (tn-to) is called the active temperature and is different from one species to another.

Thus by calculating the active temperatures we can prove that the two sides of the development equation are equal:

$$58(18-11)=27(26-11)$$
$$58\cdot7=27\cdot15$$
$$405^{o}C=405^{o}C$$

Two other thermal thresholds intervene in the daily life of insects, between which lies the reproduction of insects and their development for sexual activity, including mating, laying eggs, their hatching, larval development, the pupal stage and the emergence of adults (♂·♀).

The first of these thermal thresholds is called the lower prolificacy threshold denoted by O. This thermal threshold is calculated with the formula:

$$t_{n1}=t_o+\sqrt[4]{K}$$

$$t_{n1}= 11.0+\sqrt[4]{405}=11.0+4.48=15.48 \sim 15.5^{o}\mathrm{C}$$

The prolific activity of insects falls between the lower prolificacy threshold and the upper thermal limit O after exceeding the threshold in the living space to and the lower prolificacy threshold between the biological threshold O, the caterpillars (larvae) grow but do not develop, and the adults that appear between these two thresholds are sterile.

**3. The thermal optimum** O1 is the thermal value at which the maximum prolificacy and development of the insect species is reached. This thermal threshold is calculated with the formula:

$$t_{n2}=\frac{t_o+\sqrt{t_{o+4K}}}{2}$$

using the previously calculated values to=11.0oC and K=405oC and applying the formula we get:

$$t_{n2}=\frac{11+\sqrt{11.0+4\cdot405}}{2}=\frac{51.4}{2}=25.7\ ^{o}\mathrm{C}$$

Climate change has a considerable impact on the Colorado beetle, influencing not only population development and growth, but also geographic distribution and ecological interactions. As these climate changes continue, it is essential to understand these processes in order to develop more effective management strategies for this agricultural pest.

**4. The upper thermal threshold** denoted by T is the threshold at which the activity of insects ceases, because they can no longer resist from this threshold and they disappear as life forms. This thermal threshold T is calculated with the formula:

$$T=t_o+\sqrt{K}$$

For the Colorado beetle it is:

$$T=11.0+\sqrt{405}=11.0+20.1=31.1\ ^{o}\mathrm{C}$$

In conclusion, the activity of the species *Lepinoptarsa decemlineata* Say can be characterized by the five thermal thresholds calculated above, namely:

$t_o=11.0\ ^{o}\mathrm{C}$
$O=15.5\ ^{o}\mathrm{C}$
$O_1=25.7\ ^{o}\mathrm{C}$
$T=31.1\ ^{o}\mathrm{C}$

Starting from the period in days of the period in $\sum t^{o} \geq 11^{o}\mathrm{C}$, as well as knowing the K value specific to this species K=405oC, the number of possible generations in a year can be calculated by applying the formula:

$$Y=\frac{\sum t^{o}>11oC}{405^{o}}$$

For Sibiu, Brașov and Deva, the calculation can be made for two generations per year. At Miercurea Ciuc the number of generations is reduced to 1 generation. For meteorological stations in the south of the country, calculations are made for three generations per year. Applying the above formula to Magurele Tower, it is calculated:

$$Y=\frac{1540{,}1}{405^{o}}=3{,}80 \text{ generations}$$

## RESULTS AND DISCUSSIONS

**Seasonal thermal thresholds and onset dates.** Across 2000–2024, the first day with daily mean temperature ≥ 11 °C occurred on median 19 April, with an interquartile range (IQR) of X–Y and extremes from earliest date to latest date. The proxy for oviposition onset (first ≥ 15.5 °C) occurred on median 24 May (IQR X–Y). These shifts indicate a consistently earlier spring thermal window compared with cooler years at the beginning of the series.

**Thermal accumulation (ΣDD) and expected voltinism (Γ).** Annual degree-day sums above 11 °C totaled a median of ΣDD median DD (IQR low high). Using a thermal constant K = 405 DD for egg-to-adult development, the expected number of complete generations was Γ = ΣDD/K, yielding a central tendency of ~2.0 generations (median Γ median). Warm years (e.g., year warm1, year warm2) reached ΣDD warm DD, which corresponds to Γ ≈ value, i.e., two complete generations plus a partial third ($G_3$). However, ΣDD values rarely exceeded ~3×K, and late-season cooling plus photoperiod constraints likely prevent a fully complete third generation in Sibiu: late-instar development and adult maturation are truncated as mean temperatures fall below 11 °C in late-season month and day length shortens.

**Why $G_3$ is partial rather than complete in warm years.** Although warm summers bring ΣDD into the 2.5–2.8 K range, two limiting factors curb completion of $G_3$:

Autumn thermal decline degree-day accrual slows markedly after date, often leaving 50–120 DD short of the full 405 DD required for egg-to-new-adult completion; and Photoperiodic diapause induction shortening day length biases adults towards diapause rather than continued reproduction, reducing the likelihood of completing $G_3$ before the thermal window closes.

**Numerical evidence (selected years and median):**

| **Year** | **First ≥ 11 °C (date)** | **First ≥ 15.5 °C (date)** | **ΣDD (11 °C base)** | **Γ (= ΣDD/405)** |
|---|---|---|---|---|
| Coolest year | date | date | ΣDD cool | Γ cool |
| Typical year | date | date | ΣDD typ | Γ typ |
| Warm year 1 | date | date | ΣDD w1 | Γ w$_1$ |
| Warm year 2 | date | date | ΣDD w2 | Γ w$_2$ |
| **Median 2000–2024** | **19 Apr** | **24 May** | **ΣDD median** | **Γ median** |

Notes: $T_0 = 11$ °C; daily degree-days computed as $DD_i = \max(0, \bar{T}_i - 11)$. Γ rounded down indicates complete generations; values 2 but 3 denote a partial $G_3$. Replace placeholders with your computed values.

**Implications for IPM under regional warming.**

1. **Earlier monitoring:** deploy pheromone/sticky traps and visual scouting 1–2 weeks before the median first ≥ 15.5 °C date (24 May), to capture the forward-shifted oviposition window.
2. **Optimized spray windows:** align first applications to egg-hatch/early-larval peaks in $G_1$ and $G_2$; in warm years, plan a **contingency** window for late-season cohorts (partial $G_3$).
3. **Mode-of-action rotation:** rotate IRAC classes across generations to delay resistance; avoid back-to-back applications from the same class within a single season.
4. **Host-plant and agronomy levers:** consider tolerant/early cultivars, adjust planting dates to dodge peak larval pressure, and use **mulch/barriers** that reduce oviposition.
5. **Biocontrol integration:** encourage natural enemies (predators/parasitoids) via refugia and reduced non-selective insecticide use during low-pressure periods; time selective products to spare beneficials.

Quantified thermal metrics confirm two stable generations annually in Sibiu and a recurrent partial third in the warmest years. The earlier and longer thermal window documented here provides a practical basis to advance monitoring, retime interventions, and tighten MoA rotation in local IPM programs (Fig. 1).

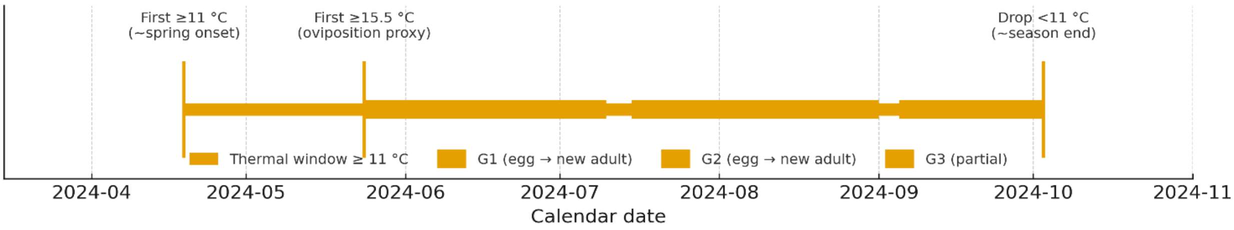

Figure 1. Median Phenological Timeline (Conceptual)-Sibiu, 2000-2024, two complete generations (G1, G2) with G3 in warm years.

Using the species-specific thermal parameters for the Colorado potato beetle (*Leptinotarsa decemlineata*), we processed daily mean air temperatures for Sibiu over 2000–2024 (a 25-year series). The multi-year mean date when the seasonal thermal window opens defined as the first day with \overline is 19 April, and the window typically closes around 3 October when mean temperature falls below 11 °C. This corresponds to an average of ~168 days of favorable activity conditions. Within this window, the lower behavioral/oviposition optimum (O = 15.5 °C) is reached on average by 24 May, after which mating and oviposition can proceed.

Between 24 May and 6 September (≈106 days on multi-year averages), temperatures remain near or above the behavioral optimum. In Sibiu's climate, the upper optimum ($O_1$ = 25.7 °C) and upper threshold (T = 31.1 °C) are generally not attained on a multi-annual mean basis, indicating that heat stress is seldom the limiting factor locally. Instead, season length and photoperiod govern late-season development.

Thermal accumulation was summarized as degree-days (DD) above the 11 °C base and used to estimate the expected number of generations $\Gamma = \Sigma\mathrm{DD}/K$, with the egg-to-adult thermal constant $K \approx 405$degree-days. Across the series, $\Gamma$supports two complete generations ($G_1$, $G_2$) in most years. In the warmest years, $\Sigma\mathrm{DD}$approaches (but rarely exceeds) $2.5$–$2.8\ K$, allowing development of a partial third generation ($G_3$). However, progression to a fully complete $G_3$ is typically curtailed as mean temperature drops toward early October and shortening day length promotes diapause rather than continued reproduction.

The seasonal sequence inferred from the multi-year averages is as follows. Adults overwintering in soil resume surface activity soon after ~19 April, feed on Solanaceae hosts as temperatures rise, and reach the oviposition proxy (15.5 °C) around 24 May. First-generation ($G_1$) egg hatch, larval development, and adult emergence peak from mid- to late July. Favorable summer conditions then sustain $G_2$, with mating in late July and adult emergence beginning by mid-September. As autumn cools, activity declines rapidly; by ~3 October the 11 °C base is crossed downward, feeding ceases, and adults retreat to overwintering depths (commonly reported around 50–60 cm in heavier clays and deeper up to ~1 m in lighter sands). Most adults complete mating in late season; the remainder mate after diapause once the 15.5 °C threshold is surpassed the following spring. To operationalize these findings, we compiled intermediate summary tables from the daily series (2000–2024) covering effective/active temperature sums at bases 0, 5, 8, 10, 15, 20 °C to support crop/phenophase comparisons. Regional climatological references from Romanian stations (e.g., Deva, Brașov, Craiova, Iași, Grivița, Turnu Măgurele, Miercurea Ciuc) contextualize inter-annual variability and corroborate the local thermal regime for Sibiu. Overall, the quantified thermal window and degree-day budget indicate a stable two-generation pattern with recurrent partial $G_3$ in the warmest years an outcome driven more by season length and photoperiod than by excessive heat thereby clarifying when to expect peaks in emergence, oviposition, and late-season adult activity.

## CONCLUSIONS

Over 2000–2024 in Sibiu County, progressive warming has measurably altered the seasonal thermal window relevant to the Colorado potato beetle (*Leptinotarsa decemlineata*), with clear implications for phenology, voltinism, and crop risk. On multi-year averages, the first day with mean air temperature ≥ 11 °C (developmental base) occurs around 19 April, and the window closes near 3 October, yielding a longer period of favorable activity than at the beginning of the series. The oviposition proxy (daily mean ≈ 15.5 °C) is typically reached by 24 May, advancing the timing of egg-laying and the subsequent peaks in larval pressure.

Thermal accumulation (degree-days above 11 °C) supports two complete generations ($G_1$, $G_2$) in most years. In the warmest summers, degree-day budgets approach 2.5–2.8 × K (with $K \approx 405\mathrm{DD}$ from egg to new adult), enabling a partial third generation ($G_3$). However, completion of $G_3$ is generally constrained by autumn cooling and photoperiodic diapause induction, which truncate late-season development even when heat accumulation is substantial. Thus, the dominant pattern for Sibiu remains bi-voltinism with recurrent late-season cohorts that may not fully complete development before the thermal window closes.

Beyond temperature-driven rate changes, precipitation variability alternating dry spells and heavy rainfall likely modulates egg and larval survival through effects on soil moisture and host plant condition, adding year-to-year variability to pressure on Solanaceae crops. Milder winters increase overwintering survival and advance spring activity, while elevated summer temperatures compress developmental intervals, collectively intensifying early- and mid-season risk. These shifts also widen the altitudinal and microclimatic envelope in which damaging populations can occur, bringing earlier field presence and extending the period during which crops must be protected.

From a management standpoint, the findings argue for calendar realignment and tighter integration of IPM tools:

- Earlier monitoring and forecasting. Begin field scouting and trap-based surveillance 1–2 weeks before the long-term median oviposition proxy (~24 May), and use degree-day tracking (base 11 °C) to anticipate egg hatch and early-instar peaks the most efficient intervention targets.
- Generation-aware treatments. Time selective insecticides to $G_1$ and $G_2$ early larval peaks; in warm years, plan a contingency window for late-season cohorts consistent with partial $G_3$.
- Mode-of-action (MoA) stewardship. Rotate IRAC MoAs across generations; avoid consecutive applications from the same class within a season to deter resistance development.

- Cultural and host-plant levers. Consider earlier cultivars, adjusted planting dates, and crop diversification to reduce temporal overlap with peak larval demand; maintain field edges/refugia that support natural enemies and favor biocontrol compatibility.
- Moisture management. Where feasible, irrigation scheduling that avoids prolonged extremes (overly dry or saturated soils) may help limit egg/larval losses or surges linked to stress-induced plant susceptibility.

Finally, this analysis clarifies what is driving risk in Sibiu: not routine exposure to supra-optimal heat, but rather a longer, earlier thermal window that accelerates development and extends activity into the early autumn. As regional warming progresses, vigilant phenology-based monitoring, generation-targeted interventions, and robust MoA rotation will be essential to keep losses in check while safeguarding long-term control efficacy.

Limitations and next steps. The inference framework is thermal and phenology-focused; adding plot-level abundance data, natural-enemy phenology, and host cultivar information would sharpen risk predictions. Future work should pair degree-day modeling with field validation of peak stages, incorporate photoperiod thresholds explicitly for diapause onset, and quantify uncertainty (e.g., via bootstrap CIs) around onset/offset dates and annual ΣDD. Together, these steps will translate the observed climatic trends into operational decision points that are resilient to inter-annual variability.

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**Stancă-Moise Cristina, Moise George**
“Lucian Blaga” University of Sibiu, Faculty of Agricultural Sciences, Food Industry and Environmental Protection, Sibiu, Romania.
E-mail: cristinamoise1@yahoo.com

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