Rapid Communication

Utilization of citizen science data to monitor alien species: the box tree moth *Cydalima perspectalis* (Walker, 1859) (Lepidoptera: Crambidae) invades natural vegetation in Greece

Christos Kazilas[1,2,*], Konstantinos Kalaentzis[1,2], Jakovos Demetriou[3,4,5], Evangelos Koutsoukos[3,4], Ilias Strachinis[6] and Pavlos Andriopoulos[4]

[1]*Institute of Biology, Leiden University, Sylvius Laboratory, Sylviusweg 72, 2333 BE, Leiden, The Netherlands*
[2]*Naturalis Biodiversity Center, PO Box 9517, 2300 RA, Leiden, The Netherlands*
[3]*Museum of Zoology, National and Kapodistrian University of Athens, 15784 Athens, Greece*
[4]*Section of Ecology and Systematics, Department of Biology, National and Kapodistrian University of Athens, 15784 Athens, Greece*
[5]*Laboratory of Vector Ecology and Applied Entomology, Joint Services Health Unit, British Forces Post Office 57, RAF Akrotiri, Cyprus*
[6]*Department of Genetics, Development and Molecular Biology, School of Biology, Faculty of Natural Sciences, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece*

**Corresponding author*
E-mail: *ckazilas@gmail.com*

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Abstract

Since the first report of the box tree moth, *Cydalima perspectalis* (Walker, 1859) (Lepidoptera: Crambidae) in northern Greece in 2013, the pest has gradually expanded its range to a total of eight administrative regions in the country. A survey consisting mainly of citizen science occurrence records provides a new insight on the distribution of the box tree moth in Greece. The data collected circumscribe invasion into boxwood *Buxus sempervirens* L. stands, especially at Mt Olympus National Park. The updated invasive status and the ecological risks are discussed with particular reference to the Natura 2000 area in Mt Olympus.

Key words: non-native species, invasive species, pest, range expansion, *Buxus sempervirens*, citizen science, Natura 2000

Introduction

Citizen science has emerged as a valuable source of information in biodiversity monitoring programs, collecting vast sums of data focusing on species distribution and phenology, but also population, habitat and ecosystem parameters (Chadler et al. 2017). Utilizing new advances in communication technology (e.g. smartphones, applications, social media etc.), public participation in scientific research has managed to shed a light on the presence, distribution, behaviour and phenology of alien species, primarily through the provision of photographic observation material (Roy et al. 2018; Johnson et al. 2020). Citizen scientists have contributed multiple times in scientific studies of alien insect species, collecting early detection records, mapping their distribution and outlining their *in situ* impacts (e.g. Roy and Brown 2015; Maistrello et al. 2016; Kazilas et al.

2020; Hadjiconstantis and Zoumides 2021). Although issues regarding the taxonomic accuracy of citizen science data have been raised (Stafford et al. 2010), these obstacles can be overcome by aiming for taxonomically unique or morphologically distinctive species.

The box tree moth *Cydalima perspectalis* (Walker, 1859) (Lepidoptera: Crambidae) serves as an exceptional example of an alien species that can be monitored via citizen science data. As the only representative of the genus *Cydalima* Lederer, 1863 that has been observed to date in Europe, it possesses a distinctive morphology compared to other native moth species. Moreover, the larvae stage of the moth is found almost exclusively on box trees (*Buxus* spp.), which makes identification by citizen scientists even less challenging. The species is naturally distributed in the subtropical regions of East Asia (Inoue 1982) and was first reported in Europe in 2007 from Germany (Krüger 2008), Switzerland and the Netherlands (Leuthardt et al. 2010; van der Straten and Muus 2010). Over the following decade, the moth continued to spread across Europe and West Asia and it is currently present in more than 30 countries (Bras et al. 2019), from the United Kingdom (Salisbury et al. 2012) to Iran (Mitchell et al. 2018). Recently the moth was also introduced into two more continents, namely North America (CABI 2020) and Africa (Haddad et al. 2020).

Given that the moth is an important pest of box trees that are commonly used as ornamental plants in Europe (Batdorf 1997), it has been hypothesized that commercial plant trade is responsible for the introduction of the box tree moth in the European region (Kenis and Rabitsch 2018). Apart from the damage to horticultural box trees in private gardens, city parks or other urban green spaces, the box tree moth has also been reported to cause severe defoliation of native *Buxus sempervirens* L. stands across Europe (John and Schumacher 2013; Kenis et al. 2013; Raineri et al. 2017). Due to its significantly fast spread and potential ecological implications in countries with natural box tree stands, a risk assessment by the European Commission assigned an invasive status to *C. perspectalis* for Belgium, France, Germany, Italy and Spain (Kenis and Rabitsch 2018). In addition, the results suggested the possibility of the box tree moth having a negative impact on other Mediterranean and continental countries, where naturally occurring *Buxus* spp. can be found (Di Domenico et al. 2012; Kenis et al. 2013).

In Greece, *B. sempervirens* (boxwood) is widely cultivated as an ornamental plant (Arampatzis 1998), while in Athens it is planted ever since the mid-19th century (Heldreich 1862). *B sempervirens* is naturally distributed from 120 m to 2200 m a.s.l., mainly north of the country and along the Pindos mountain range, while it is also locally found on Mt Pelion (central Greece) and on the islands of Corfu and Euboea (Strid 1986; Gerasimidis et al. 2009; Caudullo et al. 2017). On Mt Olympus *B. sempervirens* is more abundant than elsewhere in Greece (Heldreich 1862; Strid 1980). The boxwood formations at the northern areas of the mountain grow from 120 m

elevation together with *Phillyrea latifolia* L. up to 1900 m elevation in subalpine shrublands, while at the southern slopes the species forms extensive shrublands in deforested areas. Elsewhere on the mountain, boxwood is a common understory shrub in *Fagus sylvatica* L., *Abies borisii-regis* Mattf. and *Pinus heldreichi* Christ. forests, reaching up to 2100 m a.s.l. (Strid 1980; Gerasimidis et al. 2009; Theodoropoulos et al. 2011).

The box tree moth was detected for the first time in northern Greece in October 2013 and as of April 2015, it had been recorded in six urban localities across the country (Strachinis et al. 2015). Severe damage by the tree box moth was reported on *B. sempervirens* plants in private and public gardens, yet there was no evidence of infested wild stands during that period (Strachinis et al. 2015). Currently, the moth is classified as an alien species for Greece (Kenis and Rabitsch 2018) and no follow-up studies on its range and ecological preferences have been conducted on a national level since the first occurrence. In this study, we provide an overview of the current distribution of *C. perspectalis* in Greece based mostly on citizen science records, as well as the first evidence on the widespread occurrence of the species on wild stands of *B. sempervirens* with special reference to the Mt Olympus Natura 2000 (N2K) site.

Materials and methods

Data collection

The collection of records concerning the presence of *C. perspectalis* in Greece was mostly based on citizen science record data collected from online databases and social networks, supplemented by personal observations and data from Management Agencies of Protected Areas. The data acquisition process started on July 2016 and ended by December 2020. Observations of the box tree moth prior to July 2016, either published or unpublished, were also included in the dataset. During the collection period, citizen science records were extracted from the iNaturalist online platform (iNaturalist 2020) and Facebook insect identification groups (e.g. Insects of Greece & Cyprus). In the latter case, posters providing information on how to identify the box tree moth were created and shared online, in order to achieve the participation and engagement of citizens. Additionally, forms were distributed to the observers and photographic material, geographic coordinates, collection dates, as well as information on the number of observed individuals were obtained. The survey revealed the presence of the box tree moth within Natura 2000 protected areas. As a result, on December 2019, questionnaires were sent to 27 Management Agencies of Protected Areas in Greece to collect information about the occurrence and status of the moth within their area of responsibility. Additionally, a year later, the agencies were contacted a second time to provide any follow-up information. After the data collection period, the

identification of the acquired records was confirmed, based on the diagnostic characters mentioned in Mally and Nuss (2010) and Strachinis et al. (2015).

Spatial analysis

The distribution of the species was estimated in terms of the area of occupancy (AOO), by assigning presence to the intersected 10 km^2 cells of the European Environment Agency (EEA) reference grid, but also in terms of the occupied administrative regions, according to their delineation provided by the Hellenic Ministry of the Interior and Administrative Reconstruction. Presence within the EU Natura 2000 network of protected areas was explored, and the local habitat type was recorded in case the occurrence record was within an EU Habitats Directive Site, according to the layers obtained from the Geospatial Information Portal of the Ministry of Environment and Energy. Each occurrence record was assigned a unique value of elevation, (EU-DEM v. 1.1) and land cover (Corine Land Cover project version CLC2018), according to the layers obtained from the Copernicus Land Monitoring Service. All occurrence records and layers were projected to the ETRS89 Lambert Azimuthal Equal Area projection. Spatial analysis was conducted with the use of ArcGIS 10.6.1 (ESRI 2021).

Statistical analysis and assessment

The data were pooled and statistically analysed with RStudio 1.3.1 (RStudio Team 2021) software. The presented box plot, line graph and histograms were created using the *ggplot2* package (Wickham 2011). Figures were edited using Adobe Photoshop CC 2019 (Adobe, San Jose, CA). Lastly, in order to evaluate the risk that the box tree moth represents to native biodiversity, a standard risk assessment was carried out, implementing the Harmonia+ protocol (Belgian Biodiversity Platform 2020).

Results and discussion

A total of 76 occurrence records were accumulated, corresponding to observations made from 2013 until the end of 2020. This final dataset included both published (11 records; Strachinis et al. 2015 and Bras et al. 2019) and unpublished data (65 records).

Seasonal distribution

The majority of the records occurred from May to September (Figure 1). This pattern supports the hypothesis that the moth's activity is concentrated in the warmer months of the year (from late spring till early autumn), in accordance with observations from other European countries (Oltean et al. 2017). A single record from January refers to a dead specimen. Even though most of the country provides moderate climatic suitability to support the

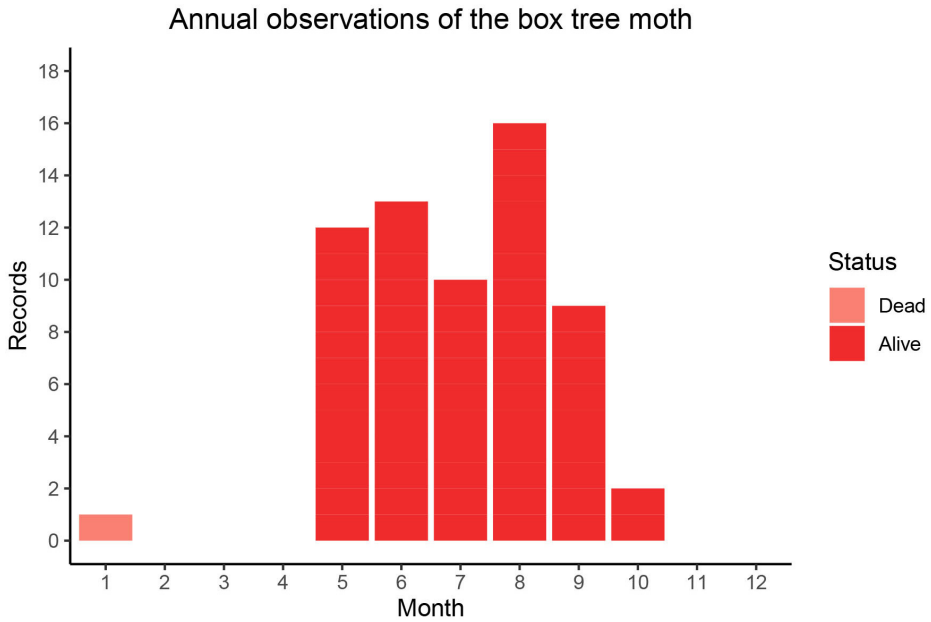

Figure 1. Seasonal distribution of *C. perspectalis* observations in Greece, from 2013 to 2020. Alive individuals are shown in deep red, while dead specimens are indicated with light red colour. The observations concern only adult specimens.

survival and reproduction of the species (Sutherst et al. 2007; Nacambo et al. 2014), the number of generations on each site remains unknown. The presence of adult individuals as early as May, may indicate up to three generations of *C. perspectalis* in Greece annually, at least in some regions. This is consistent with seasonal distribution data from other Mediterranean countries, such as Italy (Santi et al. 2015) and Croatia (Matošević et al. 2017). However, given that the moth's larval growth rate is temperature dependent (Maruyama and Shinkaji 1991), it is possible that certain populations exhibit only two generations, as is the case for some central European countries (Leuthardt and Baur 2013; Nacambo et al. 2014). Therefore, more studies are needed on a region-specific level in order to elucidate the exact number of generations in different parts of the country.

Range expansion and relative abundance

The species was first encountered in Northern Greece in 2013 and by 2015 it was found in four administrative regions (Strachinis et al. 2015). Up to date, the moth has expanded its distribution to a total of eight regions, covering most of continental Greece, while no insular records have been reported yet (Figure 2). The AOO of *C. perspectalis* has risen rapidly over the years, from 100 km^2 in 2013 to 3800 km^2 in 2020 (Figure 3). More than half of the records collected for this study concern observations from 2018 and 2019 (Supplementary material Table S1). Even though 83% of these sightings (35 out of 42) were made from localities where the species had not been previously reported, it is still unclear whether these records are the consequence of a natural range expansion or human-mediated introduction to these new areas.

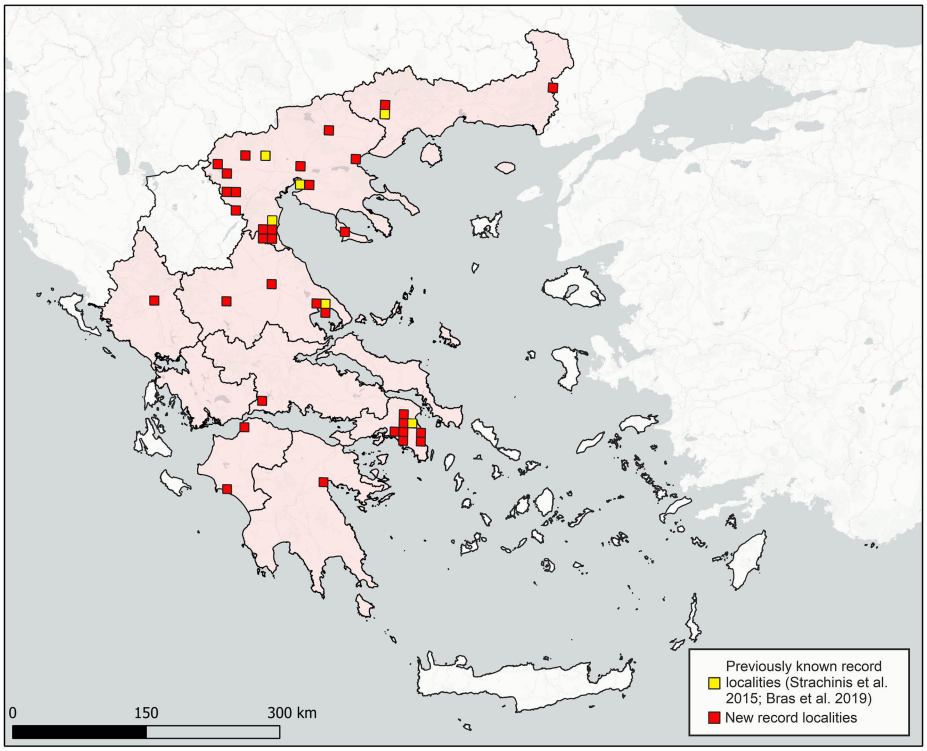

Figure 2. Distribution map of *C. perspectalis* in Greece using the EEA reference grid of 10 km^2. Light red shaded areas represent the administrative regions where the box tree moth has been found. Yellow squares correspond to the areas where the moth's presence was already known from Strachinis et al. (2015) and Bras et al. (2019), while dark red squares indicate the new locations where the moth has been observed.

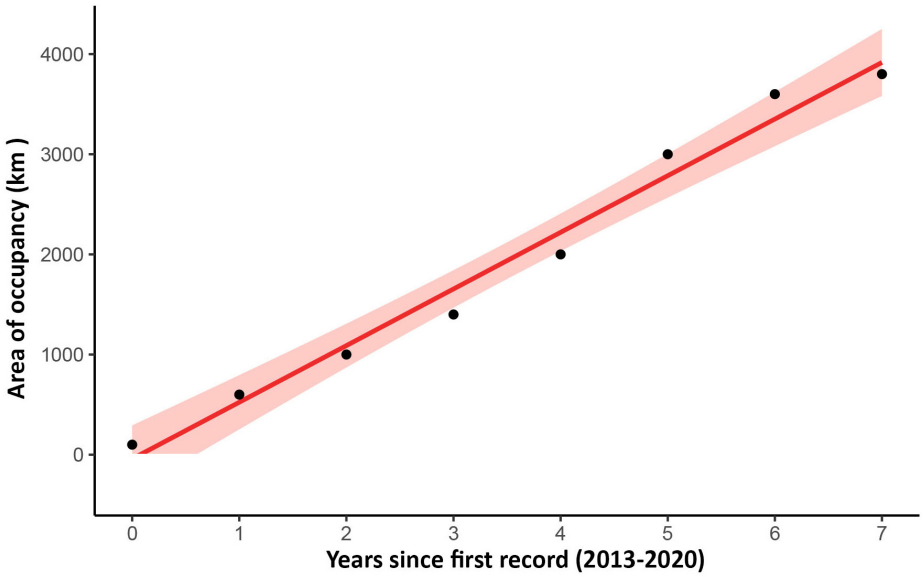

Figure 3. Spatial expansion of *C. perspectalis* distribution across Greece, from 2013 to 2020, in the form of a linear trend line. The light red shaded area represents 95% confidence interval.

During the first years of its presence in Greece, the moth was mostly found in urban environments, at low elevations, which could be related to the ease of observation by citizen scientists in these areas. However, the species has recently been recorded from mountainous areas as well, at altitudes even higher than 1500 m a.s.l. (e.g. Mt Paiko, 1577 m; Mt Olympus,

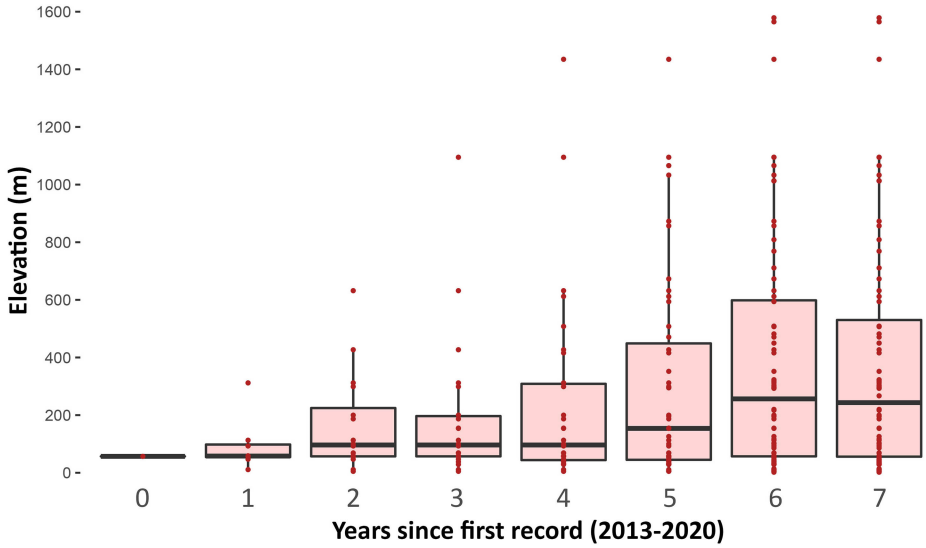

Figure 4. Cumulative vertical range expansion of *C. perspectalis* in Greece from 2013 to 2020. Despite the low elevation values during the first few years of its presence, the box tree moth has recently been observed at much higher altitudes; e.g. Mt Paiko (1577 m) and Mt Olympus (1563 m).

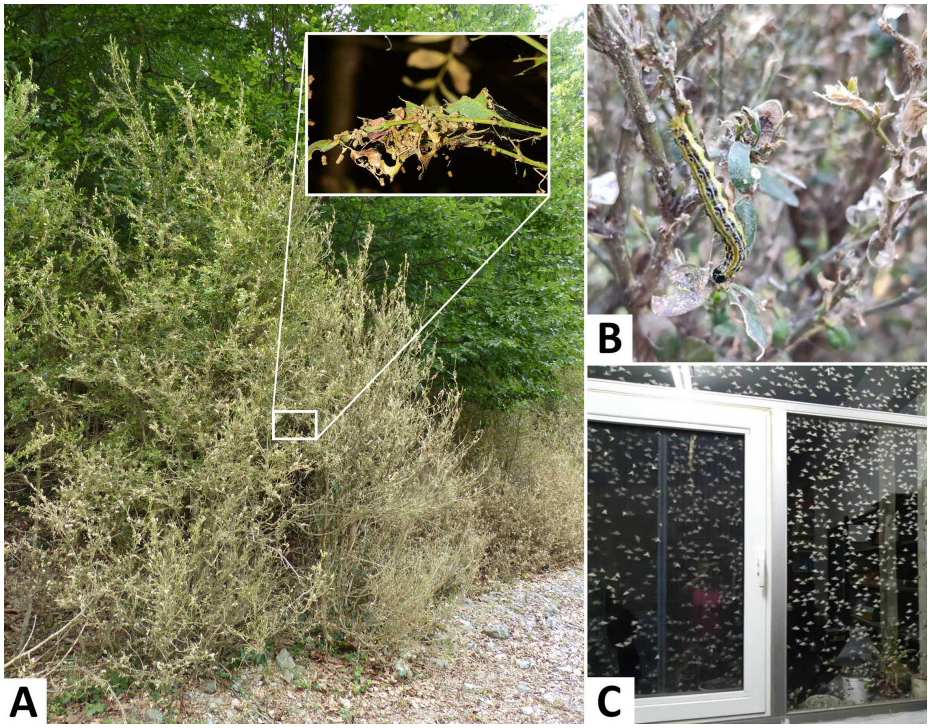

Figure 5. Photographic evidence on the presence of *C. perspectalis* in Greece. Damage on wild *B. sempervirens* plants on Mt Olympus (inset: Detail of the defoliation caused by the box tree moths; A) and infestation of cultivated *B. sempervirens* shrubs at the National Garden of Athens, Attica (B). One case of a large population of hundreds of adult individuals outside the observer's residence reported from Kerasia, Pella (C). Photos by L. N. Pamperis (A), J. Demetriou (B) and E. Grou (C).

1563 m). Nevertheless, observations at higher elevations are not very frequent and are statistically considered outlier cases, since the mean elevation values remain close to 200 m a.s.l. (Figure 4).

The majority of the accumulated records refer to observations of a single or a few individuals. However, cases of heavy infestations on *Buxus* plants by the moth's larvae (Figure 5) were also documented both by the authors

Table 1. Occurrence records of *C. perspectalis* in Greece that reported the presence of the moth in high densities (30 or more individuals were observed at a certain time).

Location	Date	Longitude	Latitude	Number of individuals	Life stage	Natura 2000 site code
Nea Kios, Argolis	18 Jul 2018	37.597500	22.742222	100+	Larvae	–
Naousa, Imathia	19 Aug 2018	40.629322	22.068636	100+	Adult	–
Kastania, Imathia	19 Aug 2018	40.407259	22.121095	100+	Adult	–
Naousa, Imathia	20 Aug 2018	40.613697	22.048352	100+	Adult	–
National Garden Athens, Attica	26 Apr 2019	37.972675	23.737489	30	Larvae	–
Arapis Canyon, Mt Olympus	12 Jun 2019	40.152980	22.420272	1000+	Adult	GR1250001
Kerasia, Pella	22 Aug 2019	40.870000	21.960000	100+	Adult	GR1240008

(National Garden of Athens, Attica; 30 individuals) and by citizen scientists (Nea Kios, Argolis; > 100 individuals). In addition, a few records from Northern Greece (Kerasia, Pella; Kastania, Imathia) reported the presence of adult moths in great densities (> 100 individuals; Figure 5C), while the largest population consisting of thousands of individuals was identified from Arapis Canyon (Mt Olympus) (Table 1). The reported incidents of hundreds of adult individuals during the summer months, might highlight the alarming infestation levels and high reproductive potential of the species in the country. Another adverse effect as a result of these mass flights is the nuisance caused to humans. Similar instances of moths occurring in great population densities have shown to trigger smoke-detector fire alarms, thus having a negative impact on people's well-being (Mound et al. 2002). Although no eradication efforts have been applied in any of the aforementioned areas, it is still uncertain whether these numbers reflect the current abundance of *C. perspectalis* in Greece, since there have been no cases of active searching for the species in the same localities after the initial observations.

Natural vegetation and potential threats

Geographic expansion has also qualitative characteristics that constitute an unsettling scheme for natural vegetation in Greece. During the first two years of the box tree moth's introduction in Greece (2013–2014), the species was observed in agricultural or urban/industrial areas, concerning five different Corine Land Cover types. In 2015, the species was encountered for the first time in natural vegetation (CLC 324 type: Transitional woodland-shrub, on Mt Falakro) and in 2016 the moth was recorded for the first time higher than 1000 m a.s.l., from the Mt Olympus National Park (CLC 312 type: Coniferous forest). By 2020 a total of 13 different Corine Land Cover types were infested, among which six types of "Forest and semi natural areas" are included (Table S1).

Furthermore, 28% of the reported observations are located within N2K protected areas, with a total of six N2K sites being affected (Table S1). In N2K sites designated as Sites of Community Importance (SCIs), where 92/43/EC habitat types have been mapped (2018 data), the box tree moth has been located at the following habitat types: "Alpine and subalpine

calcareous grasslands (6170), "*Quercus ilex* and *Quercus rotundifolia* forests" (9340), "(Sub-) Mediterranean pine forests with endemic black pines" (9530), "Mediterranean pine forests with endemic Mesogean pines" (9540) and "High oro-Mediterranean pine forests" (95A0).

On the Mt Olympus N2K site, 14 observations of the box tree moth were reported from 10 different locations. Infestations of wild *B. sempervirens* plants (Figure 5A) were reported from oak and pine forests (habitat types 9340 and 9530), at elevations ranging from 480 m to 1011 m. Boxwood shrubs are also present in habitat types 9270 on Mt Olympus, where they are distributed at the understory of fir (*A. borisii-regis*) and beech (*F. sylvatica*) forests from 700 m as high as up to 2100 m a.s.l. (Theodoropoulos et al. 2011). In addition, *B. sempervirens* can be found alongside thermophilous pines within the habitat type 9540 at around 1700 m to 1900 m a.s.l., while it is also a dominant species of the habitat type 4090, occurring at elevations above 2.500 m (Theodoropoulos et al. 2011). This highlights the potential of the box tree moth to continue its spread in other habitat types of the N2K protected site.

The moth was recorded in other N2K sites as well, although no signs of defoliation of natural box trees or other plant species in these areas have been documented so far. Other natural communities of *B. sempervirens* exist throughout Greece, occurring both in continental (i.e. Mt Vermio, Prespa National Park, Mt Varnountas, the foothills of Mt Olympus and Mt Ossa) and insular parts of the country (Corfu and Euboea; Di Domenico et al. 2012). This emphasizes the need for further research to determine whether additional monitoring and mitigation measures are needed to control the spread of this species in such areas.

Impacts and management

Comparing the data provided by Strachinis et al. (2015) to the present data under the Harmonia+ risk assessment of potentially invasive alien species scheme (Belgian Biodiversity Platform 2020), two parameters seem to have changed. Regarding the introduction of *C. perspectalis*, the probability for the species to be introduced into the wild by unintentional human actions is calculated as high. Also, the capacity of the species to disperse by natural means is also determined as high. The impacts of *C. perspectalis* have not been quantified in the country, yet some important adverse effects can be indicated, given that the moth has been classified as one of the most harmful alien species in Europe (Nentwig et al. 2018). The observed defoliation of ornamental and indigenous box trees holds both socioeconomic and environmental impacts (Kenis and Branco 2010). The fact that the distribution of indigenous *B. sempervirens* stands in Greece is not fully known constitutes an additional impediment towards a successful eradication. Regardless, immediate action should be taken to prevent further damage of the natural ecosystems. Even though chemical preparations are some of the

most effective eradication methods currently implemented in other European countries to combat the spread of this pest (Fora et al. 2016; Elisovetcaia et al. 2020), the use of these practices in Natura 2000 sites is illegal. Alternative options include pheromone traps and microbiological preparations. Further research is necessary to determine the optimal approach for the populations of *C. perspectalis* in Greece.

Conclusions

The utilization of records provided by citizen scientists across Greece has provided an up-to-date distribution of the box tree moth throughout the Greek mainland. Citizen scientists can not only actively assist in mapping the range expansion of this alien species in the country, but also act as an early warning system towards the spread of the insect to susceptible island communities or protected areas. Sharing educational material (e.g. digital posters) in social media platforms about the morphology, ecology and detrimental impacts of *C. perspectalis* on native biodiversity has been proved to be an effective way to raise public awareness. Public engagement of online communities, such as Facebook identification groups, in the study of alien insects of Greece is of high value and seems to be promising for similar future endeavours. The development of an online platform dedicated to promoting public participation in scientific research regarding alien species could allow the expansion of the current knowledge on the distribution and negative effects of *C. perspectalis* in Greece.

Despite the significance of citizen science data in biodiversity monitoring, these data have been pointed out to be a subject of multiple biases, including but not restricted to, uneven spatial and temporal coverage, detectability and sampling effort (Isaac et al. 2014). Human population density and infrastructure have been found to determine spatial biases in biodiversity monitoring relying on public participation, with citizen scientists recording species mostly in the vicinity of their house or areas they like to visit (Isaac and Pocock 2015; Geldmann et al. 2016). Regarding temporal biases, observers' behaviour has been found to be positively influenced by weekends and holidays, resulting in an increased flow of data during those periods (Knape et al. 2021). However, the use of citizen science data has been revered as complimentary to data collected using systematic protocols, especially in distribution and habitat suitability modelling where the provided predictions did not substantially differ (Lin et al. 2015; Henckel et al. 2020). In this case, our analyses depict the previously unknown wider distribution of *C. perspectalis* in Greece in urban and protected habitats, utilizing citizen science occurrence records. Although, a robust quantitative analysis of our dataset is hampered by the evident presence of spatiotemporal biases, the results highlight the impacts of this alien species on indigenous vegetation both in man-made habitats as ornamental bushes, as well as in N2K sites. Future research should focus on the presence of the species in

remote, protected areas where natural box-tree stands occur, supplemented by citizen science data collection schemes, motivating public participation and seasonal monitoring of individuals of all developmental stages.

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Authors' contribution

Research conceptualization: CK, PA; sample design and methodology: CK, KK, JD, EK, PA; investigation and data collection: CK, KK, IS, JD, EK, PA; data analysis and interpretation: CK, KK, JD, PA; ethics approval: CK, KK, IS, JD, EK, PA; funding provision: JD; writing - original draft: CK, KK, JD, EK, PA; writing - review: CK, KK, JD, EK, PA; editing: CK, PA.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Detailed list of *C. perspectalis* records from Greece (2013 to 2020).

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2021/Supplements/BIR_2021_Kazilas_etal_SupplementaryMaterial.xlsx