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Silverfish (Zygentoma) in Austrian Museums before and during COVID-19 lockdown

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ABSTRACT

The lockdowns that came with policies to reduce the spread of COVID-19 in 2020 required some 90% of museums and historic properties across the globe to be closed. Lowered visitor numbers and reduced staffing levels allowed a range of fauna to make their way indoors, bringing an increase in birds, rodents and insect pests. Silverfish are shy, so benefit from low occupancy in museums and present a potential vector for damage to books and paper. This study is the first to report changes in insect populations in museums and examines six years (2015–2020) trapping data for silverfish and similar insects (Lepismatidae): Lepisma saccharinum, Ctenolepisma calvum, Ctenolepisma longicaudatum and Ctenolepisma lineatum from: (i) the Technisches Museum Wien, (ii) Schönbrunn Palace, (iii) Hofburg Museum and a shorter record from (iv) Weltmuseum Wien. Analysis of the trap contents gives an impression that the number of insects caught had increased over time, but 2020 was distinctive and gave typically higher insect numbers during the COVID-19 lockdown compared to other years, especially for Lepisma saccharinum. Individual traps caught up to 100 silverfish in only a few weeks. Because silverfish usually need between four months to one year to become mature, we assume that it was increased activity during museum closure and not higher reproduction which led to higher numbers. The parts of the museums showing increased populations under lockdown were similar to the areas where they were more frequent in earlier years. This means that such areas deserve continued monitoring even when the museum is closed. No damage to paper objects were reported in the museums investigated.

1. Introduction

Silverfish often thrive in quiet unoccupied spaces. It was to be expected during the COVID-19 shutdown of museums, that insects and indeed other pests would thrive. This is problematic because insects are harmful to museum objects, damaging organic material such as wood, wool, paper, dry plant (herbaria), dry insects and zoological specimens. Additionally, because museums were closed it meant that cleaning, conservation and maintenance staffing levels were much reduced, so that damage could occur unobserved (Pryor, 2020).

COVID-19 was first reported in Wuhan late in 2019. Gradually it became clear that the disease was readily transmitted and potentially deadly. By early 2020 it was found to have spread globally and being a new disease there was little immunity. There were no effective treatments and the only techniques available were time-honoured isolation and quarantine (Brimblecombe, 2020). This became known as social distancing and was paralleled with people isolating in their homes and travel was much reduced. Many public venues remained closed as people worked from home or were furloughed. Understandably museums were part of these closures so in line with a reduction in international tourism, museum visitors declined dramatically. Thus, in addition to problems arising through the lack of care and maintenance was a loss of revenue (NEMO, 2020). An analysis by UNESCO (2020) suggests that 90% of museums were shut, in Austria: 11 March 2020 until 15 May 2020. Historic houses were also closed, so in general the heritage sector saw much lower visitor numbers and staffing levels were greatly reduced. While some locations used this for extra maintenance, renovation and site investigations (Forrest, 2020), others enhanced their on-line activity (Agostino et al., 2020).

There were a few early indications that this period of low human
activity was not always matched in the plant and animal kingdoms. Wild-flowers invaded the unmaintained roadside, while animals began to move from the countryside into human and urban environments that they had previously not found amenable (Brimblecombe, 2020). This was also true in the heritage environment. Here a wider range of wildlife penetrated indoors, so birds and rodents became more abundant outside historical properties, sometimes gaining access at times when buildings were frequently unoccupied because of lockdown restrictions. Entomology was somewhat sidelined during the times of COVID-19, apart from concerns over potential vectors (Berenbaum, 2020) and invasive species (Bertelsmeier and Ollier, 2020). In some museums the period saw some attention to insect pests, but also a worry about invading birds and rodents (BPMA, 2020; Calleja, 2020). As restaurants were typically closed for weeks, rats were increasingly encountered in cities and private gardens as some key food sources for the rodents declined (BBC, 2020).

This study examines different species of silverfish (Zygentoma) trapped in some Viennese museums. Silverfish are a potential pest in museums because they can cause extensive damage to cellulose based objects. In particular, they attack books (Fig. 5A), wallpaper, paper or photographs (Jackson, 1886; Pinniger, 2015; Querner, 2015). Most of the silverfish species of central Europe need high humidity to thrive. They are useful insects to study under lockdown because they are rather shy and benefit from such periods when they can be undisturbed and seemingly range more widely. For instance, the number of silverfish trapped at the Tower of London, roughly doubled since 2018 (Hallett, 2021). This insect has been trapped and counted in the museums investigated here for a number of years, so the study can build on historical data. The closures in Austria occurred in the spring when the outdoor climate and that of the museum were also amenable. The silverfish population seemed likely to grow during the closures, although it is not certain whether this was a real increase or simply that the activity or range of the insect changed. This study aimed to determine the extent of population change in 2020 and compare with populations in earlier years. Such a study provides an opportunity to assess the characteristics of changes in silverfish populations in museums. Note that in 2018 the International Commission on Zoological Nomenclature issued a formal ruling (ICZN Opinion 2427) stating the gender of Lepisma (and all genera with that ending) is neuter, following ICZN Article 30, hence the form adopted here. Silverfish considered here as likely to be found in Austrian museums are:

1.1. Lepisma saccharinum

The common silverfish, L. saccharinum is mainly found in historic buildings, especially the ground floor or basements where damper conditions prevail. They are found in many residential buildings where they live in bathrooms and other damp areas, usually in crevices or under furniture. If conditions are favorable, with high humidity >75%, they can occur in large numbers and readily multiply. Silverfish were once the typical species of Leptismatidae found in our buildings, but central heating has meant their habitat is more restricted, so usually only few individual insects are to be found. However, wet cleaning particularly where a large amount of water is used can result in a favorable microclimate. This combined with detritus as a food source result in infestations. The insects can damage cellulose-containing museum objects (typically those made of paper), books and archive materials, but also tissue paper, cardboard, wallpaper (and textiles), and materials containing starch and sugars. However, flour or oatmeal, can also serve as food and they can probably feed on dust containing dander, hair, dead insects and small fungi (Hickin, 1992; Pinniger, 2015; Querner, 2015; Querner and Sterflinger, 2021). Active infestations have not been reported in Austrian museums over recent years.

1.2. Ctenolepisma longicaudatum

The grey silverfish C. longicaudatum was known from the Netherlands (Beine Nierop and Hakbijl, 2002; Schooltz and Brooks, 2014), but has been a pest in Australia for a long time (Lindsay, 1940). C. longicaudatum now regularly appears in museums and archives in Germany (Sellenschlo, 2007), the UK (Goddard et al., 2016), Belgium (Lock, 2007), Norway (Aak et al., 2019; Mattsson, 2014, 2018), the Czech Republic (Kulma et al., 2018) and Austria (Querner et al., 2017a, b). It was identified for the first time in an Austrian museum in 2002 (Christian, 2002). The grey silverfish has spread across museums in Vienna with increases in many locations. Its presence may be a result of poor housekeeping or lack of regular cleaning. In recent years this species posed novel challenges to IPM in many museums, libraries and archives, because of its large body size, long life span, high reproduction rate and tolerance towards humidity and temperature variation.

As paper objects and photographs are susceptible to attack, archives and libraries are especially worried about this pest. Damage occurs where populations are high, especially in buildings with paper-based collections, where it poses a threat and has led to damage of paper objects, photographs or graphics in Austria, Germany and the Netherlands. It is not yet clear how best to eradicate the insect. They can be transported with packaging material so re-infestation may be frequent. It raises questions about the need to treat all cardboard boxes and tissue paper used for objects and the relevance of procedures and protocols to reduce their spread.

These insects are often also active during the day and can be found moving vertically on walls. Larger individuals are also often found behind objects leaning against the wall or behind hanging paintings. C. longicaudatum is adapted to a normal room climate which explains its wide occurrence and the increasing frequency indicates it as the dominant species in our buildings, so is a challenge for pest prevention and Integrated Pest Management (IPM) in museums, archives and libraries. The origin of C. longicaudatum is not easily determined, but transport with objects, packaging materials, hygiene articles for the toilets (Weidner and Sellenschlo, 2010), cleaning materials or building materials from the outside are likely modes of introduction. The insects reach sexual maturity within a year and can live for five or more years, with a reproductive rate of around 80–90 eggs per year (Lindsay, 1940). Over a few years the population develops exponentially if conditions are suitable and food is available.

1.3. Ctenolepisma lineatum

The four-lined silverfish, C. lineatum, occurs at fewer sites and in lower numbers. This species was not common in buildings in Vienna and is probably found only in the south of Germany and Austria (Zimmermann, 2016). The species has spread rapidly in recent years in Vienna museums (in 2012 it was only known from one location, today at over 30). In Vorarlberg (western Austria) large numbers are also found outside buildings, where they hide behind wooden panels. The origin of this species is probably the south of Europe, but it has spread to quite a few countries and continents (Huge et al., 2020).

1.4. Ctenolepisma calvum

Since 2017, this silverfish species, only recently introduced to Vienna, is also found in many museum buildings, sometimes in large numbers. C. calvum was discovered in Germany in Chemnitz (Erlacher, 2017). In Germany it is called the “ghost fish” because of its small appearance and white colour. It was first described in 1910 from Ceylon, today’s Sri Lanka (Ritter, 1910). At the beginning of the 1970s they were also found in Central America, where they are one of the most common species in human habitation, especially in Havana. Little is known about its biology and the rapid spread to Germany and Austria in the last few years is poorly understood.
1.5. *Atelura formicaria*

*A. formicaria* is a species of silverfish associated with ants. They live inside ant nests and are therefore rarely found in buildings (Christian, 1994); where found in traps, they must come from nests nearby. It is known mostly from Central Europe and absent from the UK or northern Europe (Meineke, 2016).

1.6. *Thermobia domestica*

Interestingly the firebrat *T. domestica* is described as museum pests in most of the IPM literature, but in Central Europe are not found in buildings as they need higher temperatures and are more a pest of tropical countries e.g. the Middle East. Rarely, the species can be found in steam tunnels, hot-water heaters and pipes or boiler rooms. According to Sammet et al. (2021) the species was found in Estonia and it is also known form one museum in London (Val Blyth, unpublished data).

2. Materials and methods

The silverfish trapping data used in this study come from blunder and pheromone traps set out at a range of ground floor locations in the Technisches Museum Wien, Schönbrunn Palace, Hofburg Museum (Silberkammer only) and Weltmuseum Wien. These museums all have had monitoring in place for some years now to monitor the activity of museum pests such as the webbing clothes moth, woodborers, Dermentid beetles, a range of silverfish and other arthropods that are only occasionally found in the buildings. The identification and counting of the insects has been undertaken to assess the extent of the insect problem, search for infested objects and contribute to IPM. The particular museums selected for this analysis had revealed the presence of silverfish in the past and had a higher number of silverfish observed on individual traps during the early months of the year, when COVID-19 lockdown began. Some of the museums revealed active insect infestations associated with particular objects in the past, but none had exhibited previous problems with silverfish.

The data covers the periods, up to six years, as denoted in Table S1. New traps were set out in the early parts of the year, usually in February (Weltmuseum) or March (other locations), checked 5 to 6 times per year and the pests and other arthropods identified at approximately two-month intervals across the summer (until October). Although monitoring in the Weltmuseum insect pest monitoring extends over a longer period, traps were renewed again and left over the winter without regular checks. Pheromone traps have been used for some time for monitoring specific insect pests in museums (Gilberg and Roach, 1991; Querner et al. 2013, 2017), and when placed on the ground were observed to be effective for silverfish in Viennese Museums. The trapping programme looked at four species of the family Lepismatidae: *L. saccharinum*, *C. calvum*, *C. longicaudatum* and *C. lineatum*. There were no visitors to the museums and palaces due to the closure of under lockdown response to COVID-19 from 11 March 2020 until 15 May 2020.

Insect trapping counts are necessarily represented by integer values, and frequently traps have no silverfish at all, so care over the non-parametric nature of observations becomes very important in statistical analysis of the catch. Catch rate is a common measure in studies, and palaces due to the closure of under the lockdown response to COVID-19 from 11 March 2020 until 15 May 2020.

3. Results

The overall distribution of Lepismatidae collected at approximately two-monthly intervals is shown in Fig. 1. This figure presents an image that represents the catch found in individual trapping sites at each visit over a number of years at the Technisches Museum Wien, Schönbrunn Palace, Hofburg Museum and the Weltmuseum Wien (although here the record is just three years in length). The images representing a single trap show the number of insects found as a short dash. The intensity of shading indicates the number of silverfish caught and shows sparse data, with most traps empty (see Table S1 for details). The vertical sequence is the order in which the traps are examined and includes both blunder and pheromone traps. Fig. 1a–c shows the catch at the Technisches Museum Wien. The common silverfish (*L. saccharinum*) is generally abundant, but the grey silverfish (*C. longicaudatum*) and *C. calvum* are also found frequently. *C. longicaudatum* dominated the catch at Schönbrunn Palace after 2016, which is apparent from Fig. 1f. The overall results from the trapping programme are summarised in Table S1, where it is clear that *C. lineatum* is rare, so not displayed in Fig. 1.

The average catch rate (number of insects/number of traps) for each visit to the individual traps over time at the Technisches Museum Wien is shown in Fig. 2a–c. It is clear that the catch was very high from the observations made in May of 2020, after the traps had been exposed during the lockdown closures. Although April or May collections often showed the highest numbers of silverfish over the years these are lower for previous years. The increased catch is most striking for *L. saccharinum*, but also apparent for both *C. calvum* and *C. longicaudatum*.

As with the Technisches Museum the record at Schönbrunn Palace from 2016 showed the largest catch rates in May 2020 (Fig. 2d–f), so represent silverfish caught in traps exposed during lockdown. These observations hint that closure appears to have led to higher catch rates. A similar situation pertains at the Hofburg Museum (Fig. 2g), although only *L. saccharinum* and *C. calvum* are found at this location. The shorter record at the Weltmuseum also suggests high catch, especially for *L. saccharinum* at the end of the closure period (Fig. 2j).

The catch rate of insects in pheromone traps is, as would be expected, higher than that in blunder traps, with the annual catch rates being greater each year at most sites (Table S1). Notable exceptions are the years 2015–2017 at the Hofburg Museum where the catch rate in the pheromone traps is no greater than that in the blunder traps (2015: 0.07 ± 0.025 0.13 ± 0.047; 2016: 0.053 ± 0.026 0.35 ± 0.094; 2017: 0.36 ± 0.061 0.46 ± 0.096 respectively).

In general, the trapping record gives an impression that the number of insects trapped increases over time and especially the large numbers that tend to be trapped in the spring. The number of active sites, where at least one insect has been captured each year revealed increasing activity (Fig. S2). This was not especially clear for the Technisches Museum Wien, but at both Schönbrunn Palace and Hofburg Museum there is a sense of increasing Lepismatidae activity. The Weltmuseum also reveals high activity at the end of the three-year record and as noted earlier such increases are also apparent at other locations in Austria and beyond.

At Technisches Museum Wien traps associated with the Schwer-industrie displays (heavy industry) have typically revealed *L. saccharinum* over the years, but notably contained larger numbers of insects during the pandemic closure. At Schönbrunn Palace, *L. saccharinum* was characteristically found in “Blauer Stiege unten” and “Audioguide”, while *C. longicaudatum* was typically associated with traps in less public areas such as the cloakroom, shaft, emergency bedroom, outdoor room, and more prevalent in these areas during lockdown. In the Silberkammer at the Hofburg Museum the large catches were typical of a few sites. At the Weltmuseum Wien, *L. saccharinum* were abundant in the Halle. The areas of museums that had higher abundance in lockdown were typically associated with traps that were also higher in the pre-lockdown periods.
Fig. 1. Image of the distribution of catch among traps for the Technisches Museum Wien (a–c), among traps at Schönbrunn Palace (d–f) and the Hofburg Museum (g–h). Distribution of catch among traps for 3 years at the Weltmuseum Wien (i–j). Notes: The grey scale reflects the catch, i.e. number of insects found after collection of the traps.

Fig. 2. The average catch rate (insects per trap) at the Technisches Museum Wien for each time the traps were examined (a–c). Catch rate among traps at Schönbrunn Palace (d–f), the Hofburg Museum (g–h) and the rate at the Weltmuseum Wien (i–j) each at different scales. Notes: The short vertical dashes denote the April/May sampling during lockdown 2020.
Against this background of increasing catch, hierarchical cluster analysis was used to explore the particular character of the silverfish distributions during the year of COVID-19 restrictions. The analysis is illustrated in the dendrograms of Fig. 3. These used observations of \textit{L. saccharinum} and \textit{C. calvum} for years on the basis of the number of sites in the museums with non-zero catch and the annual catch rate for the blunder and pheromone traps. The year 2020 appears distinctive at the Technisches Museum Wien and Hofburg Museum, but less so at Schönbrunn Palace, where both 2019 and 2020 cluster. Schönbrunn Palace also has a large catch of \textit{C. longicaudatum}, but cluster analysis which included these collection data did not suggest 2020 to be a unique year overall, despite some evidence of high insect abundance at the end of lockdown.

The trapping record can also be interpreted in terms of the number of traps with large numbers of insects which reflect infestations. Assuming that ten or greater reflects an infestation, the data shows the Technisches Museum Wien most prone to this, although it should be noted that it also has the largest number of traps so that the catch rate is not particularly high. This may seem a low threshold, but is based on experience from more than 15 years monitoring in Austrian settings. Since 2015, 32 traps were found with at least ten \textit{L. saccharinum} present and the largest number of traps (8) were from the year 2020, when the highest number of insects caught from these infestations (307) compared with only 296 over the previous five years. These infestations were spread among a wider range of sites, within the Technisches Museum Wien in 2020, while in earlier years they were often found from the same site. There were no traps with ten or more \textit{L. saccharinum} present at Schönbrunn Palace, but at Hofburg Museum the silverfish was found abundant in 11 traps in 2020, where the catch of more than 247 can be compared with only 157 from the previous five years. Although there is only three years of data for the Weltmuseum Wien, there were 11 traps with ten or more insects collected from four sites in Halle. In the previous two years just a few insects were trapped here. Few traps were found with more than ten \textit{C. calvum} or \textit{C. longicaudatum}.

4. Discussion

All the museums show an increase in the silverfish investigated during recent years. \textit{C. lineatum}, \textit{C. calvum} and \textit{C. longicaudatum} are all introduced species that spread in Austria over recent years. \textit{C. lineatum} is still quite rare in Vienna, so found only in small numbers. \textit{C. calvum} and \textit{C. longicaudatum} are both generally on the increase at many locations. They are probably spread with packaging (paper and cardboard), and if conditions are favorable populations can establish themselves and increase over time. We did not see a significant increase in the lockdown months for these two species. However, \textit{L. saccharinum} showed notable increases during the months of lockdown. Some individual traps captured over 150 individuals over a period of 8 weeks (as shown by the example in Fig. S3). Each museum had locations where some traps revealed a sharp increase of \textit{L. saccharinum} numbers, though most traps did not reflect this. This result probably arises because of the limited number of spaces and habitats with a favorable microclimate, especially for \textit{L. saccharinum}, a species that readily aggregates. \textit{C. longicaudatum}, by contrast is a species that spreads through buildings, and can actively migrate hundreds of meters in a single night, so populations may not be so dense.

The dramatic increase in \textit{L. saccharinum} numbers over the short period of lockdown may have a number of explanations:

(i) During lockdown, museums were closed and staff movement was very limited, so animals living within the building experienced less disturbance. \textit{L. saccharinum} prefers dark, quiet spaces so probably found a wider range of peaceful habitats.

(ii) Cleaning was reduced in all areas of museums resulting in higher food availability. It took some time for the museum staff to realise that cleaning and good housekeeping remained essential over the long term. However, during the first weeks of the lockdown work in the exhibitions was reduced to a minimum (even though regular checking of traps was still possible).

(iii) The microclimate of the specific area where traps were located was a potentially important factor that may have changed. The traps are set within historic buildings with stone floors. \textit{L. saccharinum} needs a high humidity (>75%), likely found as microclimates in small cracks and spaces along the wall and in the floor, which are relevant as habitats for these tiny insects. By contrast \textit{C. longicaudatum}, \textit{C. calvum} and \textit{C. Lineatum} often avoid climbing walls and other vertical structures. Although none of the museums has a proper HVAC system, high visitor numbers and open windows during normal periods ensure reasonable ventilation. During closure ventilation in the museums was much reduced and it was likely that \textit{L. saccharinum} was best able to find humid micro-environments. Doubtless dust accumulated because there was little cleaning, though it would have been deposited at

Fig. 3. Dendrograms for the hierarchical cluster analysis for \textit{Leptisma saccharinum} and \textit{Ctenolepisma calvum} using observations of non-zero catch and the annual catch rate for the Technisches Museum Wien (a), Schönbrunn Palace (b) and Hofburg Museum (c). Note: the scale is notional and is a distance matrix reflecting the differences between the years.
a lower rate than when visitors were present (Yoon and Brimblecombe, 2000).

The conditions were likely favorable for L. saccharinum, but the life cycle is rather longer than the 6–8 weeks of closure. Males and females have a courtship followed by an indirect transfer of the spermatophores from the male to the female. After that eggs are laid and need 2–8 weeks to hatch. For the development of the nymph to a sexually reproductive adult that can mate and lay eggs a minimum of 3–4 months are needed, but most consider this to be closer to a year; L. saccharinum live for about 3–4 years (DeVries and Appel, 2013, 2014; Marlatt, 1902; Mortia, 1926; Triplehorn and Johnson, 2005). So even under ideal climatic conditions and sufficient food, the short two-month lockdown would be insufficient for the populations to grow in substantial numbers. The increase found on the traps is probably a result of a higher activity in favorable microclimatic spaces found within the exhibition area.

Although there had been a secular increase in silverfish species in Austria for some years, enhanced populations were especially striking at the end of the lockdown closures, with some traps with more than 50 insects (see Fig. S3). There are hints in other museums of a change or a higher pest activity during lockdown, but few scientific publications studies are yet available. Lockdown saw the catch roughly doubled at the Tower of London since 2018 (Hallett, 2021) and the National Trust in England reports an increase by 11% for pests (different species) in historic properties but interestingly a reduction of silverfish L. saccharinum. They also report an increase in mould reflecting microclimates with higher humidity (NT, 2021). Increases, that parallel our work, are also noted at the British Museum (BPCA, 2020), and the problem with the invasive grey silverfish (C. longicaudatum) at properties managed by English Heritage (Pyor, 2020). Nevertheless, the Viennese museums have not found any damage to their collections despite higher insect numbers, and they have not had active infestations of any of the silverfish species. The observations in this work suggest that closed museums still need some level of cleaning and regular inspections for insect pests. Initially the focus should be in those areas where the insects are regularly found.

The museums studied here normally receive a large number of visitors, with the totals as millions for 2019: Technisches Museum Wien: 0.43; Schönbrunn: 4.2; Hofburg: 0.7; Weltmuseum: 0.15. There were no visitors to the museums due to the closure of the museums and palaces under the lockdown response to COVID-19 from 11 March 2020 to 15 May 2020. The low level of human activity in the exhibition rooms arose through brief visits of security staff and a few conservators. During the lockdown windows were kept closed and the lack of visitors probably resulted in a lower air flow between the rooms. The locations threatened within the buildings are probably similar to those that experience the insects in more typical years.

5. Conclusion

Under the lockdown closures silverfish, especially L. saccharinum, were more abundant. This probably arose because the insects could range more widely in unoccupied spaces. Future work needs to explore changes in dust deposition during closure and the potential of resuspension when museums opened and any effect from weather conditions in spring 2020. The locations threatened within the buildings are probably similar to those that experience the insects in more typical years. This suggest that closed museums still need some level of cleaning and inspections for insect pests, especially in locations commonly inhabited.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ibiod.2021.105296.

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