https://doi.org/10.31298/sl.149.1-2.6

Pregledni rad – Review paper
Šumarski list, 1–2 (2025): 67–76

OVERVIEW OF INVASION AND CONTROL MANAGEMENT OPTIONS OF *Cydalima perspectalis* (Lepidoptera, Crambidae)

PREGLED INVAZIJE I MOGUĆNOSTI UPRAVLJANJA KONTROLOM *Cydalima perspectalis* (Lepidoptera, Crambidae)

Ana Romana ARMANDA[1]*, Mario BJELIŠ[2]

SUMMARY

Box tree moth, *Cydalima perspectalis*, originally from East Asia, has invaded 40 countries in Europe and the Middle East, as well as two countries in North America. The exact pathway of invasion is uncertain, but it is believed to have reached Europe and the United States through multiple introductions by import of boxwood plants, followed by further spread due to biological characteristics of the species, climatic conditions and the wide distribution of the host plant. This review aims to provide an overview of the highly invasive *C. perspectalis* and identify perspectives for its effective control and management. Possible control methods include insecticides and environmentally friendly options such as entomopathogenic bacterial strains, fungi, nematodes, plant insecticides, and mating disruption. An integrated pest management is crucial for *C. perspectalis* control. Detection methods, prevention strategies, monitoring of pest and damage, assessing overwintering capacity, and developing effective control measures are key future perspectives. Through research, collaboration, and strategic interventions, it is possible to mitigate the impact of *C. perspectalis* and protect vulnerable ecosystems from the devastating consequences of this invasive pest.

KEY WORDS: *Cydalima perspectalis*, invasiveness, *Buxus*, monitoring, management and control

INTRODUCTION
UVOD

An invasive alien species refers to a species that has negative ecological, economic, or health consequences (Mc Neeley, 2001, Canelles et al. 2021, Roques et al. 2016), particularly noticeable in countries characterized by intensive transport systems and international commerce checkpoints (Humle, 2009; Roques et al. 2016). One such species is the box tree moth, *Cydalima perspectalis* Walker 1859 (Lepidoptera, Crambidae), a pest of *Buxus* trees which is indigenous to East Asia (Wang, 1980, Wan et al. 2014). It was accidentally introduced to Europe in Germany in 2006 through the trade of box tree *Buxus sempervirens* L. (Kruger 2008; Van der Straten and Muus, 2010; Bird et al. 2020), followed by an invasion recorded in almost all countries in eastern and south-eastern Europe, the Middle East (Kenis et al. 2013; Nacambo et al. 2013), North America after introduction to Canada (Wiesner et al. 2021) and in the United States in 2021 (USDA APHIS, 2021, USDA APHIS, 2022). Although a single finding was recorded in Algeria in 2018, no further establishment or spread of the pest has been observed in Africa (Haddad et al. 2020; Kazilas et al. 2021). In its native area, *C. perspectalis* hosts belong to the genus *Buxus* and few other non-*Buxus* host plants (Coyle et al. 2022). Within the Western Palearctic region, the genus *Buxus* is widely represented, which allowed the fast spread

[1] Ana Romana Armanda, MEng, University of Split, Croatia
[2] Assoc. Prof. Mario Bjeliš, PhD, University Department of Marine Studies, University of Split, Croatia
*Corresponding author: Ana Romana Armanda, email: ararmanda@unist.hr

of pest (Kvaček et al. 1982). In North America, where the pest was introduced in 2018, there are no native wild *Buxus* species (Wiesner et al. 2021). The larvae of *C. perspectalis* feed on the leaves and bark of *B. sempervirens*, resulting in complete defoliation and the eventual death of the trees (Bunescu and Florian, 2016). An international trade of ornamental host materials is considered to be the most influential rapid worldwide pest spread, followed by the pest's adaptability to different environments and climatic conditions (Gninenko et al. 2014; Bras et al. 2022). Studies have reported that in the native range of *C. perspectalis*, natural enemies play a significant role in reducing pest populations and subsequently limiting their expansion (Mally and Nuss, 2010).

The primary objective of this study was to provide a comprehensive overview of the documented data on the global invasion history of *C. perspectalis*, starting from its initial appearance in Europe, the Middle East, and North America until the present day. Additionally, the study aimed to present the currently available methods for detecting, monitoring, and suppressing populations of *C. perspectalis*.

MATERIALS AND METHODS
MATERIALI I METODE

The search for relevant publications for this study encompassed published scientific articles, abstracts, short communications, and reports focused on the geographic areas where *C. perspectalis* is present. The study presents a comprehensive list of research topics organized into three main categories: (1) invasive pathways, (2) monitoring, and (3) control management. The research area of **invasive pathways** explores the potential ways in which *C. perspectalis* can be introduced, particularly through infested host plants facilitated by human transport and trade. The **monitoring** section provides a concise overview of the following subsections: pheromones, olfactory lures, traps, photoeclectors, and visual host-plant monitoring and damage assessment. These methods contribute to the monitoring efforts aimed at tracking *C. perspectalis* populations and their impact. The **control management** section offers a report on the biological, biotechnical and chemical methods used to suppress *C. perspectalis* populations. It highlights various strategies employed to manage and mitigate the negative effects of this invasive species.

RESULTS
REZULTATI

Invasive pathways – *Putevi invazije*

After being initially detected in southwestern Germany in 2006 and in the Netherlands in 2007 (Kruger, 2008; Van der Straten and Muss, 2010), *C. perspectalis* spread further and was observed in several other European countries (Kenis et al. 2013; Nacambo et al. 2014). The global spread and establishment of *C. perspectalis* can be attributed to various overlapping processes, such as multiple introductions, bridgehead effects, mixing events, biological characteristics of the species (e.g. the ability to fly) and the wide distribution of its host plant (Gninenko et al. 2014; Wiesner et al. 2021; Bras et al. 2022). So far, out of its native range, *C. perspectalis* has invaded 40 countries in the Western Palearctic area and 2 countries in the Nearctic area. (Table 1 and Figure 1). The suggested climate models confirmed that *C. perspectalis* will became a serious pest in southern and central Europe (Nacambo et al. 2014), while northern and southern distribution of *C. perspectalis* is limited by the temperature requirements for completing generation cycle and entering diapause. However, *C. perspectalis* has also been observed in southern China, where the climate is subtropical and temperatures rarely fall below 10°C, which can be attributed to the presence of different geographic biotypes with adaptive temperature thresholds for biological cycle, diapause initiation and termination (Canelles et al. 2021). Therefore, factors related to climate and temperature play a significant role in determining the distribution and potential spread of *C. perspectalis* (Nacambo et al. 2014). Genetic analysis of pest populations collected from the original range in South Korea and China during the period 2012-2017 and from invaded areas in Europe between 2007 and 2016 reveal a total of 12 haplotypes indicating a high level of genetic diversity. In the invaded area, only 5 out of the 12 haplotypes were observed, suggesting a potential genetic bottleneck or reduction in diversity during the invasion process. The number of haplotypes also varied among the invaded countries. Austria, Greece, and Switzerland had only one haplotype each, Germany and France exhibited the highest genetic diversity, with 4 and 5 haplotypes, respectively, while other European countries maintained a relatively stable number of 2 or 3 haplotypes (Matošević et al. 2017, Bras et al. 2019). These findings strongly suggest that the invasive populations of *C. perspectalis* in Europe originated from China, as the haplotypes observed in Europe were also found in the Shandong Province, which is known for producing *Buxus* trees for export. There are several possible reasons for this, including a single funding event with significant genetic diversity, secondary dispersal, or multiple introductions directly from China in various locations at the same time. Furthermore, between 2005 and 2010, the Netherlands imported over 80% of its ornamental plants, with a significant portion coming from East Asia, particularly China (Bras et al. 2019). The introduction of *C. perspectalis* in Canada remains unknown, but it is believed to be the result of human-induced translocation outside of the nursery sector (Wiesner et al. 2021).

Table 1. World-wide invasion history of Cydalima perspectalis
Tablica 1. Kronološki prikaz širenja Cydalima perspectalis u svijetu

Year – *Godina*	Country – *Država*	Literature source – *Izvori*
2006	Germany (Njemačka)	Kruger (2008)
2007	Switzerland (Švicarska)	Leuthard (2010)
	France (Francuska)	Feldtrauer et al. (2009)
2008	The Netherlands (Nizozemska)	Muus et al. (2009)
	United Kingdom (Ujedinjeno Kraljevstvo)	Salisbury et al. (2012)
2009	Austria (Austrija)	Perny (2010)
	Liechtenstein (Lihtenštajn)	Slamka (2010)
2010	Romania (Rumunjska)	Szekely (2011)
2011	Belgium (Belgija)	Casteels et al. (2011)
	Italy (Italija)	Bella (2013)
	Hungary (Mađarska)	Safian & Horvath (2011)
	Turkey (Turska)	Hizal et al. (2012)
	The Czech Republic (Češka)	Šumpich (2011)
2012	Slovenia (Slovenija)	Jež (2012)
	Croatia (Hrvatska)	Matošević (2013)
	Slovakia (Slovačka)	Pastoralis et al. (2013).
	Poland (Poljska)	CABI (2022)
2013	Greece (Grčka)	Strachinis et al. (2015)
	Russia (Rusija)	Shchurov et al. (2013)
	Spain (Španjolska)	Perez – Otero et al. (2014)
	Denmark (Danska)	Hobern (2013)
2014	Bulgaria (Bugarska)	Beshkov et al. (2015)
	Bosnia and Herzegovina (Bosna i Hercegovina)	Ostojić et al. (2015)
	Montenegro (Crna Gora)	Ostojić et al. (2015)
	Serbia (Srbija)	Ostojić et al. (2015)
	North Macedonia (Sjeverna Makedonija)	Načeski et al. (2018)
	Georgia (Gruzija)	Matsiakh (2014)
2015	Ukraine (Ukrajina)	Budashkin (2016)
	Luxemburg (Luksemburg)	Ries et al. (2017)
	Moldova (Moldavija)	Elisovetcaia et al. (2020)
2016	Albania (Albanija)	Vetek et al. (2019)
	Portugal (Portugal)	Corley et al. (2018)
2017	Ireland (Irska)	Plant et al. (2019)
	Kosovo (Kosovo)	Geci et al. (2020)
2018	Lithuania (Litva)	Paulavičiute & Mikalauskas (2018)
	Maltese Islands (Malta)	Agius (2018)
	Gibraltar (Gibraltar)	Perez & Guillem (2019)
	Canada (Kanada)	Wiesner et al. (2021)
2019	Algeria (Alžir)	Haddad et al. (2020)
	Azores (Portugal) (Azori)	Vieira (2020)
	Belarus (Bjelorusija)	Sinchuk et al. (2022)
2021	United States (Sjedinjene Američke Države)	USDA (2021)

Monitoring – *Nadzor*

C. perspectalis occurrence, flying period, infestation, and damage can be detected through visual inspections of host plants and by using traps and lures (USDA APHIS, 2022; Ferracini et al. 2022). Visual inspections of host plants in the field and nurseries are essential for overall monitoring activities. These observations help assess the first seasonal appearance of *C. perspectalis* adults after overwintering, as well as evaluate the level of infestation and damage (Oletan et al. 2017; Gottig and Herz, 2018).

Traps and attractants – *Lovke i atraktantni*

Traps and lures are useful tools used to monitor the adults of *C. perspectalis.* Ferracini et al. (2022), as well as Kim and Park (2013) and Bjeliš et al. (2023a), demonstrated that funnel traps captured significantly higher numbers of male *C. perspectalis* compared to delta sticky traps or wing traps. Kazerani et al. (2019) demonstrated that there is no significant effect of trap colour and height positions of the pheromone traps. Gottig and Hertz (2017) tested the use of light traps to capture both male and female *C. perspectalis* moths,

Šumarski list, 1–2, CXLIX (2025), 67–76

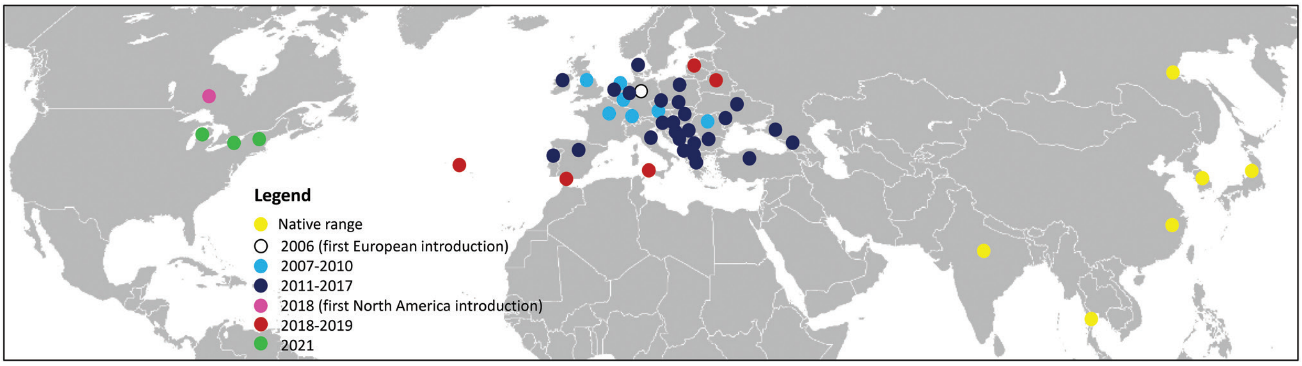

Figure 1: Graphical representation of the world-wide invasion history of *Cydalima perspectalis*
Slika 1: Grafički prikaz rasprostranjenosti *Cydalima perspectalis* u svijetu

reporting advantages (attracting both sexes equally, which is important for obtaining data on the temporal occurrence and proportion of both sexes in the field) and disadvantages (dependence on electricity, bulkiness, attraction of various non-target and beneficial insects, high maintenance requirements) (Gottig and Hertz 2017). Pheromones, olfactory lures and bisexual lures have been tested for the control and management of *C. perspectalis*. Kawazu et al. (2007) identified the sex pheromone of *C. perspectalis* by analysing ovipositor extracts. Analysis identified three pheromone compounds as potential candidates: (Z)-11-hexadecanal (Z11-16: Ald), (E)-11-hexadecenal (E11-16: Ald), and (Z)-11-hexadecenol (Z11-16:OH), with a ratio of approximately 5 : 1.25 : 1 in the crude extract. Based on findings by Kim and Park (2013) from field and laboratory bioassays, it was concluded that the attractive sex pheromone mixture for *C. perspectalis* consists of a combination of Z11-16:Ald and E11-16:Ald at a ratio of approximately 5 : 1.25. Molnar et al. (2019) developed bisexual lures to attract both male and female *C. perspectalis* moths with different compositions of lures and observed their effectiveness in attracting the moths. These findings indicate that the combination of phenylacetaldehyde, eugenol and methyl salicylate in the trap is the most effective in attracting both male and female *C. perspectalis* moths. Bjeliš et al. (2023a) evaluated different lure doses and found that 3-6 mg of pheromone per trap is the most effective amount.

Photoeclectors – *Fotoeklektori*

Photoeclector is a simple tool that takes advantage of insect phototaxis, and it has been proven to be effective in extracting and estimating the number of *C. perspectalis* larvae on *Buxus* plants (Kulfan et al. 2020). Observations had shown that the larvae of *C. perspectalis* began to leave the photoeclectors shortly after placement, with over 98% of all larvae emerging within the first 8 days. Similar results were obtained when larvae were examined one month after diapause. This method provides a reliable means of detecting and estimating the presence of *C. perspectalis* larvae, especially during unfavourable weather conditions such as low temperatures and precipitation in winter and early spring, which can limit the detection of larvae in the field (Kulfan et al. 2020).

Visual host-plant monitoring and damage assessment – *Vizualna metoda praćenja štetnika i ocjena zaraze*

Observation of host plants in the field is a crucial monitoring measure for gaining a better understanding of the development of preimaginal stages, the degree of infestation, overall damage to host plants, the timing of key life cycle events and the development of management strategies of *C. perspectalis*. (Oltean et al. 2017, Gottig and Herz 2018, Burjanadze et al. 2019). The spatial distribution of *C. perspectalis* larvae on the host plant exhibits an uneven vertical pattern, as highlighted by Kulfan et al. (2020). Although *Buxus* plants are primarily defoliated in the lower parts followed by the middle elevation zone, and the least in the upper elevation zone (Matošević, 2013, Kulfan et al. 2020), overwintering larvae prefer middle and higher plant parts (Kulfan et al. 2020). Several authors have dealt with the assessment of damage and infestation intensity in cultivated plants in private gardens. Amaudov et al. (2017) and Burjanadze et al. (2019) recommend classifying damage into 5 damage levels based on the degree of defoliation (from 0 (0%) = undamaged to 4 (>76%) = very strong). Gottig and Herz (2018) used a 0.25 m^2 frame to determine the number of preimaginal stages in hedge rows where the percentage of damage should be determined separately for each hedge and each elevation level. In the case of tall plants, damage can be measured at 3 levels above the ground (Kulfan et al. 2020). Kulfan et al. (2020) classified foliar damage by visual inspection as 0%, 50% and 100% damage. Fora and Posta (2015) assessed defoliation based on the percentage of damage, the amount of damage, and the importance of damage. Akinci and Kordoglu (2019) used the same method to assess damage to wild native box trees. Baur et al. (2019) used two methods to estimate damage in wild boxwoods. The first method involved randomly selecting boxwoods and assessing the percentage of damaged leaves on 5 branches per tree. The second method involved observing 10 boxwoods and 50 leaves per tree, scoring each leaf into 5 damage classes based on percentage.

Management and control – *Upravljanje i suzbijanje*

Biological methods – *Biološke metode*

Natural enemies of *C. perspectalis* – *Prirodni neprijatelji C. perspectalis*

Data on the occurrence of natural enemies and their impact on the population reduction of *C. perspectalis* are predominantly reported in its native range of South and East Asia (Mally and Nuss, 2010; Wan et al. 2014). In Asia, *C. perspectalis* has several natural enemies (Table 2) (Wan et al., 2014).

Data on present parasitoids of *C. perspectalis* in Europe include larval parasitoid *Pseudoperichaeta nigrolineata* (Walker 1853) (Diptera, Tachinidae) reported in Switzerland (Wan et al. 2014) and Italy (Ferracini et al. 2022), *Stenomalina* cf. *communis* (Ness 1834) (Hymenoptera, Pteromalidae) in Britain (Nacambo et al. 2014; Bird et al. 2020), *Apechthis compunctator* (L.) (Hymenoptera, Ichneumonidae), a pupal parasitoid reported in Switzerland (Wan et al, 2014), and *Nemorilla floralis* (Fallén, 1810) (Diptera, Tachinidae) in Croatia as a first world record of *N. floralis* parasitism on *C. perspectalis* larvae (Bjeliš et al. 2023b). Studies in natural boxwood forests in France and Spain report parasitization by the tachinid fly *Campsilure concinnata* Meigen 1824 (Morel et al, 2013; Lopez et al, 2014). According to Fauna Europaea, all four tachinid species (*P. nigrolineata*, *S. communis, C. concinnata* and *N. floralis*) are widely distributed in Europe. In addition to the confirmed parasitoids, *Trichogramma brasicae* Bezdenko 1968 and *Trichogramma dendrolimi* Matsumura 1926 (Hymenoptera, Trichogrammatidae) have been evaluated as highly polyphagous egg parasitoids of *C. perspectalis* (Gottig and Herz, 2016). Beneficial predators such as *Chrysoperla carnea* Stephens 1836 (Neuroptera, Chrysopidae) and *Orius majusculus* Reuter 1879 (Heteroptera, Anthocoridae) have been observed preying on *C. perspectalis* eggs. Therefore, conserving natural enemies like *O. majusculus* and implementing the release of beneficial insects like *C. carnea* can be considered as supportive tools in the biological control of *C. perspectalis* (Gottig, 2017) (Table 2).

Entomopathogenic bacteria, nematodes and fungi – *Entomopatogene bakterije, nematode i gljive*

Various bacterial strains were tested for their insecticidal activity against *C. perspectalis* larvae. Salioglu and Goktur (2021) found that *Bacillus subtilis* Ehrenberg 1835 resulted in 82.5% efficacy, while *B. thuringiensis* subsp. *kenyae* had 65% efficacy. Tozlu et al. (2022) observed high mortality rates for larvae treated with bacterial strains including *B. cereus* Frankland & Frankland 1887, *Vibrio hollisae* Hickman 1982, and *B. brevis*, with 100% mortality achieved at different time durations for each strain. In laboratory experiments *C. perspectalis* larvae has shown susceptibility to the use of the baculovirus *Anagrapha falcifera* nucleopolyhedrovirus (AnafaNPV), providing a new means of pest control (Rose et al., 2013). *Saccharopolyspora spinosa* Mertz and Yao 1990 based active ingredient *spinosad* derived from the actinomycete is recommended for suppressing *C. perspectalis* larvae with a high efficacy rate of 99% (Somsai et al. 2019; USDA APHIS, 2022). Entomopatho-

Table 2. Natural enemies of *Cydalima perspectalis* in Asia and Europe
Tablica 2. Prirodni neprijatelji *Cydalima perspectalis* u Europi i Aziji

Order *Red*	Family *Porodica*	Species *Vrsta*	Host stage *Stadij*	Type *Tip*	Source *Izvori*	?
Diptera	Tachinidae	Compsilura concinata	Larva	Parasitoid	Chen et al., 2005; Wan et al., 2014; Morel et al., 2021	+
	Tachinidae	Exorista larvarum	Larva	Parasitoid	Shi & Hu, 2007; Wan et al., 2014	+
	Tachinidae	Pseudoperichaeta nigrolineata	Larva	Parasitoid	Wan et al., 2014; Ferracini et al., 2022	+
	Tachinidae	Stenomalina communis	Larva	Parasitoid	Bird et al., 2020	-
	Tachinidae	Nemorilla floralis	Larva	Parasitoid	Bjeliš et al., 2023a	+
Hymenoptera	Braconidae	Chelonus tabonus	Egg	Parasitoid	Wan et al., 2014;	+
	Braconidae	Dolichogenidea stantoni	Larva	Parasitoid	She & Feng, 2006; Wan et al., 2014;	+
	Chalcidae	Brachymeria lasus	Pupa	Parasitoid	Chen et al., 2005	+
	Encyrtidae	Tyndarichus sp.	Egg	Parasitoid	Wan et al., 2014	-
	Ichneumonidae	Apechthis compunctator	Pupa	Parasitoid	Wan et al., 2014;	-
	Ichneumonidae	Casinaria sp.	Larva	Parasitoid	Wan et al., 2014;	-
	Trichogramma tidae	Trichogramma brassicae	Egg	Parasitoid	Gottig, 2012	+
	Trichogramma tidae	Trichogramma dendrolimi	Egg	Parasitoid	Gottig, 2012	+
Thysanoptera	Aeolothripidae	Aeolothrips sp.	Egg	Predator	Chen et al., 2005	-
Neuroptera	Chrysopidae	Chrysoperla carnea	Egg	Predator	Gottig, 2017	+
Heteroptera	Anthocoridae	Orius majusculus	Egg	Predator	Gottig, 2017	+

genic nematodes *Steinernema carpocapae* Weiser 1955 and *Heterorhabditis bacteriophora* Poinar 1976 were tested and found to have high efficacy against *C. perspectalis* mortality rates of 97.8-100% for *S. carpocapae* and 92-98.9% for *H. bacteriophora*, highlighting the potential of these nematode species for controlling the pest (Wan et al. 2014). Zemek et al. (2020) demonstrated a 46.4% mortality rate of pupae treated with fungi *Isaria fumosorosea* Wize 1904, when treated with highest concentration of fungal spores (1x108 spores). The cumulative mean mortality, including malformed adults, varied among the treatments, with the highest mortality (60%) observed in larvae treated with suspensions of 1 × 108 spores (Zemek et al. 2020). In the forests of Iran, the presence of fungal mycelium infecting larvae was observed, leading to the identification of *Bauveria bassiana* as a natural pathogenic fungus affecting *C. perspectalis* (Zamani et al. 2017). Mortality of 100% was observed with a suspension of 1 × 108 conidia/ml of *B. bassiana*. Burjanadze et al. (2019) reported that a suspension of 1 × 108 conidia/ml of *B. bassiana* caused 80% larval mortality under laboratory conditions and 60% in the field. These findings highlight the potential of *B. bassiana* as an effective biological control agent against *C. perspectalis*, both in laboratory and field settings.

Biotechnical methods – *Biotehničke metode*

Botanical insecticides and essential oils – *Botanički insekticidi i esencijalna ulja*

Szelenyi et al. (2020) conducted laboratory experiments to assess the repellent effects of essential oils (lavender, cinnamon, and eucalyptus) applied on *Buxus* plants on the behaviour of female *C. perspectalis*. The results showed that cinnamon oil had the greatest deterrent effect on females when it came to egg-laying. Gokturk et al. (2019) tested essential oils from various plants (*Artemisia absinthium* L., *Seriphidium santonicum* L., *Seriphidium spicigerum* Koch, *Cuminum cyminum* L., *Mentha pulegium* L., *Origanum majorana* L., *Origanum onites* L., *Origanum syriacum* L., *Origanum vulgare* L., and *Satureja hortensis* L.) on the 2nd and 5th instar larvae of *C. perspectalis*. The essential oil of *O. vulgare* demonstrated an 80% efficacy against both the 2nd instar larvae and the 5th instar larvae, while the essential oil of *M. pulegium* had the lowest effect on both instar larvae, with a maximum efficacy of 52%. The effects of *Azadirachta indica* A. Juss 1830 plant extract, specifically azadirachtin, on *C. perspectalis* larvae were tested by feeding treated leaf discs to 3rd larval stage larvae and reached 62% of mortality after two weeks. Field application of azadirachtin yielded limited success, and it was challenging to determine a precise difference in the number of *C. perspectalis* before and after treatment. (Gottig and Herz, 2018). Essential oils, such as cinnamon oil and *O. vulgare* oil, can potentially deter *C. perspectalis* females and effectively control larvae. Furthermore, the use of azadirachtin from *A. indica* shows promise, although its efficacy may vary in different settings. Further research is needed to optimize the application methods and determine the long-term effectiveness of these treatments in the field.

Mating disruption – *Metoda konfuzije*

Since the goal of matting disruption is to disrupt the mating process, this technique is the most effective when applied over extensive areas using pheromones (Miller and Larry, 2015). An experimental mating disruption product had been tested in Croatia for 2 years (2021-2022) on a 70-hectare urban area. (Simmons et al. 2023). The product was developed by TRECE* based on their CideTrakt meso-dispenser system, a solid rubberized plastic dispenser based on the major pheromone component for BTM (Z11-16:Ald). The results of the two years experiments show a 99% trap "shutdown" and BTM larval reductions by as much as 75% in treatment compared to control plots. Dispensers placed at the rate of 50/ha and 80/ha achieved similarly high rates of trap shutdown, which suggests that the lower rate of dispenser placement would be effective (Simmons et al. 2023). A Box T Pro Press product is currently available on the EU market for managing C. perspectalis that can be directly applied to Buxus plants. This product utilizes female pheromones to saturate the area, preventing males from locating females and disrupting the mating process. The active ingredient in this product is (Z)-11-hexadecenal, with a concentration of 70 g/kg (7% p/p). Application of the pheromone can be done by placing small blobs, approximately the size of a small coin, on the trunk or in the corners of the branches.

Laboratory mass rearing and sterile insect technique – *Masovni uzgoj u laboratoriju i tehnika steriliziranja štetnika*

The sterile insect technique (SIT) is an environmentally friendly method used to manage insect pests on a large scale (Klassen, 2005). To implement the SIT for *C. perspectalis*, one crucial step is the development of an artificial diet that can support the insect's full life cycle in laboratory rearing. Previous attempts have involved successfully using costly dried or freeze-dried *Buxus* spp. powder added to the diet (Kawazu et al. 2010). A diet that does not rely on host materials would lead to sustainable cost-effective and practical mass rearing in the laboratory (Hickin and Nadel, 2022). In conjunction with the artificial diet, ionizing radiation is used to sterilize *C. perspectalis* females and reduce the fertility of males and their offspring. Preliminary assessments of radiation biology have determined that an optimal radiation dose for *C. perspectalis* falls between 130 and 200 Gy (Nadel and Simmons, 2022). However, there is currently limited information available regarding sterile male competitiveness and the estimation of effective overflooding ratios of irradiated males compared to wild males (Marec and Vreysen, 2019). Further research and evaluation are needed to optimize the rearing process, determine the competitiveness of sterile males, and assess the effective overflooding ratios. Once these factors are better understood, the SIT can be a valuable tool in managing *C. perspectalis* populations.

Chemical control – *Kemijske mjere*

In Asia, various chemical insecticides are commonly used to control *C. perspectalis* populations: pyrethroids, organophosphates, spinosyns and phenylpyrazoles have been employed (Wan et al. 2014). Among these, spinosad and fipronil are recommended treatments in certain regions of China and have shown effectiveness, particularly against early larval stages of *C. perspectalis* (Kenis, 2016). In Europe, there is no approved chemical product specifically for controlling *C. perspectalis* (Kenis et al. 2013). Fora et al. (2016) conducted a field study testing 5 different insecticide products from the group of neonicotinoides and synthetic pyrethroids. In a field study conducted in Romania by Somsai et al. (2019), a significant number of insecticides were tested, but again from the groups of neonicotinoides and synthetical pyrethroids. Even though some of them have shown a 100% larval mortality, almost all of them are forbidden to use in EU nowadays. In North America, both the United States and Canada accepted and recommended insecticides that had already been tested and approved in Europe and Asia (Fora et al., 2016; Coyle et al. 2022; USDA, 2022).

DISCUSSION AND CONCLUSION
RASPRAVA I ZAKLJUČCI

The current review given in this article provides and brief overview of the box tree moth *C. perspectalis*, which has successfully invaded and established populations on several continents and in numerous countries (Kenis et al. 2013; Nacambo et al. 2014; Wiesner et al. 2021). Still, several questions and possibilities for the improvements of the overall strategies to combat this pest should be implemented. Invasive pathways from native area to the Palearctic area are certainly most explored due to extensive genetic proofs, and they demonstrate that the pest was introduced through international trade of infested plant materials first to the Netherlands and then to the surrounding countries through secondary trade (Bras et al. 2019; 2022). Several haplotypes from the pest origin found in Europe support this hypothesis. Contrary, there is lack of information regarding the pathway to North America and its first detection one the Canadian border with the US, while further spreading to the US by natural dispersal is realistic, as well as further spreading along three states in the US (Wiesner et al. 2021). A scientifically proven invasion pathways to North America could contribute to the overall mitigation strategies. Methods of detection and monitoring of *C. perspectalis* showed which tools were weak in the first decade after the pest was introduced into the Palearctic area. Originally proposed trapping methodology based on the use of the delta sticky trap baited with 1 mg pheromone lure shows insufficient effect for pest detections. Several further experiments demonstrate that both trap type and pheromone dose were improved. Ferracini et al. (2022) as well as Kim and Park (2013) and Bjeliš et al. (2023a) have demonstrated that funnel trap type captured significantly more *C. perspectalis* males compared to delta sticky traps or wing traps and that there is no significant effect of trap colour and height positions of the pheromone trap (Kazerani et al. 2019). Bjeliš et al. (2023a) evaluated different lure doses and found that 3-6 mg of pheromone per trap is the most effective amount, especially when compared with 1 mg recommendation. Pheromone-embedded traps are widely used in surveillance programs for to confirm the pest presence in new areas, delimit the scale of infestations, and estimate population densities. However, some questions remain about the effectiveness of these traps, in particular the spatial scale of their attractiveness. The mark-release-recapture study ("multiple release – single trap design" and "multiple trap-single release design" experiments) proposed by Turchin and Odendaal (1996) can be applied with the goal to estimate the "effective sampling area" of the preferred funnel type of traps, which may yield important parameter estimates required by monitoring simulation frameworks to evaluate different surveillance strategies. Certainly, the use of bisexual lures is a significant improvement for developing not only female detection tasks, but also for use in control purposes (Molnar et al. 2019). Control methods for *C. perspectalis* include a range of methods with more disadvantages than advantages. The use of various insecticides in private gardens, backyards and public places, even effective have toxicological limitations (Fora et al., 2016; Coyle et al. 2022; USDA, 2022). Among environmentally friendly options, such as entomopathogenic bacteria, fungi and nematodes, there are promising results, but the majority of them need to be more explored and commercially available (Morel et al, 2013; Lopez et al, 2014, Wan et al. 2014, Zamani et al. 2017, Zemek et al. 2020, Salioglu and Goktur 2021, Tozlu et al. 2022). The role of confirmed natural enemies in the invaded areas cannot show significant results in a short time, even though the capacity and range of natural enemies is an essential part of the overall IMP, especially in natural vegetation (e.g. natural boxwood) (Wan et al, 2014, Nacambo et al. 2014; Bird et al. 2020. Ferracini et al. 2022, Bjeliš et al. 2023b). Commercially available parasitoids and predators show significant efficacy in pest control (Gottig and Herz, 2016) and can be considered as supportive tools in the biological control of *C. perspectalis.* Biotechnical methods of control so far are rapidly developing and represent the possibility of commercial availability both for small producers and for application in large state programs to prevent the spread and suppression of *C. perspectalis.* Hereby, the use of the botanical insecticides (Gottig and Herz, 2018) has made them widely tested and available products. Mating disruption method is another commercially available method for use both on small and large areas. Box T Pro Press product is currently available on the EU market for managing *C. perspectalis* that can be directly applied to *Buxus* plants. Application of the pheromone can be done by placing small blobs on the trunk or in the corners of the branches.

Based on the brief overview of the achievements in the period from the first appearance of *C. perspectalis* until today, it is clear that the pest surprised the scientific community and the end users with its speed of spread, and the enormous invaded area and damage it caused in the Palearctic area. However, considering the overall importance of natural *Buxus* forests in the Palearctic area as a feature of the horticultural industry, any effort to timely detect pests on still uninfected areas and the application of precise monitoring tools and modelling methods as well as the application of effective control methods remain a challenge.

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SAŽETAK

Šimširov moljac, *Cydalima perspectalis*, porijeklom iz istočne Azije, prisutan je u 40 zemalja u Europi i na Bliskom istoku, kao i u dvije države u Sjevernoj Americi. Točan put invazije nije do kraja poznat, ali vjeruje se da je do Europe i Sjedinjenih Država stigao višestrukim unošenjem uvezenih biljaka šimšira, nakon čega je uslijedilo daljnje širenje zbog bioloških karakteristika vrste, klimatskih uvjeta i široke rasprostranjenosti biljke domaćina. Cilj ovog preglednog rada jest pružiti pregled literature o visoko invazivnoj vrsti *C. perspectalis* i razmotriti buduća perspektivna rješenja za učinkovitu kontrolu i praćenje. Moguće metode suzbijanja uključuju insekticide i ekološki prihvatljive metode kao što su primjena entomopatogenih bakterija, gljivica, nematoda, biljnih insekticida i metode konfuzije. Primjena metoda integrirane zaštite ključna je za kontrolu *C. perspectalis*. Metode detekcije, strategije prevencije, praćenje štetnika i zaraze, procjena sposobnosti prezimljavanja i razvoj učinkovitih mjera kontrole ključne su buduće perspektive. Istraživanjem, suradnjom i strateškim intervencijama moguće je ublažiti utjecaj *C. perspectalis* i zaštititi osjetljive ekosustave od razornih posljedica ovog invazivnog štetnika.

KLJUČNE RIJEČI: *Cydalima perspectalis*, invazivnost, *Buxus*, praćenje, upravljanje i kontrola