

THE BOX-TREE MOTH *CYDALIMA PERSPECTALIS* (WALKER, 1859) IN BRITAIN: AN OVERVIEW OF ITS SPREAD AND CURRENT STATUS

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Abstract

The arrival of *Cydalima perspectalis* (Walker, 1859) (Lep.: Crambidae) in the British Isles in 2007 and its subsequent geographical spread to the end of 2018 are documented. Earliest reports might relate to wandering adults from Europe, but the establishment of a breeding population is most likely a consequence of accidental importation of pre-imaginal stages in association with the larval foodplant of Box, primarily *Buxus sempervirens*, which is also a native British tree. Once established the adults are capable of significant dispersal, in both sexes, so that continued range expansion does not depend on further importations. The spread of the species from 2007 to 2018 is illustrated by a series of distribution maps. The moth now affects all of England apart from the far north-west and has established a foothold in both South and North Wales, though much of that Principality is, apparently, unaffected at present. In Scotland, the moth is known from the south-east in Fifeshire, but is likely to spread. The pest status and potential control measures are discussed briefly.

Keywords. Box-tree Moth, *Cydalima perspectalis*, *Buxus sempervirens*, invasive species, introduced species, pest species.

Introduction

The Box-tree Moth *Cydalima perspectalis* is an Eastern Palaearctic moth associated with various species of Box *Buxus*. It has been introduced to Europe as larvae in infected plants and has spread rapidly. It is widely reported in the literature as a pest of domestic *Buxus* and increasingly as a threat to native *Buxus*-dominated ecosystems across Europe (e.g., John & Schumacher, 2013). We show here that the species arrived in Britain during 2007 and for some years spread little, probably depending upon subsequent importations or movements of host plants to reach new areas. However, from about 2013 it appears to have started to expand its geographical range and numerical abundance, particularly in the years 2017 and 2018. We investigate this spread by collating available British Isles records of the moth and analysing these, including comparison with the spread across Europe. The changes in distribution over time of both adult and larval data are presented as a series of maps and discussed.

Data gathering methods

The British and Irish network of County Moth Recorders (CMRs) has been the primary source of fully reliable records of the species and of any negative reports, from each of the Watson-Praeger Vice-counties of Britain and Ireland (Watson, 1852; Praeger, 1901). We have accumulated all records reported to the CMRs to the end of 2018. Perhaps unsurprisingly, the bulk of reports to CMRs are of adult moths, either seen or caught at light traps.

The website of the European Boxwood and Topiary Society (EBTS) provides a facility for users to report occurrences of this species and we have accessed all such data for 2018 (www.ebts.org/bmctracker). A good proportion relate to either larvae, occasionally pupae, or active feeding damage rather than to adults. Similarly, reports submitted to the Royal Horticultural Society (RHS) are dominated by occurrences of early stages. These records that the RHS hold are available via the National Biodiversity Network and are a combination of data from the web survey (www.rhs.org.uk/advice/profile?pid=760), started in autumn 2015 and enquiries received via the Gardening Advice Service. The details of the numbers of submissions are indicated in Table 1.

Table 1. RHS Box-tree moth web survey submissions and enquiries received via the Gardening Advice Service.

Year	2015	2016	2017	2018
Number of reports	383	536	3587	6003

All incoming data were transferred to MS Excel spreadsheets for manual checking and imported to the Map Mate database for analysis and map production. The database is maintained by the Corresponding Author and may be accessed by appointment.

Taxonomic Matters

The Box Tree Moth, alias Box-tree Moth or Box Tree Webber and sometimes shortened to simply the Box Moth, was described by Walker (1859) as *Phakellura perspectalis* from a specimen collected in North China and preserved in the National Collection at the Natural History Museum, London. Other authors have, at various dates, placed this moth in other genera including *Diaphania* Hübner, 1818, *Glyphodes* Guenée, 1854, *Palpita* Hübner, 1808, *Neoglyphodes* Streltzov, 2008 and *Cydalima* Lederer, 1863, with the latter currently accepted as a result of a phylogenetic analysis by Mally & Nuss (2010).

Origins and the spread across Europe

Invasions of Lepidoptera into Britain have been discussed in detail by various authors (e.g., Agassiz, 1996). *Cydalima perspectalis* is considered to be a native



Plate 1. *Cydalima perspectalis* (Walker). Adult moth.

of China (Type Locality = North China) and Korea. It also occurs in Japan and the Russian Far East (Inoue, 1982) where it may be invasive (Mally & Nuss, 2010). Its larvae feed on the leaves and shoots of Box *Buxus* spp. and severe infestations can lead to complete defoliation of plants or even death. Data are sparse on the biology of the species outside its native range, but in Shanghai, China, three and four generations per year have been observed with six to seven larval instars. Larvae pupate on the leaves and the species over-winters in the larval stage. *Cydalima perspectalis* features on the European and Mediterranean Plant Protection Organization (EPPO) Alert List.

The species was found new to Europe in 2006 (Krüger, 2008) in the city of Weil am Rhein and its surroundings, Baden-Württemberg, Germany, although it may have arrived a year earlier (Salisbury *et al.* 2012, EPPO 2008, van der Straten & Muus 2009). Especially interesting is the apparent absence of any documented range expansion westwards from the Eastern Palaearctic home region. Indeed, eastern records seem to post-date the arrival in Western Europe. Thus, it was not noted in the Chechen Republic of Russia (between the Black Sea in the west and the Caspian Sea in the east) until 2012 (Proklov & Karayeva, 2013) nor in nearby Georgia until 2014 (Matsiakh *et al.* 2018) and it was not observed in the Crimea until 2015 (Turys, 2015). The arrival of the species in Western Europe appears, at first glance, to be completely random,

but can be easily explained if the primary agent is artificial importation with the host plant.

As for western Europe, it was reported in Denmark in 2013 (Hobern, 2013) whilst in the south-west, the moth was first reported for France in 2008 (Feldtrauer, 2009), but was not found in Spain until 2014 (Vives Moreno, 2014). During 2007, the same year that provided the first British record, the species appeared in the Netherlands (Muus *et al.*, 2009) and Switzerland (Billen, 2007) whilst in 2008 there were further German records, with examples at Baden-Württemberg and at Niedersachsen and Nordrhein-Westphalen. Both Austria and Lichtenstein appear to have been colonised during 2009 (Slamka, 2010).

In 2010 it was reported from Belgium (Casteels *et al.*, 2011), as well as northern Italy (EPPO, 2011). For Romania (Székely *et al.*, 2011), Hungary (Safián & Horvath, 2011) and Slovenia (Seljak, 2012) it first appeared in 2011, then in Croatia (Koren & Črne, 2012; Matošević, 2013) and Poland (Kudła & Dawidowicz, 2016) during 2012, in Slovakia (Pastoralis *et al.*, 2013), on urban *Buxus* trees in Montenegro (Hrnčić *et al.*, 2017) and Greece (Strachinis *et al.*, 2015) all in 2013. It appeared during 2014 in Serbia (Glavendekić, 2014), then Bosnia/Hercegovina (Ostojić *et al.*, 2015), Bulgaria – at the Varna Botanical Garden on the Black Sea coast (Beshkov *et al.*, 2015) and Macedonia (Načeski *et al.*, 2015) all in 2015. Finally, it was noted on native *Buxus* communities in the Elbasan prefecture of Albania (Raineri *et al.*, 2017) and in the European portion of Turkey, north and west of the Bosphorus (Mavus & Okyar, 2017) in 2017. The position in Albania is of interest. Beshkov & Nahirnić (2019) note that although it was reported as a new there in 2017, more than 80 nights collecting by them and others during 2016-2018, even in localities where *Buxus* is native and abundant, produced only two single specimens.

In the Mediterranean area, the island of Malta provided its first record in 2018 – a confirmed introduction at a garden centre (Agius, 2018). In 2018 it traversed the North Atlantic Ocean, having now been reported and photographed by Karen Yukrich on 25 August in Toronto, Ontario, Canada (Yukich, 2018).

The European spread appears to be directly attributable to multiple importations of infested *Buxus* plants via the nursery trade, initially leaving the eastern part of Europe unaffected. This is supported by the knowledge that many of the primary introduction sites are garden centres or large public gardens to which plants are regularly imported. Nevertheless, this is not always the case and it seems clear that once established at a site, the species appears likely to undergo a period of “consolidation and natural spread”. This process may



Plate 2. *Cydalima perspectalis* (Walker). Window feeding by the larvae.

account, in particular, for a raised proportion of new sites notified during the years 2017 and 2018 and also raises the possibility that in countries where the first detection was of “feral” communities the true date of (artificial) introduction was probably earlier than that stated.

This broad supposition is, perhaps, supported by the British experience.

Arrival and spread in Britain and Ireland

This chronological summary is presented as Maps 2 to 13. The Ordnance Survey’s alphanumeric ten-kilometre grid square references are indicated in the text so that individual records discussed can be related to the maps. The moth was first recorded in the Channel Islands, on Guernsey, in 2014, but as the Channel Islands are, biogeographically, not a part of the British Isles, they are excluded from the following review.

Records from 2007 – 2013

The first record of *C. perspectalis* in Britain is incorrectly given (Mitchell 2009) as being of the adult seen in a garden in Weybridge, Surrey (O.S. ten-kilometre grid square TQ06) on 4 September 2008. Mitchell (2009) also records it for the morning of 5 September 2008 rather than for the conventional previous night of 4 September). However, a single adult was found a year

earlier by R. Bailey in a commercial poly-tunnel at a site in Wye, East Kent on 7 September 2007 (Clancy, 2012). Although this latter record is contained within a review of rarer immigrant moths, there does not seem to be any published evidence of significant immigration activity on that date, nor during the few preceding days.

The 2008 report of an adult from Weybridge is supplemented by observations of larvae and pupae at a nearby commercial nursery on 4 September 2008, also by A. R. Mitchell, with a small number of larvae and several dead pupae being found the following year. Two further examples, both adults, were noted at Icklesham, East Sussex (TQ81) on 23 and 24 September 2008 (K. Thornton & P. Jones, det. M. Parsons); these are recorded in an editorial note following the report by Mitchell (2009), but were incorrectly attributed to Mitchell himself by Clancy (2010).

One moth was noted the following year in South Essex, at Leigh-on-Sea (TQ88), on 18 September 2009 by G. Bailey (Clancy, 2010. *op. cit.*) and is the same as that given by Bailey (2010) and Langmaid & Young (2010). In the same year there was another at Biddenden, East Kent (TQ83) on 21 September, S. J. Broyd (Langmaid & Young, 2010) and repeat larval records from the Weybridge nursery site (Salisbury *et al.*, 2012).

During 2010 the species was added to the Hertfordshire list at Bishops Stortford (TL42), with a male at mv light in a garden in the north of the town on 8 August (Fish & Reeves, 2011). There are subsequent reports, of both adults and larvae noted on 1 April 2010 at Barnes, Surrey (London, TQ27) (RHS database), of larval feeding damage noted on 24 May 2010 near Brentford, Middlesex, (TQ17) and of an adult at Potters Bar, Middlesex (TL20), on 20 September (Salisbury *et al.*, 2012). These same authors also report an adult at light in Densole, East Kent (TR24) on 13 July and perhaps more interestingly, one adult at a light trap in Bristol (ST67) on 8 October. This, and the adult at Bishops Stortford eight weeks earlier, might reflect the start of a "natural" spread of adults from the primary areas of introduction, although artificial introduction to the area cannot be completely ruled out.

Thus, by the end of 2010 there are just 10 British records known, affecting only nine discrete sites in the south-east of England plus the single example in Bristol.

This relatively slow spread continued during 2011 with larvae and pupae found at Stoke Poges, Buckinghamshire (SU98) in May – the first record of the larval stage in a private garden in Britain (Salisbury *et al.*, 2012). There were reports of larvae near Gilstone Park, Hertfordshire (TL41) on 24 May, adults at Buckhurst Hill, South Essex (TQ49) between 20 July and 4 October over two generations, adults at Woodford Green, Essex, (TQ49), with 17 being recorded over a range of dates from 22 June to 1 July by Robin Barfoot, larvae

Table 2: Numbers of records and numbers of affected sites (10Km grid squares) from 2007 to 2018.

Year	Number of records	Number of sites	Cumulative number of sites
2007	1	1	1
2008	2	2	3
2009	2	2	5
2010	5	7	12
2011	6	5	17
2012	9	8	20
2013	19	15	33
2014	85	16	42
2015	113	24	54
2016	978	51	288
2017	5447	166	342
2018	9175	260	348

at Ottershaw, Surrey (TQ06) in September and finally a single adult at Barnehurst, Kent (TQ57) on 22 September in an mv light trap operated by Tony Steele.

Apart from being noted again at Woodford, South Essex between 10 July and 7 August, the moth appeared in 2012 near Fernhurst, West Sussex (SU92), where young larvae were found in October and rather more interestingly, at Tilehouse Green, Warwickshire (SP17) on 26 July, where an adult was caught in an mv light trap operated by S. Hackett and at Kenilworth, Warwickshire (SP27), also in July.

During 2013, adults were again found in parts of Essex, but there were also reports from Bonchurch, Isle of Wight on 27 July and Prestbury Road, Cheltenham, Gloucestershire on 6 August (both melanic examples – the first documented examples of the melanic form in Britain). Adults were also found in the south at Hayling Island and at Chandlers Ford, Hampshire, where a large infestation was found at a nursery. The moth also travelled significantly northwards and was noted in 2013 at a wholesale plant importer in Newcastle, Co. Durham. The strength of the resident population in the London area was consolidated with a report of over a hundred larvae and several pupae found on newly planted Box at Islington, Middlesex during the year. In the south-east there are reports for this year from Luton, in Bedfordshire and in the East Anglian region at Grantham, Lincolnshire and New Costessey, Norfolk; at this latter site, adults were trapped in an mv light trap on 3, 9, 20 and 22 October at a site adjacent to a garden centre.

Records from 2014 to 2018

In both 2014 and 2015, in addition to the broader “London Area” (which includes all of Middlesex, with parts of West Kent, Surrey, South Essex and Hertfordshire), there were records from Dorset, Sussex, Buckinghamshire, Gloucestershire, Norfolk, Lincolnshire and Yorkshire (a melanic), along with single examples on the Lizard (a melanic) and at Falmouth, Cornwall. In 2015 & 2016, public awareness increased significantly following national press, radio & TV coverage. In addition, the RHS, having received an increase in queries, added a web survey form for the public to fill in. During 2016 and 2017, the species continued to consolidate its base in the London area. For example, over 800 were recorded in a light-trap on one night in Putney. At the same time, the species seems to have undertaken a significant range expansion gaining more of a foothold in Essex, with increased numbers seen at some sites and with reports as far distant as Somerset, Dorset, Hampshire, Isle of Wight, Sussex, Kent, Hertfordshire, Suffolk, Norfolk, Berkshire, Buckinghamshire, Gloucestershire, Huntingdonshire, Northamptonshire, Northumberland and Monmouthshire. Whilst a proportion of these can be related directly or indirectly to the nursery trade, others cannot. This sudden and dramatic spread (Maps 11 & 12), might indicate a “natural” range expansion whilst it has been noted by some that, with an increasing number of coastal records being reported some, at least, might indicate primary immigration from the Continent (Mark Parsons, personal communication).

During 2018, a drastic increase in numbers of adults was noticed by many casual observers - especially those operating light traps. Interestingly, this may have imparted upon researchers a false impression of a significant range expansion. However, careful analysis of Table 2 and a comparison of Maps 12 & 13 reveals that there was, in reality, almost no range expansion from 2017 to 2018. Beyond the secondary effect of emphasising the absolute need to accumulate adequate and accurate scientific data before attempting any analysis, the significance of this reduction in site recruitment is unclear.

Arrival in Wales

In the north, single adults were noted at light traps in Caernarvonshire at the two widely separate locations of Pwllheli and Llandudno during July 2015 and represent the first Welsh records. In the autumn of the same year, larvae were discovered at Ruthin (SJ16) on 15 September and Wrexham (SJ35) on 11 October.

In the south of the Principality, the first arrival seems to be an adult at Cwmafan, Glamorgan (SS89) on 5 August 2016 (Mark Hipkin). A single record for 2017 is available of an adult in a light trap at Caerleon, Monmouthshire on

7 October (Dave Brooks). It is unclear if Box grows within the areas affected by these adult moth sightings and so it is equally unclear if the moths had migrated here from some distance or if they represent an undiscovered introduction site nearby. In 2018 there was a small influx in Monmouthshire (adults), Glamorgan (adults and larvae in Cardiff), Breconshire (adults) and Carmarthenshire (adults). Thus the bulk of Welsh records relate to adult moths with, apparently, just three breeding localities – in Ruthin, Wrexham and Cardiff. At the start of 2019, much of Wales apparently remains Box-moth free!

Arrival in Scotland

The species is currently scarce in Scotland, with a presence provided by just two observations of adult moths, both during July 2018 – at Dalgety Bay (NT18) on 23 July (Alistair Shuttleworth) and Newburgh (NO21) on 27 July

(Julie Goring), both in Fifeshire. There is no particular reason why a northwards spread would not continue, although Highland areas might be unreachable; climate modelling by Nacambo *et al.* (2014) has shown that the moth has the potential to threaten all *Buxus* spp. stands in the Western Palaearctic region *except* those in Northern Fennoscandavia, Northern Scotland and high mountain regions. Box is certainly present in some Scottish National Trust properties. Map 1 shows the distribution of planting status during 2016, based on a survey by the RHS and the University of Bristol of 1397 home gardeners. In the map there is a bias towards responses coming from the



Map 1. The distribution of Box plantings, based on a survey of 1397 home gardeners, divided into Box growers (black points) and non-growers (grey open circles).

south-east; some of this is to be expected given the distribution of UK residents (4.7% of the responses from the survey came from Scotland, but based on the 2011 Census data 8.4% of UK residents live in Scotland).

Arrival in Ireland

An adult male, of the melanic brown form, was recorded in the south-east at Tramore, Co. Waterford, on 24 July 2017 and was new to Ireland (Bryant, 2017). This was followed the next year by one in the north at Newtown, Co. Down, on 13 July 2018. Subsequently, larval populations were discovered at Bangor Co. Down on 10 September, in Belfast, Co Antrim, on 20 September and finally at Williamstown, Dublin on 22 September 2018. Thus, at the end of 2018, the moth is known only from the eastern seaboard at five discrete localities.

Reliability of data set

The accuracy of identification in the data set is likely to be near 100%. The bulk of records of adults have been filtered through the County Moth Recorders and are judged fully reliable. Although some misidentification of early stages is possible, there are rather few other lepidopterous species that feed on Box and experienced Box growers are largely familiar with signs of diseases and similar that might mimic the effects of unseen moth larvae.

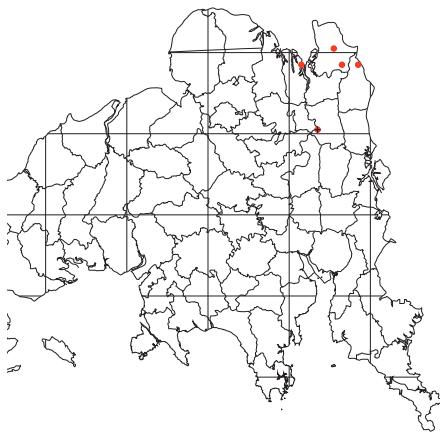
On the other hand, an analysis of the data presented in Table 2 suggests that sites are not always “repeat reported” following an initial report. This affects the actual numbers of reported sites in any given year. For this reason, the distribution maps (Maps 2 – 13), are cumulative. That is, they assume that there is no loss of any population once established.

Summary of distribution and status in the British Isles at the end of 2018

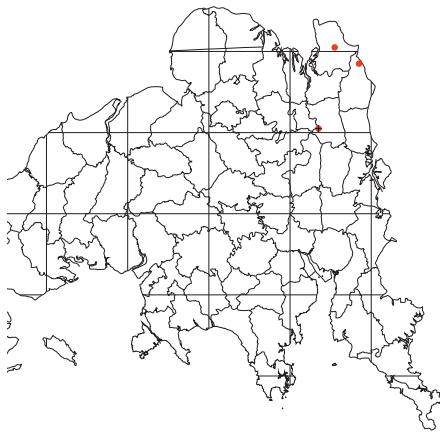
The distribution of the species at the end of 2018 is indicated in Map 13. Records of adults (red spots) and those of early stages (black +) are indicated separately. The map suggests a status of “Common Resident” for the species. Almost the entirety of England is now affected, apart from the north-west, with the species clearly poised to extend further into Wales and Scotland. The preponderance of records in the south-east, generally, and the London area specifically is clear from the map.

Adult Flight Period

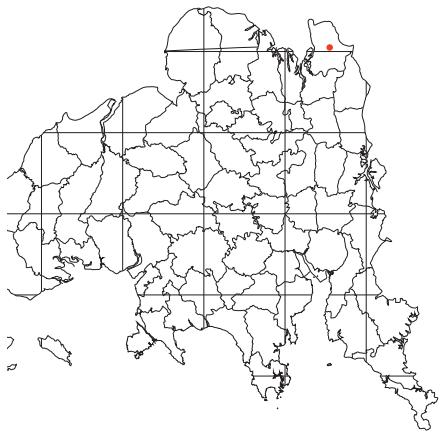
The adult flight period in Britain is represented graphically in Fig. 1. Regrettably, although we have a large dataset of 6902 adult records, almost all reports fail to provide numerical data and are, by default, treated by the database as single examples. Just occasionally, hugely larger than normal numbers of



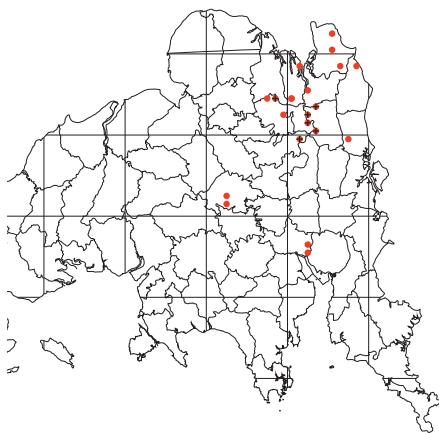
Map 2. 2007 records.



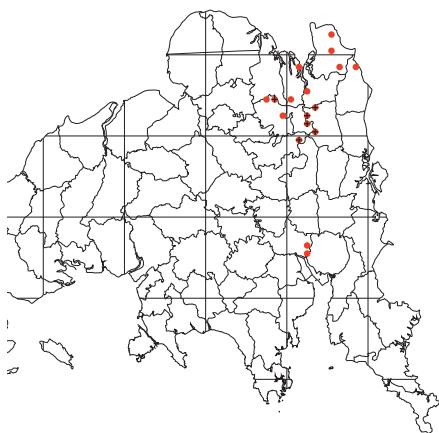
Map 3. Cumulative to end 2008.



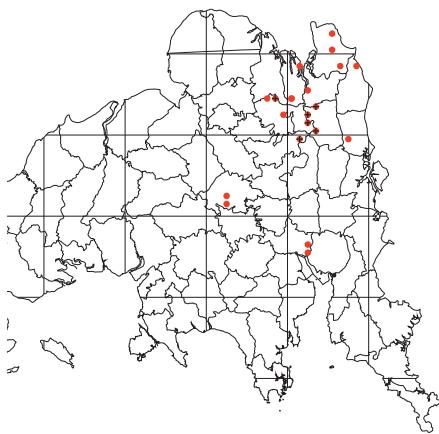
Map 4. Cumulative to end 2009.



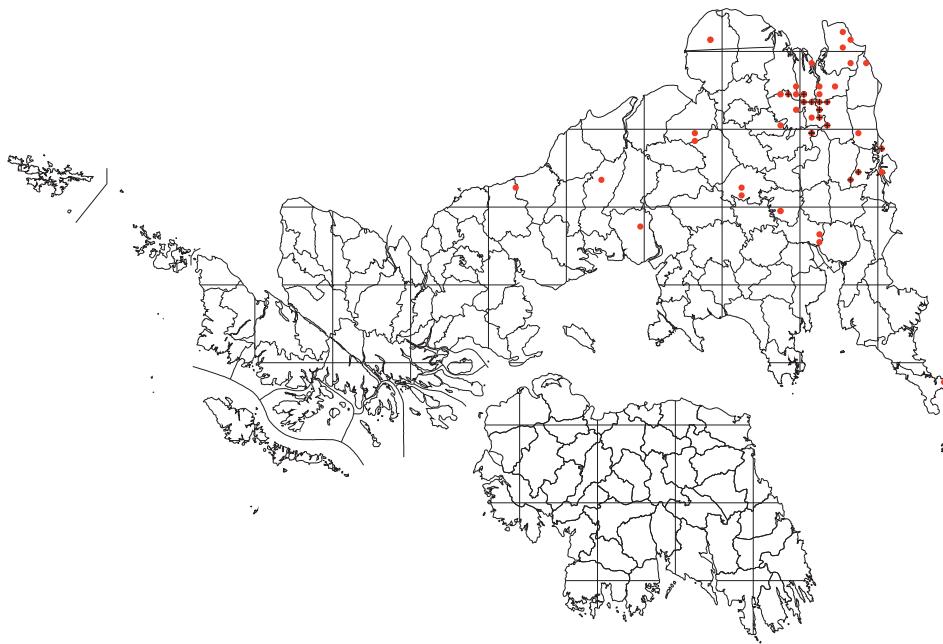
Map 5. Cumulative to end 2010.



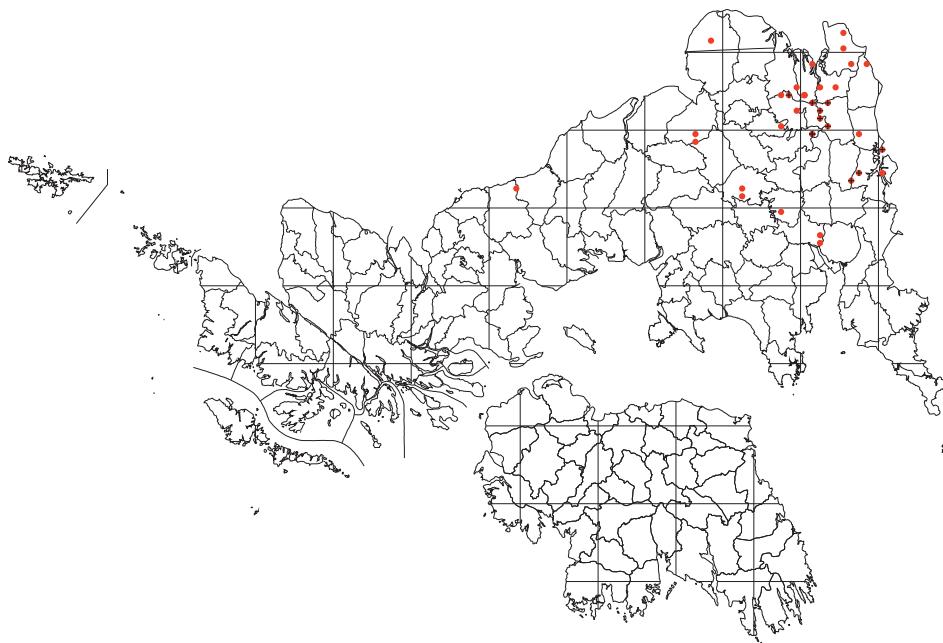
Map 6. Cumulative to end 2011.



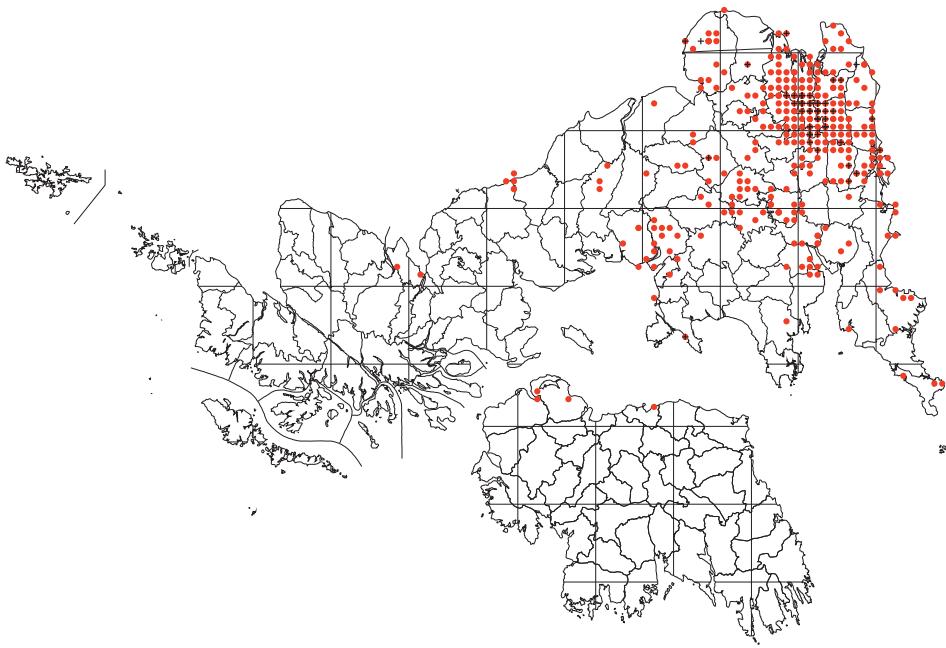
Map 7. Cumulative to end 2012.



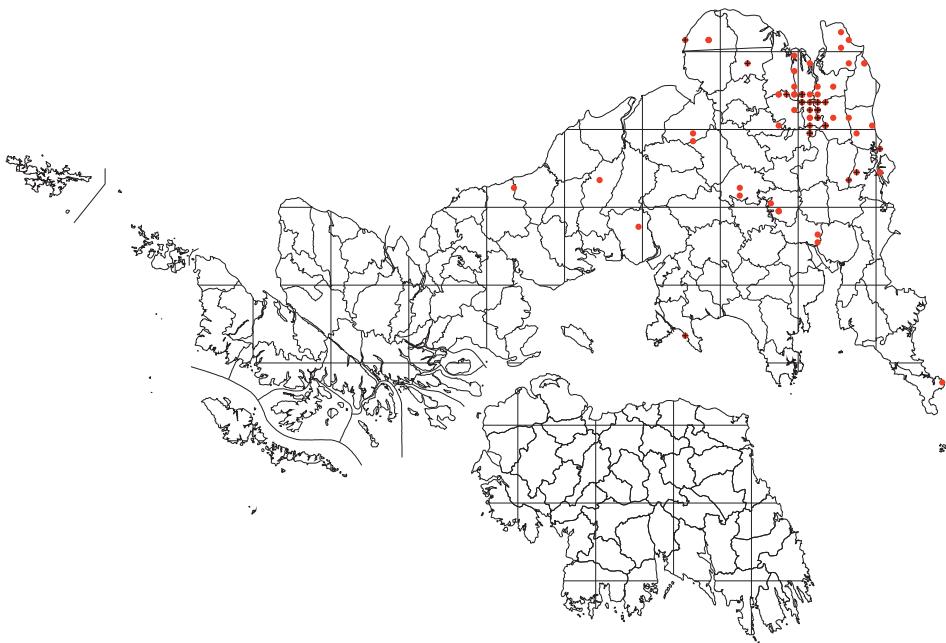
Map 9. Cumulative to end 2014.



Map 8. Cumulative to end 2013.

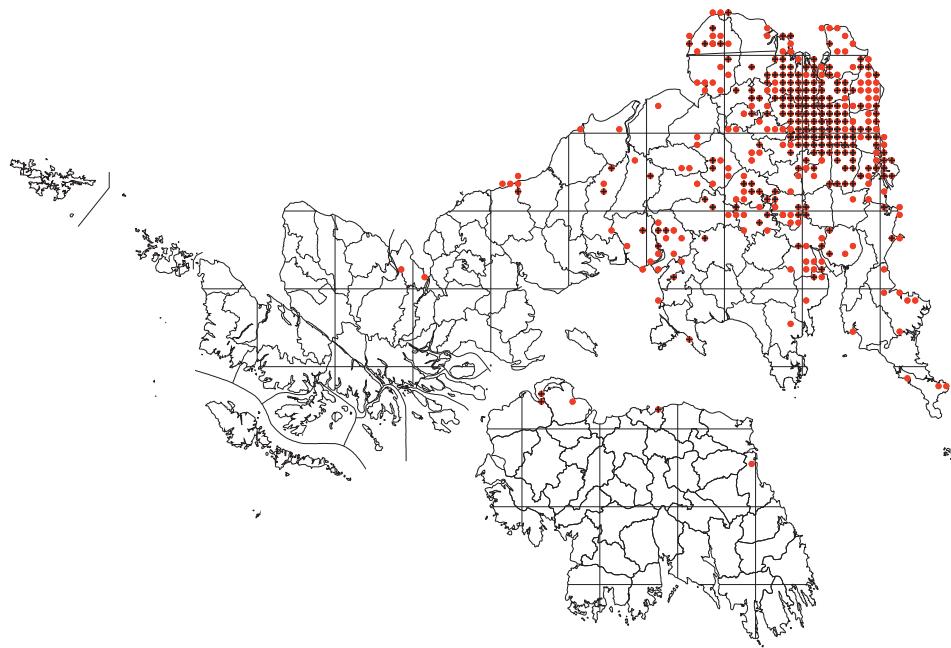


Map 11. Cumulative to end 2016.

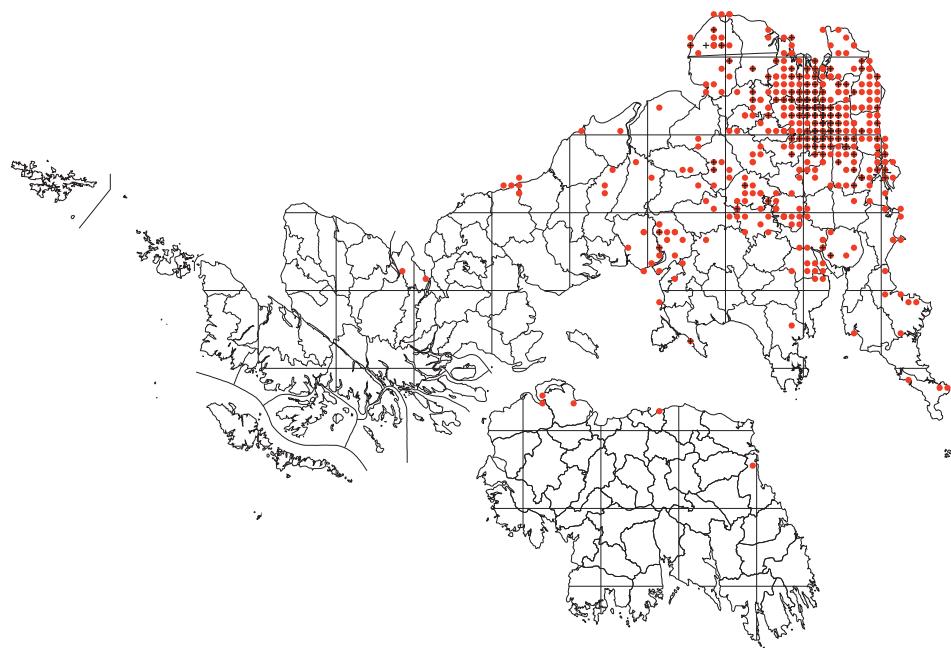


Map 10. Cumulative to end 2015.

Map 13. Cumulative to end 2018.



Map 12. Cumulative to end 2017.



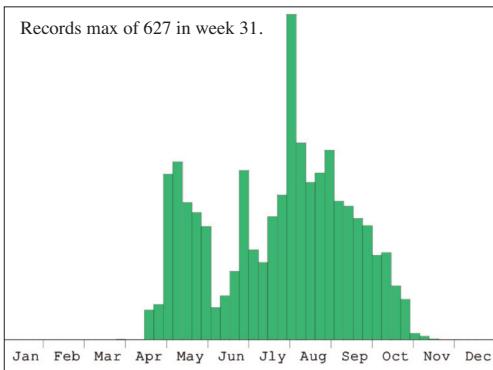


Fig. 1. Flight period by Standard Week (see, e.g., Plant, 1994) of records of adult *Cydalima perspectalis* in Britain, 2007 – 2018 inclusive ($n = 6902$).

July to early September, climaxing at the start of August. The timing of these peaks may vary with latitude, but the chart shows that the moth is on the wing continuously, somewhere in Britain, from May to October inclusive, with multiple overlapping generations.

It must be noted that the clarity of some reports to the web sites is not always of the highest standard and in some cases it may be that adults have been reported when larval feeding signs were actually seen. Beyond editing obvious errors, it is impossible to identify these records and thus impractical to follow them up for any sort of clarification. Consequently, we have taken them at face value and the reader should view the flight chart with this in mind. Nevertheless, it is known from personal observations that overwintering caterpillars resume feeding in the spring and their subsequent rate of development is likely influenced by the microclimate within the Box plant host. One of us (SB) is maintaining a captive population at RHS Wisley and has observed adults present from April until October, whilst CWP has observed "wild" adults on the wing in late October and early November in both Britain and Europe.

How does it spread

It is not known for sure how *C. perspectalis* reached the UK. The first few reports all relate to adults and it is clear that the adult moth is quite a strong flyer. In Bulgaria where there is no native *Buxus*, *C. perspectalis* is a pest only in towns and villages, but it is collected also at light in various primary habitat regions, far away from human settlements and its host plant (Beshkov *et al.*, 2015). Elsewhere, one of us (CWP) witnessed a single adult male *C. perspectalis* at the top end of an Alpine valley in the Savoie Département of south-east France, within sight of Mont Blanc, on 15 August 2017. There is no

adults are reported; to plot such numbers would distort the graph artificially. Furthermore, plotting logarithmic values does not correct these anomalies visually. Consequently, we have plotted here the number of records against date and the shown values are independent of individual moth numbers.

There is a peak of adults in flight during May and a much larger emergence from late

Buxus for several kilometres; the moth was evidently swept up the valley at the head of what transpired to be a very short, but violent, thunderstorm. This may provide additional support for the notion that the moth is capable of dispersal. The first British reports may well originate from such dispersal, from established sites on the European Continent.

That said, the fact that the first few reports are of adults is an expected phenomenon, because there are people regularly looking for moths; we are not aware of an equivalent group watching, at the wider landscape level, for caterpillars on Box plants! Certainly, reports of breeding followed rapidly after the first sightings of adults – though the two events are not always linked at any given site. The first breeding reports emanate from primary importation of larvae on infected Box plants from overseas and it seems possible, if not probable, that this event occurred in parallel with “natural” range expansion from Europe.

This would fit the trend observed in Continental Europe where initial introduction has been proven to be, or is shown most likely to have taken place *via* plant importations. For example, Beshkov *et al.* (2015) report the first Bulgarian presence at the Varna Botanical Garden on the Black Sea coast. Matošević (2013) records the species new for the Croatian fauna at an arboretum. Strachinis *et al.* (2015) discuss the spread of the species in Greece and note that it has either actively dispersed from neighbour countries (e.g. Turkey) or been passively introduced *via* one or more relatively recent commercial importations of plants of *Buxus* sp. infested with the moth’s eggs or larvae. The introduction of *C. perspectalis* in Sochi, Russia is attributed to infected plants bought from Italy during the building of the Winter Olympic village in 2012 which then spread to surrounding areas and also natural boxwood stands (Gninenko, 2014). On the other hand, in Albania the arrival was observed at native *Buxus* communities (Raineri *et al.*, 2017). Here, as well as in the adjacent countries of both Montenegro and the Former Yugoslav Republic of Macedonia, *Buxus* is an essential component of several unique forest ecosystems (Šilič, 1983; Nacambo *et al.*, 2013).

It has been assumed that *C. perspectalis* is capable of spreading across Europe via natural dispersal of adults and aided introduction of larvae (e.g., Kappeli, 2008; Kruger, 2008; Feldtrauer *et al.*, 2009; Muus *et al.*, 2009; Sigg, 2009). In addition to commercial importation of plants the moth could, equally, survive a car or lorry journey as stowaway fertilised females.

One of the major stimulations of dispersal within highly mobile species such as moths is intense over-population of the natal area. One of us (CWP) witnessed over 10,000 freshly emerged adults flying around a single 125 watt mv bulb and settling on the vegetation “like snowflakes” at a site in Macedonia during July 2018; it is probable that these adults subsequently dispersed over a

far wider area. Little has been established concerning the natural enemies of *C. perspectalis* outside its native range and it may be that populations are currently able to increase dramatically, in part due to such a release/escape from natural control mechanisms. This would allow range expansion by the free-flying adults from breeding areas that were, initially, established by trade and then supplemented by movement of infested plants.

It therefore seems likely that whilst Britain may have hosted immigrant examples of the moth, and may continue to do so, these early colonists may have failed to thrive and that the moth did not become established until early stages (eggs, larvae and pupae) arrived on imported plants. Maps 2 – 13 suggest that there are likely to have been multiple introductions for the first few years, from 2007 to 2012. Further importations and internal movements of plants are likely to account for the spread of new records depicted in the 2013 to 2016 maps.

Is it really a pest?

There is widespread acceptance that *Cydalima perspectalis* is a “pest”, although in considering this, and any potential control measures, we start here from a deliberately neutral position, in order to evaluate the evidence that is currently available for Britain.

The species featured on the Alert List of the European and Mediterranean Plant Protection Organization (EPPO) from 2008 to 2011 and it is treated as a serious pest in *Buxus* forests in Europe and the Caucasus by Mitchell *et al.* (2018), although few supporting data are presented. Matziakh *et al.* (2018) regard it a serious pest of native *Buxus colchica* forests in Georgia, recording lethal damage by the larvae both there and in Southern Russia. Evidence from the Grenzach-Whylen Nature Reserve in Germany, which contains that country’s largest Box forest, showed that during 2009 and 2010 the caterpillars attacked all the Box trees present, causing more than 90% defoliation, with 27% of trees losing all their leaves. Although the moth population then decreased, having eaten most of its food source, by 2012 the trees that had been fully defoliated died as their bark had also been eaten. Observations showed that the eco-system in the forest was beginning to change with new ground cover taking the place of *B. sempervirens*. Since Box trees have a slow rate of growth, it is predictable that co-occurring tree species that have faster growth rates would replace the Box and alter permanently the character of the woodland ecosystem. Any Box that remains would likely now only persist in smaller clumps.

In the Jura Mountains, Denny (2018) notes that the change in light conditions at ground level due to the defoliation/death of the *Buxus* ground cover meant they observed no *Cyclamen* plants in infested areas visited. This is likely to

have repercussions for associated organisms and *Cyclamen* may not be the only vegetation adversely affected.

There is no doubt that this species is capable of total defoliation of Box plants; in this context it clearly is also a pest of ornamental plants. The significance of Box as a component of British heritage should not be overlooked; it is used in traditional topiary, or parterres, which are key features of historic gardens. Losses from this sector may well be judged as disastrous though techniques for managing the arrival of *C. perspectalis* have been shown to work in parks and gardens where they have been adopted as part of regular horticultural practices. In the shorter term, aesthetic damage to historic topiary may hold the high ground.

Natural Box communities are scarce in Britain, with few large closed canopy Box woodlands remaining, such as at Ellesborough Warren, Boxwell, Box Hill and Shirburn Hill. All are designated Sites of Special Scientific Interest and form critically important ecological habitats. It is vital for the ecological management of these areas that a good working knowledge of any longer term damaging effects of the moth are both known and understood. There is an increasing concern for the commercial value of the wood crop, as infested wood deteriorates due to the drying out effect caused by the attack. Owners who understand the value of their timber and are reluctant to see their assets deteriorate and become useable only as firewood, are using selective felling, prior to being affected by *C. perspectalis*, to avoid the total loss of their assets. However, for owners that do not manage their Box the value is unknown, and this Box timber is therefore likely to be lost, as happened in France and Germany 2015-16. In the UK around 30 people gain their living working predominantly with box timber. Historically much was imported from France and Spain, but English Box is exported to many countries worldwide for a variety of uses including musical instruments such as recorders, clarinets, oboes etc. (Crompton personal communication with C. Poole).

Most British and European entomologists will be aware that moths such as the Green Oak Tortrix *Tortrix viridana* L. are capable of the *total* defoliation of oak trees, though rarely more than a handful of trees in a relatively small area are defoliated and the wider biotope is unaffected. Attacked trees develop new leaves – usually in the same summer but if not, then the next year. The long term effects of this defoliation appear to be negligible.

T. viridana is, of course, a native species that affects a native tree host. A potentially more useful comparison might be with the non-native Horse Chestnut leaf-miner *Cameraria ohridella* Deschka & Dimić, whose invasion of Western Europe, including Britain, parallels in many respects that of *C. perspectalis*. It is, now, normal to see late summer Horse Chestnut trees with

every leaflet affected by double figures of leaf mines, such that the entire foliage becomes brown and the trees unsightly. Small areas of green remaining at leaf tips become physically isolated from the tree's "sap movement system" and photosynthesis ceases. To all intent and purpose, the tree appears dead. Not only that, but every single Horse Chestnut tree, at least in the south-east, is affected. Yet, the next year they spring back to life as normal. Horse Chestnut trees are larger and evidently more resilient to damage whilst still being able to gain sufficient resources during the period that their leaves are functional, although whilst they produce the same quantity of seeds, these are of a lower quality (Thalmann, *et al.*, 2003).

A major difference, however, between *Cameraria* and *Cydalima* is that *Cameraria* is unable to feed in any way other than as an internal leaf miner. Although very slow growing, Box should recover from a single defoliation but in London and many surrounding areas *C. perspectalis* is now a problem that is likely to reoccur each year. Significant defoliation, repeatedly, across a growing season, or over several years, is likely to weaken plants and lead to plant death. Both Nacambo *et al.* (2014) and Strachinis (2015) suggest that in areas that are climatically suitable for the support of at least two generations of moths per year, heavy infestations inevitably lead to bark consumption by the larvae which results in girdling of affected sections. Box, in both horticultural and natural environments, is also facing disease pressure from the fungus *Cylindrocladium buxicola*.

Overall, we cannot escape reaching the conclusion that *C. perspectalis* must to be regarded as a pest species. At present, the damage caused is predominantly confined to parks, gardens and stately homes. However, larva were found on native Box at Box Hill, Surrey, during September 2018 (I. Cavadino). The threat to native Box woodlands is regarded as being severe and we strongly recommend that control measures are considered, so that as native trees inevitably become affected a policy is already in place to address the problem in a manner that is both appropriate and effective.

Control measures

The "do nothing" scenario is highly unlikely to be sufficient. Plant trade is international and millions of Box trees are traded across the Western Palaearctic, including imports from China so waiting for the moth to "eat itself to extinction" would not succeed (and in the meantime both natural Box woodland and much historically valuable topiary would be lost).

Control measures in East Asia comprise a combination of biological control by nematodes (Choo *et al.*, 1991; Lee *et al.*, 1996), mating disruption (Kawazu *et al.*, 2007) and pesticidal control (Zhou *et al.*, 2005). Natural enemies include

various non host-specific parasitoids (Nacambo *et al.*, 2014) and birds (Strachinis *et al.*, 2015). Birds, however, are probably only of minor value, because of the high level of toxic alkaloids sequestered by the larvae (Leuthardt & Baur, 2013). However, tests in France where bird boxes were placed in an infested area, showed that birds are now beginning to learn to eat the caterpillars and that the toxicity has in the short-term no effect on their young (Martin *et al.*, 2018).

The automatic response of many gardeners would likely be to reach for some form of insecticidal spray. However, an increasing number of anecdotal reports challenge the efficacy of this method and the overall conclusion is tending towards the likelihood that it may eliminate more beneficial insects than target caterpillars. This may be especially true where systemic insecticides are selected; a greater level of success might be had with some contact insecticides provided that they are properly applied, but this is likely to be an impractical approach in areas of natural Box woodland. Ideally, selected pesticides should be non-persistent in the environment.

Within parks and gardens, the use of pesticides should, similarly, be undertaken with extreme care. A formal advice note may be found at <http://hertsmiddx-butterflies.org.uk/bc-box-moth-advice-note-july-2017.pdf>. This notes that where bushes are small, the removal of the larvae by hand is encouraged, although it is realised that this approach is unlikely to be appropriate where large, older topiary bushes are involved. From the personal experience of one of us (C. Poole) however, this is unlikely to be practical for gardeners and is not effective enough to warrant the time and effort. During 2018, it took four hours every week to pick out caterpillars on just under 40m of hedging at Ham House, Surrey (in Spring 2019 a significant number of caterpillars were found on the hedges that had been missed using this manual control method allowing them to overwinter and resume eating in the spring). High pressure spraying with water to remove larvae is also regarded as ill-advised, because the need to allow the water jet to penetrate to the inner branches causes damage to the plants and, perhaps of greater significance, creates localised conditions that encourage the increase of the fungus *Cylindrocladium buxicola*, which can lead to death of Box plants.

As a last resort spraying, using a pesticide, may well be considered, although neonicotinoids should be avoided. None of the pesticides available will be specific to *C. perspectalis* and will kill other non-target invertebrates. Therefore, if considered the only option, these should be applied with extreme care. Still weather conditions should be selected, with just the target plant sprayed, avoiding any spray falling to the ground or any spray drift to neighbouring plants (including grasses). Plants in flower should not be sprayed as this will

be harmful to pollinating insects. Where there has been an infestation, vigilance is likely to be required as re-infestation is highly probable. New plantings of Box should be carefully considered when designing a garden and maintenance should include monitoring (pheromone traps) and an action plan to deal with infestations.

In the majority of cases the pruning of affected plants is unlikely to be an effective control option. Often box plants are already carefully pruned to their desired shape and the caterpillars frequently reside within the interior of the canopy meaning they would not be removed this way.

Toxins extracted from a number of subspecies of the bacterium *Bacillus thuringensis* (Bt) ssp. *kurstaki* have been used for many years to control Lepidoptera caterpillar problems on vegetables, soft fruit, ornamentals and amenity vegetation. Although not a registered for use by UK home gardeners, it is registered for professional use with appropriate spraying qualifications. Bt is used in many countries and is considered the most effective control method at present as demonstrated by its use at Manoir D'Erygnac (Chabane, 2018) and Marqueyssac (Lemoussu, 2018) gardens where *Buxus* forms one of the key plants of the garden planting scheme. The same treatment forms one of three licenced control methods (*vide* Forest Research, OPM Manual) for the Oak Processionary Moth *Thaumetopoea processionea* L. (OPM). We do not have easy access to any monitoring data that might exist, but the reality is that Bt treatment was used, at least in England, to reduce populations of OPM caterpillars before they formed nests; it was never expected to eliminate the moth and certainly it has not done so. Kenis (2018, Informal presentation to the Scientific Symposium on Boxwood Pests, in Tours, France during October 2018) reported that aerial spraying with Bt was not successful in controlling infestations as coverage levels were not high enough, due to physical obstructions or lack of access for vehicle mounted spraying.

In any event, British legislation dictates that at present it can only be applied by suitably qualified personnel, thus making it too expensive for gardens with small amounts of Box. In parks and gardens with significant amounts of Box, such as Ham House (Surrey) and Regent's Park (London), treatment with Bt based sprays (applied with high pressure atomising sprays or knapsack sprayers) is giving very effective control when applied at the right time. Where spraying at the wrong point in the *C. perspectalis* life cycle, such as Chiswick House and Gardens, West London (DECIS, a broad spectrum pyrethroid insecticide was used in 2018), significant damage was inflicted on the plant stock and established trees (C. Poole, 2018 & 2019 personal observation and communication with King). However, treatment with Bt does not on its own prevent re-colonisation of treated areas.

An egg parasitoid (*Trichogramma* sp.), is available for home release in parts of France. However, Boutte & Baubet (2018. Informal report to the Scientific Symposium on Boxwood Pests, in Tours, France during October 2018) reported that drone drops of *Trichogramma* were not successful in controlling infestations due to lack of controlled coverage and/or access.

Pheromone traps are commercially available and are evidently increasingly popular. However, they are unlikely to give overall control as only male *C. perspectalis* will be attracted. Gravid females will ignore the traps and continue egg-laying. It is likely that *C. perspectalis* follows the expected pattern of lepidopteran males emerging before the females so that they are available to mate immediately after the latter emerge from the pupal state. In confined areas, large numbers of pheromone traps might reduce the number of males available before female emergence (within the same brood), but if only one or two remain available for mating then re-infestation of the Box tree will be inevitable. Van der Straten & Muus (2010) undertook extensive field trials of pheromones and, indeed, concluded that these did not give satisfactory control.

One further aspect may offer potential for effective control. Insects select their oviposition sites using visual, physical and chemical cues. Molnár *et al.* (2017) investigated volatile chemicals associated with the excreted larval frass pellets of *C. perspectalis*. These chemicals were then synthesised and offered as a “cocktail” by means of specially constructed dispensers attached to Box trees. They discovered that female moths laid significantly fewer eggs on Box plants equipped with the dispensers, compared to those treated with natural frass or with untreated control plants.

With the spread of *C. perspectalis* causing significant damage to untreated horticultural Box, the use of other plants as alternatives is being actively promoted by garden centres, designers and writers (O'Brien P. 2018, Mitchell, A. 2018, Griffiths S. 2018). At the RHS Wisley, Surrey, Matthew Pottage (Curator) has created a parterre with ‘alternatives’ to Box. This demonstrates the options available, however none of the plants have the same set of properties and characteristics that Box possesses, the ability of its foliage to form crisp lines, dense even coverage, evergreen colour and in a range of scales. The ‘alternatives’ also have their own issues with pests and diseases.

Conclusions

Since the first record of *C. perspectalis* to the British Isles in 2007 this moth has successfully become established. By the end of 2016 it was a significant defoliator of Box plants throughout much of South East England. It is now a “Common Resident” widely distributed across England and present in Wales, Scotland, Northern Ireland and Ireland, with the potential to consolidate and

expand its range further. *C. perspectalis* is the greatest insect threat faced by Box-growers and by native Box communities in the UK and it is now a problem that is likely to reoccur repeatedly throughout a growing season and in successive years. Control measures mentioned by us, as well as any others that are not discussed, should be considered carefully and in great detail, to facilitate a control protocol that is both effective and which avoids harm to non-target organisms and the wider environment.

Continued monitoring of the moth into the future is considered essential at both the amateur and professional level. Those involved as amateur lepidopterists are encouraged to ensure that appropriate County Moth Recorders continue to be notified of all records at the end of each year, whilst horticulturalists and others are encouraged to visit the EBTS website www.ebts.org/bmctracker which continues to provide a facility for reporting infestations.

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