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Bark beetles (Coleoptera: Curculionidae: Scolytinae) in supranational migration of the Czech Republic

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Abstract: This study analyses the bark beetle species spectrum (Scolytinae) in supranational migration across the Czech Republic (2020–2025) using a Johnson-Taylor suction trap network. Out of 2 129 identified individuals (45 species), *Pityogenes chalcographus* (Linnaeus, 1761) and *Crypturgus cinereus* (Herbst, 1793) were dominant, with their 2021 outbreak temporarily altering the community's proportional abundance. Ecological indices (H', J') confirmed an acute internal asymmetry caused by massive pest flights. The findings support the dispersal flight phenomenon, where individual scattering into vast air volumes explains the high proportion of sub-recedent species without compromising the representative value of the samples. The proven efficacy of suction traps for invasive species detection led to their official integration into the Czech national phytosanitary surveillance system.

Keywords: air dispersal; biodiversity; forest protection; long-distance flight; pest monitoring; spatial distribution

Bark beetles (Curculionidae: Scolytinae) have attracted extraordinary attention in recent decades, which is a logical consequence of the damage recorded in forest stands. Europe has experienced repeated bark beetle outbreaks of unprecedented proportions, which have significantly altered forest ecosystem structures. This situation has prompted a number of publications focusing primarily on crisis management and public debate (Mentberger 2006; Chalupa 2012; Hlásny et al. 2019; Choma et al. 2020). Professional interest has focused primarily on the ecology of harmful species and the timing of management interventions (Zumr 1995; Skuhravý 2002; Zahradník 2004; Kindlmann 2012),

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forest protection products and their application (Zahradník 2006), as well as on the development of various forest protection methods (Lubojacký 2018; Zahradník, Zahradníková 2015a, b; Lubojacký, Liška 2023; Holuša, Fiala 2025; Zahradník et al. 2018; Holuša et al. 2021). Alongside these practical measures and publications focused on evaluating catches through standard monitoring using pheromone traps (Zahradník 2016a, b), online projects for sharing information on the course of swarming (kurovcoveinfo.cz) have also been developed. Studies have also focused on faunistic surveys of specific locations (Nakládal 2011; Foit 2014; Fiala 2017, 2019, 2020; Týr 2021; Procházka 2023; Procházka et al. 2014). However, the issue of long-distance bark beetle migration via air currents has been largely neglected until now. No major studies have been published in recent years, even abroad. Only partial results have been published (Fiala, Hradil 2024; 2026 in preparation), but no comprehensive study has addressed the issue in a broader ecological context.

In comparison with other terrestrial arthropod sampling methods, suction traps prove to be a highly effective technique (Yi et al. 2012). They allow for sampling from a large area within a short time period and are also valuable for the long-term monitoring of arthropods (Benton et al. 2002). The disadvantages were summarised by Fryč (2016); these primarily include high capital costs and technical difficulties in securing the production of suction traps (as mass production of stationary devices does not exist domestically or abroad, it is addressed through improvised manufacturing based on existing models). Suction traps must be in continuous operation, and spare parts – which are mostly non-standard – must be readily available in case of failure (e.g. motor breakdown). Continuous operation also requires a connection to the power grid. Furthermore, there are high demands on the operator's time flexibility to ensure the daily collection and dispatch of insect samples for identification (locations are mostly in open terrain). Finally, the expert processing of samples is labour-intensive due to the high volume of daily catches.

The suction trap sampling method itself was first described by Johnson (1950) and subsequently improved by Taylor (1951). The subsequent development of large (stationary) traps was described by Johnson and Taylor (1955). These devices can be used to collect data for long-term studies on wildlife (Benton et al. 2002). Until now, the target organisms for Johnson-Taylor suction traps in the Czech Republic have been limited to aphidomorphous insects. However, these devices are also an effective tool for capturing a wide range of other invertebrates; an exhaustive list and individual global studies were summarised by Teulon and Scott (2006). In the context of the Czech Republic, this information has been summarised in contributions by Lauterer (2006) and Fryč et al. (2024). Suction traps are assumed to capture small-bodied insects more effectively than other methods (Marshall et al. 1994). Furthermore, the vast majority of aeroplankton individuals are small; therefore, suction traps are likely to be a highly effective tool for sampling a significant portion of the aerial fauna (Johnson 1957).

Although bark beetles (Curculionidae: Scolytinae) have been overlooked in suction trap monitoring, dispersal by flight is an essential strategy for them to locate new host trees (Jones et al. 2019). It is precisely their ability to actively fly above the tree canopy that allows them to utilise wind currents for long-distance migration, which can reach unexpected distances.

Nilssen (1984) documented catches of bark beetles [e.g. *Dryocoetes autographus* (Ratzeburg, 1837) or *Hylastes cunicularius* Erichson, 1836] up to 171 km from the nearest host stands; furthermore, a dispersal exceeding 40 km was confirmed even for the economically significant *Ips typographus* (Linnaeus, 1758). This is supported by Forsse and Solbreck (1985), who specifically investigated the flight activity of *I. typographus* using suction traps. The generally accepted radius of suction traps (r = 80 km) is considered an indicative sampling area within which the obtained data are statistically representative. This radius well reflects the ability of the subfamily Scolytinae to utilise both active flight 2.1–6 km for *Dendroctonus ponderosae* Hopkins, 1902 or 3.6–5.7 km for *I. typographus* and, primarily, long-distance passive transport in air currents. For certain species, such as *D. ponderosae*, this transport can reach distances of 30–110 km per day (Jones et al. 2019).

Jones et al. (2019) further specify the most important factors in flight timing, which include not only environmental conditions, as stated by Forsse and Solbreck (1985), but also the beetles' body mass, lipid content, ambient temperature, wind, landscape

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characteristics, and stand density and composition. The intentionally higher network density in certain regions (e.g. Čáslav and Lípa) was chosen in the past to increase data robustness within the rugged terrain of the Bohemian-Moravian Highlands. The combination of the high detection efficiency of suction traps and the specific flight biology of bark beetles above the forest canopy opens new possibilities for understanding their supraregional dynamics.

The aim of this study is (*i*) to perform a quantitative and qualitative analysis of the species spectrum at selected locations, followed by an evaluation of community parameters using ecological indices. Furthermore, the study aims (*ii*) to assess the interannual variability of flight activity and community stability throughout the monitoring period, including an evaluation of the influence of dominant taxa on the overall catch structure. Finally, it seeks (*iii*) to verify the effectiveness of Johnson-Taylor suction traps as a suitable tool for the detection and monitoring of bark beetles.

MATERIAL AND METHODS

Monitoring bark beetles using Johnson-Taylor suction traps utilises the same infrastructure as the long-term monitoring of aphidomorphous insects by ÚKZÚZ (Central Institute for Supervising and Testing in Agriculture), which was initiated in 1992. Since 2020, the targeted evaluation of bark beetles (Curculionidae: Scolytinae) has been introduced for aeroplankton samples collected from all monitored localities (Table 1). The collected material was first cleaned and fixed at the ÚKZÚZ Laboratory of Plant Pest Diagnostic in Opava and then transferred for initial sorting to the ÚKZÚZ Field Inspection Department in Havlíčkův Brod. The final processing of the obtained data was carried out in Opava.

Johnson-Taylor suction traps are stationary devices with a standardised height of 12.2 m, primarily designed for the mass collection of invertebrates from air currents. The traps are permanently located in open landscapes at five ÚKZÚZ testing stations (Figure 1), and their continuous operation is ensured by a connection to the electrical grid. The sites are not overshadowed by tall buildings or continuous woody stands. The devices operate on the principle of continuous air suction, followed by separation through a stainless-steel mesh (Figure 2). Captured aeroplankton samples are fixed in containers with 75% ethyl alcohol. To ensure precise sampling, rotating carousels are installed inside the technical housing, which perform an accurate exchange of the containers at 24-hour intervals. From April 1 to November 30, daily samples were collected twice weekly (Mondays and Fridays). After separating the samples for aphidomorphous insect monitoring (the primary purpose of the traps), the remaining material was pooled into cumulative samples based on calendar weeks. Data from each locality were evaluated separately.

The structure of the bark beetle communities was described using basic quantitative characteristics and ecological indices. The monitored quantitative parameters included abundance (C), the number of samples (N), and species richness expressed as the number of taxa (S). The significance of individual species within the community was interpreted through dominance (D) and frequency (F) indices. For a comprehensive assessment of biodiversity, the Shannon-Weaver diversity index (H'), Pielou's evenness index (J'), and Margalef's species richness index (d) were applied; the latter has proven to be a highly sensitive indicator of species variety relative to total abundance in other groups (e.g. aphidomorphous insects). The similarity in species composition between individual localities was then precisely expressed using the Sørensen similarity index (S_S).

Table 1. Characteristics of the studied locations with Johnson-Taylor suction traps

Locations	Altitude (m a.s.l.)	Temperature (°C)	Rainfall (mm)	Coordinate
Čáslav	260	8.9	555	49°54'10.015'N, 15°24'53.193'E
Dobřichovice	206	8.9	522	49°56'08.0'N, 14°17'05.0'E
Chrlice	190	9.0	451	49°7'25.856'N, 16°38'2.599'E
Lípa	505	7.5	594	49°33'22.133'N, 15°32'13.146'E
Věrovany	207	8.7	502	49°28'24.380'N, 17°16'27.069'E

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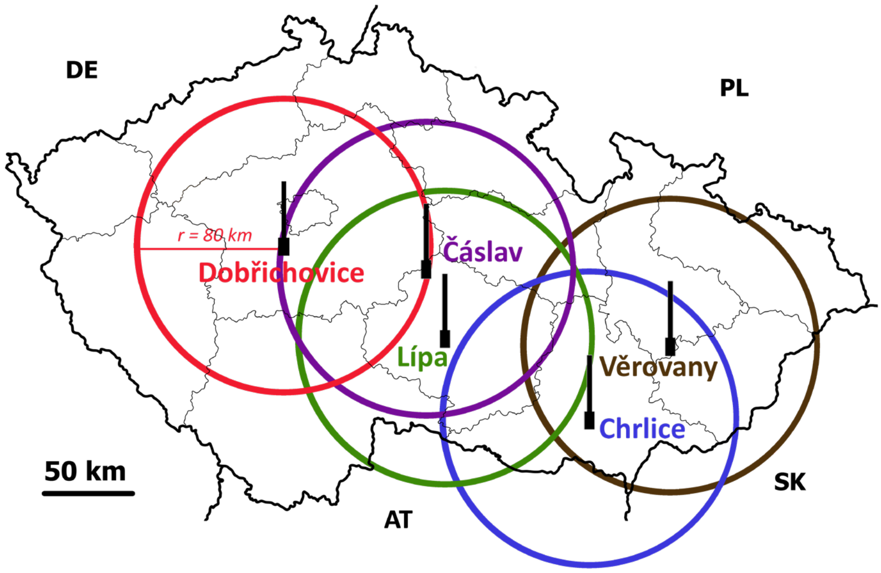

Figure 1. Locations of Johnson-Taylor suction traps and their indicative areas (r = 80 km)
DE – Germany; PL – Poland; SK – Slovakia; AT – Austria

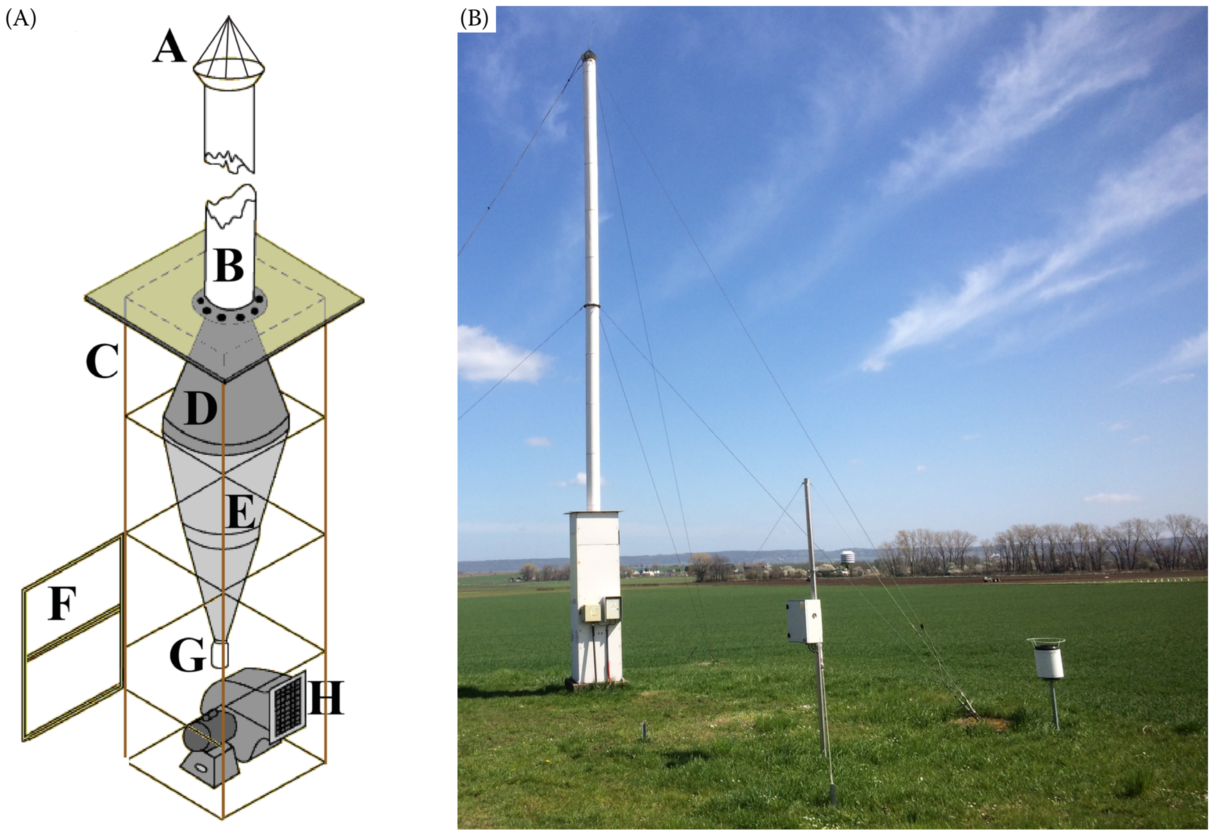

Figure 2. Design and field installation of the Johnson-Taylor suction trap (Fryč, Rychlý 2017; modified): (A) technical design diagram with detailed components (A – suction basket, B – PVC pipe, C – technical box, D – expansion chamber, E – stainless steel netting, F – operating procedure, G – automatic bottle changer, H – electric fan); (B) field view of the trap installation in Čáslav, operated primarily for monitoring aphidomorph insects, showing the surrounding context and the accompanying meteorological station

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Quantitative characteristics and ecological indices:
- Abundance (C),
- Number of samples (N),
- Number of taxa (S),
- Dominance index (D; %), see Equation (1); the following classes were adopted (Tischler 1949):
  - eudominant (> 10%),
  - dominant (5–10%),
  - subdominant (2–5%),
  - recedent (1–2%),
  - subrecedent (< 1%).

$$D = \frac{C_i}{C} \times 100 \quad (1)$$

where:
C_i – number of individuals of individual taxa;
C – abundance.

- Frequency index (F; %), see Equation (2); the following classes were adopted (Schwerdtfeger 1975):
  - constant (> 60%),
  - subconstant (40.1 – 60%),
  - accessory (20.1 – 40%),
  - accidental (5.1 – 20%),
  - subaccidental (< 5%).

$$F = \frac{n_i}{N} \times 100 \quad (2)$$

where:
N – number of samples;
n_i – the number of samples in which the given taxon i occurs.

- Shannon-Weaver diversity index (Shannon, Weaver 1963) (H'), see Equation (3); the following threshold values were adopted (Staub et al. 1970):
  - very high (> 5.0),
  - high (3.5 – 5.0),
  - medium (2.5 – 3.5),
  - low (1.5 – 2.5),
  - very low (< 1.5).

$$H' = \sum_{i=1}^{S} \frac{C_i}{C} \log_2 \frac{C_i}{C} \quad (3)$$

where:
S – number of taxa.

- Pielou's evenness index (Pielou 1966) (J'), see Equation (4); the following classes were adopted:
  - very high (0.9 – 1.0),
  - high (0.7 – 0.9),
  - medium (0.5 – 0.7),
  - low (0.3 – 0.5),
  - very low (0.0 – 0.3).

$$J' = \frac{H'}{H_{\max}} = \frac{H'}{\log_2 S} \quad (4)$$

- Margalef's species richness index (Margalef 1957) (d), see Equation (5); the following classification was adopted (Staub et al. 1970):
  - very high (> 5.0),
  - high (3.0 – 5.0),
  - medium (2.0 – 3.0),
  - low (1.0 – 2.0),
  - very low (< 1.0).

$$d = \frac{S-1}{\log C} \quad (5)$$

- Sørensen similarity index (Sørensen 1948) (S_S; %), see Equation (6); the following classification was adopted (Mueller-Dombois, Ellenberg 1974):
  - very high (> 75%),
  - high (50 – 75%),
  - medium (25 – 50%),
  - very low (< 25%).

$$Ss = \frac{2c}{a+b} \times 100 \quad (6)$$

where:
a – number of taxa at locality A;
b – number of taxa at locality B;
c – number of taxa common to both localities.

RESULTS AND DISCUSSION

Flight activity

In total, 1 049 samples were collected using Johnson-Taylor suction traps between 2020 and 2025; these yielded 2 129 bark beetle individuals (Scolytinae), with 45 species in 23 genera subsequently identified (Table 2).

The suction trap network covers nearly three-quarters (72.45%) of the area of the Czech Republic, which is unique in both European and global contexts. The remaining areas (27.55%)

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Table 2. Total catches in Johnson-Taylor suction traps in 2020–2025

Year	2020	2021	2022	2023	2024	2025	Σ
Species	20	22	30	22	20	23	45
Genus	13	16	19	17	15	15	23
In total (pcs)	239	528	577	239	305	241	2 129

consist primarily of the peripheral regions of the border mountains (Figure 1). Given this coverage, the monitoring focuses on actual supraregional migration rather than local occurrences. The results of this study can therefore be considered representative at the national level.

Evidence supporting the interpretation of catches as supraregional is based on a comparison of the identified species, together with a detailed analysis of host woody plants and wind patterns in the vicinity of the suction traps. Landscape analysis within a 500 m radius (78.54 ha) around the suction traps confirmed a strong predominance of agricultural land. Woody plants occurred at an average density ranging from 9.49 (Čáslav) to 15.72 (Lípa) individuals per ha, with the exception of the Věrovany site, where the average density was only 1.88 individuals per ha (Table 3). Conifers, representing key host plants, were only minimally represented, ranging from 1.66 (Dobřichovice) to 2.88 (Chrlice) individuals per ha, while at the Věrovany site, they were completely absent, even when ornamental species (*Thuja*, *Juniperus*, *Chamaecyparis*, etc.) were included. Nevertheless, the suction trap at this location, operating at a height of 12.2 m, continuously captured species associated with conifers. This phenomenon can be explained by wind flow analysis. At all sites, wind speeds of 10–30 $km \cdot h^{-1}$ prevailed during 78–85% of the monitored period, which hinders the active orientation of insects and favours their passive dispersal (Atkins 1961; Byers 1988). A stable wind direction (e.g. N–SSW in Věrovany) may subsequently create transport corridors connecting the sites with distant forest complexes. Given the absence of target hosts in the immediate vicinity, it is probable that the captured individuals represent a component of homogeneous aeroplankton transported by wind currents from other regions, independently of the local vegetation.

Currently, 126 confirmed bark beetle species are reported from the territory of the Czech Republic (Zahradník 2017; Knížek 2020; Fiala, Knížek 2020; Knížek, Kopecký 2021; Fiala et al. 2024). Although

Table 3. Characteristics of host plant availability and wind dynamics at the monitoring sites

Locations	Total number of woody plants	Mean density ($ind.ha^{-1}$)	Number of conifers in the vicinity	Conifer density ($ind.ha^{-1}$)	Primary wind sector	Proportion (%)	Secondary wind sector	Proportion (%)	Proportion of wind speed 10–30 $km \cdot h^{-1}$ (%)
Čáslav	745	9.49	157	2.00	SW–NW	45–50	SE–S	20–25	~ 80
Dobřichovice	584	7.44	130	1.66	SSW–W	55–60	WNW–N	20–25	~ 78
Chrlice	979	12.47	226	2.88	N–NE	35–40	SSE–S	~ 30	~ 82
Lípa	1 235	15.72	170	2.16	WSW–NNW	40–45	SSE–S	30–35	~ 82
Věrovany	148	1.88	0	0.00	N–NE	~ 35	S–SSW	~ 30	~ 85

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the official catalogue lists 119 species (Alonso-Zarazaga et al. 2025), two of them are included erroneously (Knížek, Fiala 2026, personal communication). However, the total species diversity is officially expected to expand to 129 taxa in the near future, as three newly discovered species are currently in the process of being published. In the context of these findings, a total of 45 species were identified during our monitoring, representing 35.7% of the known bark beetle fauna of the Czech Republic. This indicates either the selectivity of the method or the specific behaviour of certain bark beetle species. Indeed, many species on the aforementioned checklist are rare, lead a cryptic lifestyle, or fly only over extremely short distances within the forest understory. As confirmed by Procházka et al. (2018), many bark beetles exhibit distinct vertical stratification within forest stands, with individual species showing clear vertical centres of flight activity. However, the findings of this study show significant discrepancies for several species when compared to data obtained within forest stands. A typical example is the ambrosia beetle *Xyleborinus saxesenii* (Ratzeburg, 1837), which Procházka et al. (2018) report as having a vertical centre of activity at 7 m; however, in the samples from the suction trap network at a height of 12.2 m, it figures as a dominant taxon. Similarly, *Xyleborus monographus* (Fabricius, 1792), for which a preference for the canopy layer (21 m) is reported, was recorded in the suction traps only as a recedent taxon. Conversely, species such as *Scolytus carpini* (Ratzeburg, 1837) (with a centre of activity at 7 m), *Scolytus multistriatus* (Marsham, 1802) (14 m), and typically canopy specialists like *Taphrorychus bicolor* (Herbst, 1794) and *Xyleborinus attenuatus* (Blandford, 1894) (21 m) were recorded in the suction traps only as subrecedent. The high capture rate of species with a lower centre of activity (*X. saxesenii*) indicates their massive flight above the tree canopy as part of long-distance dispersal, while the subrecedent representation of certain canopy species may reflect their lower population density in the surrounding landscape or a different dispersal strategy. These discrepancies suggest that the classical forest stratification breaks down in the open landscape; consequently, Johnson-Taylor suction traps at a height of 12.2 m do not monitor local vertical preferences but rather sample a homogeneous aeroplankton. This aeroplankton consists of species from various forest strata, mixing according to their willingness to leave the forest microclimate and engage in active migration over the open landscape.

In terms of occurrence, a group of 10 species exhibited a stable presence, being recorded in the traps every year throughout the monitoring period. Conversely, 16 species were captured only sporadically, with a single annual occurrence over the entire six-year period; this indicates a high proportion of incidental captures of species occurring at low population densities. It is also necessary to mention that the aforementioned species catalogue is a synthesis of data from all sampling methods (individual collecting, flight intercept traps, pheromone traps, beating), and should be regarded as potential diversity. Our catches therefore represent the species that are actually detectable by suction traps.

The flight dynamics of bark beetles exhibit seasonal trends that correspond to the phenology of the primary subfamily Scolytinae representatives under the conditions of the Czech Republic (Figures 3 and 4). This can be divided into four logical segments based on the observed trends.

Early spring activity (weeks 13–17). During this period, the suction traps capture the initial dispersal flights following overwintering. Species such as *Hylastes attenuatus* Erichson, 1836 and *Pityogenes chalcographus* (Linnaeus, 1760) appear during this phase. The early occurrence of *X. saxesenii* as early as week 14 (2024) is noteworthy, suggesting its capacity for early spring dispersal compared to most native species. Sporadic captures during this period may indicate the onset of non-native species synchronised with the earlier budburst of their host trees.

Main flight wave (weeks 18–27). This period is dominated by the economically most significant species (e.g. *P. chalcographus*). Secondary to these, *Crypturgus cinereus* (Herbst, 1793) asserts itself significantly, forming a constant companion to the main migration waves. It is also during this period that captures of the faunistically noteworthy species *Eidophelus caucasicus* (Lindemann, 1877) and the successfully naturalised North American species *Gnathotrichus materiarius* (Fitch, 1858) are concentrated.

Summer generation (weeks 28–37). Flight activity during this period is more dispersed. *P. chalcographus* remains the dominant species, but species with a later peak abundance also begin

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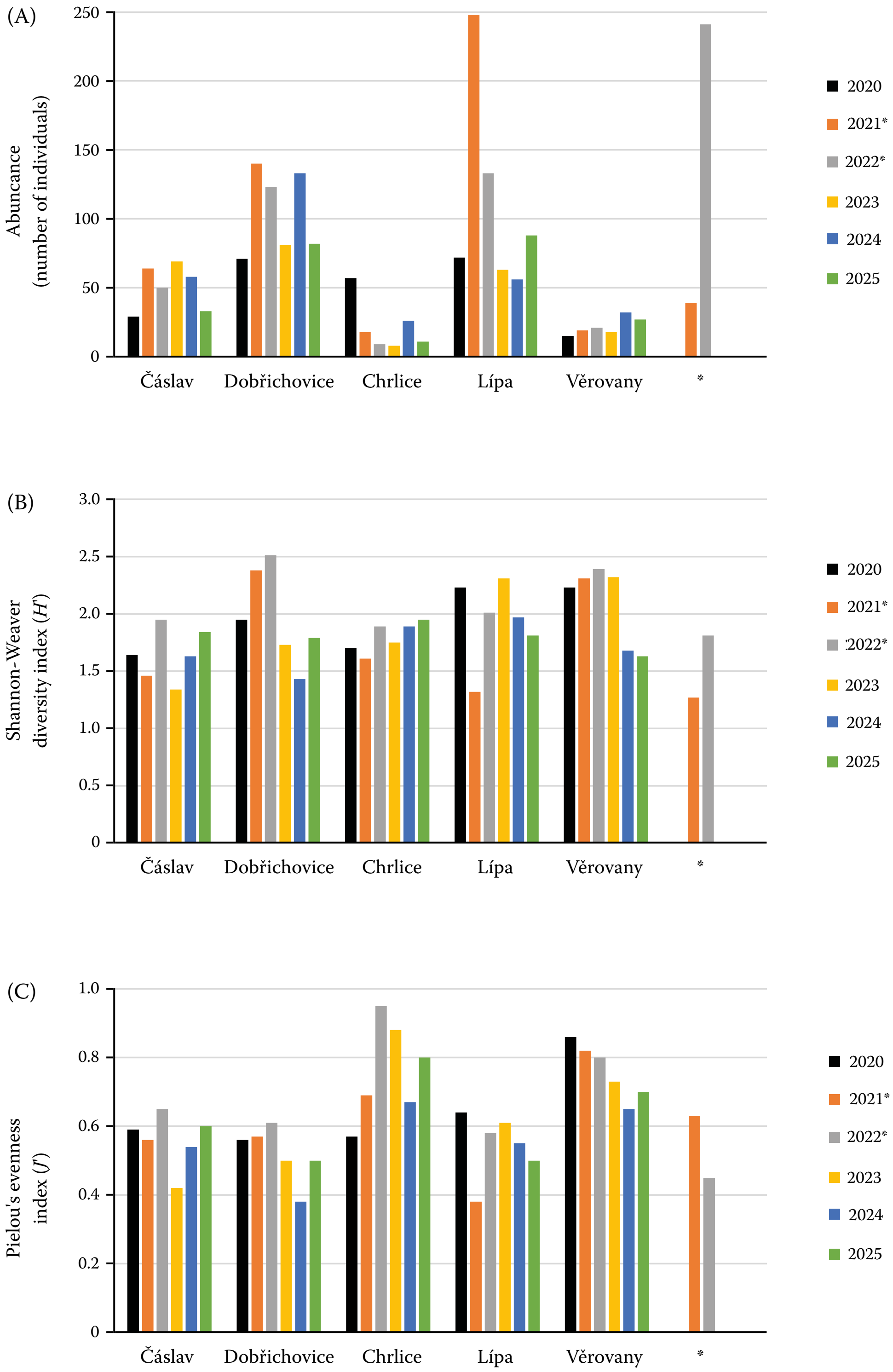

Figure 3. Heatmap of seasonal distribution of bark beetle (Scolytinae) catches in a Johnson-Taylor suction trap network between 2020–2025

*A portion of the samples collected in 2021 and 2022 was primarily utilised for internal testing of laboratory detection and determination as part of the preparation for the CAI (Czech Accreditation Institute) accreditation process; for procedural reasons, location and collection date data are not available for these specimens; however, following the completion of testing, the samples were evaluated using standard methods and included in the final overview; the complete dataset is provided in Figure S1 in the Electronic Supplementary Material (ESM)

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Location	Čáslav						Dobřichovice						Chrlice					
Year	2020	2021*	2022*	2023	2024	2025	2020	2021*	2022*	2023	2024	2025	2020	2021*	2022*	2023	2024	2025
Spring activity	1	1	3	0	8	0	10	1	1	0	11	4	1	0	0	0	8	0
Main flight wave	16	42	37	38	22	20	39	101	86	43	48	48	14	18	9	3	11	6
Summer generation	12	20	10	31	28	13	18	36	35	35	73	30	41	0	0	5	7	5
Autumn decline	0	1	0	0	0	0	4	2	1	3	1	0	1	0	0	0	0	0

Location	Lípa						Věrovany						Ø				
Year	2020	2021*	2022*	2023	2024	2025	2020	2021*	2022*	2023	2024	2025	Čáslav	Dobřichovice	Chrlice	Lípa	Věrovany
Spring activity	8	2	1	1	3	10	2	1	1	3	3	0	2.17	4.50	1.50	4.17	1.67
Main flight wave	40	215	101	52	24	65	7	9	17	12	12	21	29.17	60.83	10.17	82.83	13.00
Summer generation	22	31	31	9	29	12	6	9	3	3	17	6	19.00	37.83	9.67	22.33	7.33
Autumn decline	2	0	0	1	0	1	0	0	0	0	0	0	0.17	1.83	0.17	0.67	0.00

Figure 4. Heatmap of the seasonal distribution of selected bark beetle species (Scolytinae) in a Johnson-Taylor suction trap network between 2020–2025 (species are ranked by their overall dominance)

*A portion of the samples collected in 2021 and 2022 was primarily utilised for internal testing of laboratory detection and determination as part of the preparation for the CAI (Czech Accreditation Institute) accreditation process; for procedural reasons, location and collection date data are not available for these specimens; however, following the completion of testing, the samples were evaluated using standard methods and included in the final overview; the complete dataset is provided in Figure S2 in the ESM

to appear. The August peak in Chrlice (2020) was primarily composed of the species *C. cinereus*. Captures of the phytosanitarily potentially significant species *Hylesinus wachtli orni* A.G. Fuchs, 1906 (associated with ash trees) also occur here, demonstrating the method's ability to detect even rare or frequently overlooked species.

Autumn decline (weeks 38–49). During this period, flight activity is minimal. Flight activity in the open landscape practically ceases in connection with declining temperatures, likely due to unsuitable conditions for active flight (increased incidence of precipitation and strong wind currents) and the beetles' preparation for overwintering. Nevertheless, noteworthy captures such as *Hylesinus varius* (Fabricius, 1775) or *Scolytus rugulosus* (P.W.J. Müller, 1818) are recorded during this time; these may be related to the search for overwintering sites or delayed development during warmer years. The study confirms the high efficacy of the suction trap sampling method for the detection of faunistically and phytosanitarily significant bark beetle species. These results demonstrate that the system can serve as an early warning tool while providing unique data on species that are frequently underrepresented in conventional pheromone monitoring.

Community structure

The comprehensive list of species captured by the Johnson-Taylor suction traps (Table 3) can be summarised into four functional categories (Tables 4 and 5). For primary (economic) pests, a decline to 1–2 detected species was recorded in the last three years, compared to a maximum of 4 species in 2022. Although a total of five taxa were recorded throughout the monitoring period, their fluctuating capture rates across the network indicate a variable migration intensity over time. This trend suggests that the occurrence of economic pests is highly dependent on specific seasonal cycles of pest and the effectiveness of local pest management, which may have reduced their pressure in recent years. The category of secondary and technical pests exhibits the highest diversity, peaking in years 2022–2023 (13 species); the total of 24 captured taxa confirms the dominant position of this group in the samples and demonstrates a gradual turnover in species composition. This fact suggests that while the suction trap method continuously samples the species background, the capture of specific less abundant species is likely influenced

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Table 4. List of taxa, abundance, dominance, and frequency of bark beetles (Scolytinae) in Johnson-Taylor suction trap catches in the Czech Republic in 2020–2025 (nomenclature: Zahradník 2017)

Taxon	Status	Abundance (pcs)	SD	Dominance (%)	SD	Frequency (%)
Eudominant						
Pityogenes chalcographus (Linnaeus, 1761)	P	1 315	91.38	61.77	6.83	32.13*
Crypturgus cinereus (Herbst, 1793)	I	303	56.04	14.23	10.77	11.15*
Dominant						
Xyleborinus saxesenii (Ratzeburg, 1837)	S	134	11.81	6.29	3.20	6.96*
Subdominant						
Ernoporus tiliae (Panzer, 1793)	I	54	5.51	2.54	2.03	3.43*
Recedent						
Dryocoetes autographus (Ratzeburg, 1837)	I	36	5.14	1.69	0.95	1.81*
Pityophthorus pityographus (Ratzeburg, 1837)	S	36	3.74	1.69	1.07	2.76*
Xyleborus monographus (Fabricius, 1792)	S	32	3.44	1.50	0.67	1.91
Crypturgus pusillus (Gyllenhal, 1813)	I	31	4.62	1.46	0.83	2.57*
Polygraphus poligraphus (Linnaeus, 1758)	S	24	4.20	1.13	1.82	1.91*
Subrecedent						
Ips typographus (Linnaeus, 1758)	P	21	4.28	0.99	1.75	1.33*
Scolytus rugulosus (P.W.J. Müller, 1818)	S	19	2.32	0.89	0.80	1.53
Hylesinus varius (Fabricius, 1775)	S	16	1.75	0.75	0.57	1.24*
Taphrorychus bicolor (Herbst, 1793)	I	16	1.97	0.75	0.47	1.33*
Hylastes attenuatus Erichson, 1836	S	12	1.26	0.56	0.52	1.05
Ips duplicatus (C.R. Sahlberg, 1836)	P	11	3.13	0.52	0.54	0.38*
Cryphalus asperatus (Gyllenhal, 1813)	I	7	0.98	0.33	0.31	0.57
Pityophthorus lichtensteinii (Ratzeburg, 1837)	I	6	0.63	0.28	0.23	0.57
Eidophelus caucasicus (Lindemann, 1877)	I	5	1.17	0.23	0.38	0.48*
Crypturgus subcribrosus Eggers, 1933	I	4	0.82	0.19	0.34	0.38*
Dryocoetes villosus (Fabricius, 1792)	I	4	0.82	0.19	0.34	0.38*
Pityophthorus exsculptus (Ratzeburg, 1837)	I	4	0.82	0.19	0.19	0.38
Trypodendron lineatum (Olivier, 1800)	S	4	0.82	0.19	0.20	0.38
Hylastes brunneus (Erichson, 1836)	S	3	0.84	0.14	0.15	0.19
Hylastes cunicularius Erichson, 1836	S	3	0.84	0.14	0.34	0.29
Orthotomicus laricis (Fabricius, 1792)	S	3	0.55	0.14	0.20	0.29*
Gnathotrichus materiarius (Fitch, 1858)	N	2	0.52	0.09	0.09	0.19
Hylastes pinicola (Bedel, 1888)	S	2	0.82	0.09	0.14	0.10
Pityogenes bistridentatus (Eichhoff, 1878)	S	2	0.52	0.09	0.17	0.19
Pityophthorus glabratus Eichhoff, 1878	I	2	0.82	0.09	0.34	0.10
Scolytus intricatus (Ratzeburg, 1837)	S	2	0.52	0.09	0.22	0.19
Scolytus multistriatus (Marsham, 1802)	S	2	0.52	0.09	0.19	0.19
Anisandrus dispar (Fabricius, 1792)	S	1	0.41	0.05	0.13	0.10
Cryphalus piceae (Ratzeburg, 1837)	S	1	0.41	0.05	0.17	0.10
Hylastes angustatus (Herbst, 1793)	S	1	0.41	0.05	0.07	0.10
Hylastes linearis Erichson, 1836	S	1	0.41	0.05	0.17	0.10
Hylesinus crenatus (Fabricius, 1787)	S	1	0.41	0.05	0.17	0.10

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Table 4. To be continued

Taxon	Status	Abundance (pcs)	SD	Dominance (%)	SD	Frequency (%)
Hylesinus wachtli Reitter, 1887	S	1	0.41	0.05	0.13	0.10
Ips acuminatus (Gyllenhal, 1827)	P	1	0.41	0.05	0.17	0.10
Orthotomicus suturalis (Gyllenhal, 1827)	I	1	0.41	0.05	0.07	0.10
Pityogenes bidentatus (Herbst, 1783)	I	1	0.41	0.05	0.17	0.10
Pityokteines spinidens (Reitter, 1895)	S	1	0.41	0.05	0.17	0.10
Pteleobius vittatus (Fabricius, 1787)	S	1	0.41	0.05	0.17	0.10
Scolytus carpini (Ratzeburg, 1837)	S	1	0.41	0.05	0.07	0.10
Tomicus piniperda (Linnaeus, 1758)	P	1	0.41	0.05	0.07	0.10
Xyleborinus attenuatus (Blandford, 1894)	N	1	0.41	0.05	0.17	0.10

*A portion of the samples collected in 2021 and 2022 was primarily utilised for internal testing of laboratory detection and determination as part of the preparation for the CAI (Czech Accreditation Institute) accreditation process; for procedural reasons, location and collection date data are not available for these specimens; however, following the completion of testing, the samples were evaluated using standard methods and included in the final overview; complete dataset in Table S1 in the ESM; SD – standard deviation; P – primary pests; S – secondary/technical pests; I – indifferent species; N – non-native species

by stochastic factors or specific climatic conditions of a given year. For indifferent and associated species, the data shows significant fluctuations, ranging from a peak of 12 in 2022 to a low of 6 in 2023. Despite this instability, the total diversity reaches 14 taxa. This discrepancy, where the total sum is higher than any single year, suggests that many of these species are transient. Their presence in the samples is likely not a result of stable local populations, but rather an accidental capture during dispersal or a response to short-term changes in the surrounding spontaneous vegetation. The detection of a total of two non-native (invasive) species (captured between 2021 and 2023) confirms the network's ability to capture taxa occurring in the area at low population densities (e.g. during the initial phase of dispersal). Their sporadic occurrence and subsequent absence in the last two years might indicate a 'failed' initial colonisation attempt or a high sensitivity to specific overwintering conditions in the locality.

The dominance structure analysis (Tables 4 and 6) confirms a highly uneven distribution of abundance among species. The core is consistently formed

Table 5. Annual number of bark beetle species identified in individual functional categories in Johnson-Taylor suction traps in the period 2020–2025

Year	2020	2021	2022	2023	2024	2025	Σ
Primary (economic) pests	3	3	4	2	1	2	5
Secondary and technical pests	9	9	13	13	12	11	24
Indifferent and associated species	8	9	12	6	7	10	14
Non-native (invasive) species	–	1	1	1	–	–	2

Table 6. Dominance levels and numbers of taxa in Johnson-Taylor suction traps in 2020–2025

Year	2020	2021	2022	2023	2024	2025	Σ
Eudominant	2	2	2	1	1	2	2
Dominant	2	–	1	2	1	1	1
Subdominant	2	1	5	1	3	1	1
Recedent	2	2	3	6	3	4	5
Subrecedent	12	17	19	12	12	15	36

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by two eudominant species, namely *P. chalcographus* (61.77%) and *C. cinereus* (14.23%), while the majority of the other identified species (36) are classified as subrecedent, each with an occurrence below 1%. Interannual fluctuations in the number of recedent species suggest a dynamic turnover in the middle part of the assemblage, while the representation of dominant species remains stable throughout the monitoring period. A significant finding is the low dominance of our primary economic pests, particularly *I. typographus* (0.99%), which confirms the selective nature of suction traps towards species with different flight strategies. However, the high proportion of subrecedent taxa demonstrates the network's capacity to capture even very low densities of migrating insects.

The frequency of occurrence analysis (Tables 4 and 7) reveals high temporal fragmentation of bark beetle flight activity within the aerial plankton. No species were recorded in the constant or subconstant categories throughout the entire monitoring period; this suggests that the presence of bark beetles in the samples is not continuous but rather occurs in time-limited waves. Similarly, the eudominant *P. chalcographus* (32.13%) reaches an overall frequency belonging only to the accessory category, meaning it appears, on average, in only one out of every three samples. The vast majority of the recorded biodiversity falls into the subaccidental category, with a frequency of occurrence below 5%. It should be noted that a portion of the samples from 2021 and 2022 was primarily utilised for other purposes (see the note below Table 4). The combination of high cumulative diversity and low annual frequencies reveals that suction trap captures reflect stochastic migration events rather than the long-term presence of specific populations in air currents.

Ecological indices and diversity

Ecological indices (Figure 5) evaluate the stability of bark beetle (Scolytinae) populations in the aerial plankton while simultaneously revealing its internal structure, which is not apparent from abundance values alone. Comparison of species composition similarity between sites and years using the Sørensen index (Table 8) allows for an assessment of the homogeneity of dispersal flight across the entire network of stations. The pronounced interannual and local variability of the catches, which causes the fluctuations in the indices, is visualised in Figure 5; particularly evident are the extreme fluctuations in 2021 and 2022 (including test samples).

The Shannon-Weaver diversity index (H') confirms that although the suction trap network detects high species richness (Tables 2 and 4), the overall diversity of the bark beetle aeroplankton assemblage remains unstable across both time and space. While the total value for the monitoring period (H'_{cumul} = 2.29) indicates a moderately diverse assemblage, the internal dynamics reveal the fundamental influence of eudominant species. The lowest overall diversity was recorded in 2021 (H'_{total} = 1.84), which stands in stark contrast to its abundance. This implies that massive flights of a few dominant species (especially *P. chalcographus*) significantly prevail in the samples and reduce the value of the diversity index. Conversely, 2022 (H'_{total} = 2.37) represents the peak of stability, as the assemblage remained the most species-balanced despite high abundance. However, local extremes also exist, such as the high diversity in Lípa (2023: H' = 2.31) compared to the low value in Chrlice (2023: H' = 1.75). These results demonstrate the network's ability to sensitively reflect site-specific differences in the quality and composition of the surrounding forest stands.

Table 7. Frequency classes and numbers of taxa in Johnson-Taylor suction traps in 2020–2025

Year	2020	2021*	2022*	2023	2024	2025	Σ
Constant	–	–	–	–	–	–	–
Subconstant	–	–	–	–	–	–	–
Accessory	1	1*	1*	1	1	1	1
Accidental	3	1*	3*	2	2	2	2
Subaccidental	15	20*	26*	19	17	19	42

*A portion of the samples collected in 2021 and 2022 was primarily utilised for internal testing of laboratory detection and determination as part of the preparation for the CAI (Czech Accreditation Institute) accreditation process; for procedural reasons, location and collection date data are not available for these specimens; however, following the completion of testing, the samples were evaluated using standard methods and included in the final overview

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Year	Selected species	Spring activity	Main flight wave	Summer generation	Autumn decline	*
2022*	*Taphrorychus bicolor* (Herbst, 1793)	0	1	4	0	1
	Ips typographus (Linnaeus, 1758)	0	1	0	0	5
	Ips duplicatus (C.R. Sahlberg, 1836)	0	0	0	0	8
	Xyleborus monographus (Fabricius, 1792)	0	12	0	0	–
	Pityophthorus pityographus (Ratzeburg, 1837)	0	8	1	0	3
	Crypturgus pusillus (Gyllenhal, 1813)	0	8	3	0	1
	Ernoporus tiliae (Panzer, 1793)	0	5	0	0	8
	Dryocoetes autographus (Ratzeburg, 1837)	0	5	0	0	11
	Xyleborinus saxesenii (Ratzeburg, 1837)	1	21	2	0	17
	Crypturgus cinereus (Herbst, 1793)	0	50	10	0	5
	Pityogenes chalcographus (Linnaeus, 1761)	1	122	57	0	172
2021*	*Xyleborinus saxesenii* (Ratzeburg, 1837)	0	5	4	0	–
	Crypturgus pusillus (Gyllenhal, 1813)	0	6	2	0	1
	Ernoporus tiliae (Panzer, 1793)	0	12	0	0	–
	Crypturgus cinereus (Herbst, 1793)	0	125	14	0	15
	Pityogenes chalcographus (Linnaeus, 1761)	1	216	67	1	22
2020	*Dryocoetes autographus* (Ratzeburg, 1837)	0	3	0	0	–
	Hylastes attenuatus Erichson, 1836	2	3	0	0	–
	Xyleborus monographus (Fabricius, 1792)	0	5	1	0	–
	Ips typographus (Linnaeus, 1758)	1	7	3	0	–
	Polygraphus poligraphus (Linnaeus, 1758)	0	3	8	1	–
	Xyleborinus saxesenii (Ratzeburg, 1837)	0	10	3	0	–
	Crypturgus cinereus (Herbst, 1793)	1	12	35	2	–
	Pityogenes chalcographus (Linnaeus, 1761)	15	49	45	2	–

Year	Selected species	Spring activity	Main flight wave	Summer generation	Autumn decline	*
2025	*Xyleborus monographus* (Fabricius, 1792)	0	3	0	0	–
	Dryocoetes autographus (Ratzeburg, 1837)	0	3	0	0	–
	Crypturgus cinereus (Herbst, 1793)	0	3	0	0	–
	Crypturgus pusillus (Gyllenhal, 1813)	0	3	1	0	–
	Pityophthorus pityographus (Ratzeburg, 1837)	3	4	2	0	–
	Ernoporus tiliae (Panzer, 1793)	0	16	0	0	–
	Xyleborinus saxesenii (Ratzeburg, 1837)	1	20	4	1	–
	Pityogenes chalcographus (Linnaeus, 1761)	8	95	56	0	–
2024	*Pityophthorus pityographus* (Ratzeburg, 1837)	1	2	1	0	–
	Dryocoetes autographus (Ratzeburg, 1837)	0	4	0	0	–
	Crypturgus pusillus (Gyllenhal, 1813)	1	2	2	0	–
	Scolytus rugulosus (P.W. J. Müller, 1818)	0	7	0	0	–
	Ernoporus tiliae (Panzer, 1793)	0	7	0	0	–
	Crypturgus cinereus (Herbst, 1793)	1	8	5	0	–
	Xyleborinus saxesenii (Ratzeburg, 1837)	15	2	11	0	–
	Pityogenes chalcographus (Linnaeus, 1761)	10	74	129	1	–
2023	*Taphrorychus bicolor* (Herbst, 1793)	0	1	2	0	–
	Xyleborus monographus (Fabricius, 1792)	0	4	0	0	–
	Scolytus rugulosus (P.W. J. Müller, 1818)	0	2	2	0	–
	Pityophthorus pityographus (Ratzeburg, 1837)	0	4	0	0	–
	Hylesinus varius (Fabricius, 1775)	0	3	1	0	–
	Ernoporus tiliae (Panzer, 1793)	0	3	1	0	–
	Dryocoetes autographus (Ratzeburg, 1837)	0	7	0	0	–
	Crypturgus cinereus (Herbst, 1793)	0	12	4	0	–
	Xyleborinus saxesenii (Ratzeburg, 1837)	0	12	4	2	–
	Pityogenes chalcographus (Linnaeus, 1761)	2	90	66	2	–

Figure 5. Distribution of catches within the Johnson-Taylor suction trap monitoring network in the Czech Republic: (A) abundance, (B) Shannon-Weaver diversity index (H'), (C) Pielou's evenness index (J')

*A portion of the samples collected in 2021 and 2022 was primarily utilised for internal testing of laboratory detection and determination as part of the preparation for the CAI (Czech Accreditation Institute) accreditation process; for procedural reasons, location and collection date data are not available for these specimens; however, following the completion of testing, the samples were evaluated using standard methods and included in the final overview; the complete dataset including parameters C, N, S, H', J', d, X_{total} and X_{cumul} is provided in Table S2 in the ESM

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Table 8. Sørensen similarity index of bark beetle species composition (S_S, expressed in %) between individual Johnson-Taylor suction trap locations from 2020 to 2025

Year	2020					2021					2022				
Location	Č	D	Ch	L	V	Č	D	Ch	L	V	Č	D	Ch	L	V
Č	100	–	–	–	–	100	–	–	–	–	100	–	–	–	–
D	44	100	–	–	–	50	100	–	–	–	40	100	–	–	–
Ch	53	36	100	–	–	73	34	100	–	–	50	21	100	–	–
L	56	55	53	100	–	35	41	50	100	–	42	57	53	100	–
V	31	35	43	47	100	62	48	67	56	100	38	48	50	53	100

Year	2023					2024					2025					Σ				
Location	Č	D	Ch	L	V	Č	D	Ch	L	V	Č	D	Ch	L	V	Č	D	Ch	L	V
Č	100	–	–	–	–	100	–	–	–	–	100	–	–	–	–	100	–	–	–	–
D	50	100	–	–	–	45	100	–	–	–	48	100	–	–	–	57	100	–	–	–
Ch	31	24	100	–	–	40	38	100	–	–	29	26	100	–	–	57	48	100	–	–
L	61	64	44	100	–	60	69	42	100	–	56	35	38	100	–	67	62	60	100	–
V	44	30	31	52	100	57	50	77	44	100	77	44	36	53	100	59	56	81	62	100

Č – Čáslav; D – Dobřichovice; Ch – Chrlice; L – Lípa; V – Věrovany

Pielou's evenness index (J') provides evidence of a strong internal imbalance within the assemblage. The cumulative value (J'_{cumul} = 0.42) is low, confirming that the captured aeroplankton does not consist of a balanced structure but is, on the contrary, sharply polarised. The lowest evenness rate in 2021 (J'_{total} = 0.41) corresponds with the dip in Shannon diversity and clearly documents a state where the dominant component suppressed the proportional representation of other taxa. An interesting detail is the local differences, where, for instance, the Lípa site (2021) exhibits extremely low evenness (J' = 0.38), whereas Věrovany reaches a high value (0.82). These fluctuations suggest that while a massive, species-selective flight was occurring at some sites, at others, the assemblage remained much more numerically balanced at that time.

The Margalef's richness index (d) completes the overall perspective on the suction trap network's ability to detect species diversity in relation to the catch volume. The cumulative value for the entire period (d_{cumul} = 5.74) testifies to the high potential of the method to capture a wide spectrum of species. A key finding is the extreme increase in this index in 2022 (d_{total} = 4.56), which corresponds with the highest biodiversity recorded throughout the entire six-year monitoring period. While in other years the index fluctuates depending on abundance (e.g. the 2024 slump: d_{total} = 3.32), 2022 stands out as a period with the highest ratio of newly recorded species per unit of catch. Locally, this trend is confirmed particularly by Dobřichovice (2021: d = 3.44), which exhibits above-standard species saturation compared to the other monitored sites.

The Sørensen's similarity index of bark beetle species composition (S_S) shows mostly high to very high values across sites in the aggregate assessment (Σ), ranging from 48 to 81%. The highest degree of similarity was recorded between the Chrlice and Věrovany sites (S_S = 81%), indicating a very close faunistic affinity among the Moravian stations. In the year-on-year comparison, 2021 was the most stable year, with average similarity reaching its highest values, whereas 2022 exhibited the greatest regional differentiation (e.g. Čáslav vs. Chrlice, S_S = 21%).

CONCLUSION

The present study confirmed that the Johnson-Taylor suction trap network represents an effective tool for monitoring the dynamics and species

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richness of bark beetles (Curculionidae: Scolytinae) on a national scale across the Czech Republic. During the six-year period (2020–2025), a total of 45 species were identified, representing a significant portion (35,7%) of the domestic fauna of this subfamily.

The results point to the specific flight biology of bark beetles in comparison with other insect groups. Unlike aphidomorph insects, which often form massive homogeneous clouds, bark beetles tend to disperse into a vast volume of air during supraregional migration. Given that these individuals move through space at very low densities, the statistical probability of capturing a specific individual with a suction trap of relatively small intake diameter is objectively low.

This phenomenon explains the high proportion of subrecedent species (36 taxa) in the captured samples. The detection of these species is not a random failure; on the contrary, it confirms the sensitivity of the network, which is capable of capturing fragments of the insect spectrum dispersed within such a vast volume of air. In this context, a study by Forsse and Solbreck (1985) states that approximately 10% of the *I. typographus* population flies above the forest canopy, thereby gaining the opportunity to cover considerable distances via wind currents. It is precisely these high-flying individuals that suction traps capture, which explains the low numbers compared to traps placed directly within forest stands. Despite these low densities, the results show high spatial consistency in species composition (up to S_S = 81%), confirming that the captured samples are representative of the entire station network and reflect the structure of the migrating assemblage on a national scale.

From the perspective of biosafety and phytosanitary surveillance, suction traps have proven to be an invaluable tool. In agreement with the studies of Teulon and Scott (2006), their potential can be confirmed for: (*i*) determining the actual distribution of species in the landscape, (*ii*) conducting delimiting surveys for invasive and quarantine species, and (*iii*) detecting rare or cryptic taxa that traditional methods may overlook.

The results of this work demonstrate that although Johnson-Taylor suction traps were historically designed primarily for monitoring aphidomorph insects, their application can be significantly broader. While for some species, such as *Atomaria (Agathengis) linearis* Stephens, 1830 (Coleoptera: Cryptophagidae), no direct relationship was found between the number of individuals in suction traps and crop damage in the fields (Cochrane, Thornhill 1987), for faunistic studies and monitoring the spread of non-native and invasive species, these data remain highly beneficial.

Specifically, the insights gained from this study regarding bark beetle occurrence contributed to the official inclusion of detection surveys for quarantine insect species using Johnson-Taylor suction traps operated by ÚKZÚZ in the Czech Republic. Consequently, this network no longer serves solely for forecasting aphidomorph insects but has become an integral part of the national biosecurity system.

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