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Changing Insect Catch in Viennese Museums during COVID-19

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Abstract: The COVID-19 pandemic led to significant changes in societies across the globe. In many countries in Europe, national lockdowns during the spring of 2020 meant that museums were closed, and maintenance and housekeeping were at a minimum. We compared the insect monitoring data of 15 museums in and around Vienna between the years 2018 and 2022 to see potential effects of the two lockdowns (spring 2020 and winter 2020/21) on insect populations. In Vienna, these changes altered the presence of pests, most notably an increase in silverfish by late spring (March–May 2020). We also found increased numbers of other pest species (notably *Tineola bisselliella* and *Attagenus* sp.), though these changes were seen later (June–October 2020). *Thylodrias contractus*, although found only in one museum, appeared to show decreased numbers during 2020. Storage areas in some of the museums revealed no significant increase in insect catch during the COVID-19 related closures. Since there are rarely visitors in such spaces, the situation did not change much during the closures. Silverfish are shy insects, but they were able to range more freely during the closures in the mostly darkened rooms. The increase of *Tineola bisselliella* and *Attagenus* sp. could be a result of reduced cleaning in the first lockdown. In the second lockdown, no significant changes were found. Human activity from staff was much higher compared to the first closure; a second reason could be the time of year, as in the winter period, it is mainly larvae that are active. Increased insect populations remind us that even when museums are unoccupied, they still need monitoring for possible risks from pests. No damage to the objects from the pests was observed in the museums investigated.

Keywords: COVID-19 lockdown; closures; silverfish; clothes moth; carpet beetles; Austria

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1. Introduction

The spread of COVID-19 beginning late 2019 led museums, galleries, and libraries to close in spring 2020 in many parts of the world [1,2]. This was part of national lockdowns, largely to reduce the rate of infection in public spaces. The disruption led to many social changes of relevance to museums as their occupancy and mode of use changed when people shifted their mode of work—the home office becoming common [3], increased Internet use [4], or increased cooking within homes [5]. Changing availability of food and more unoccupied urban spaces meant that animals and birds showed expanded ranges [6], although some of this may have arisen due to increased observability. Among birds, there was no increased probability of occurrence in urban areas during COVID-19 lockdown as the relatively short duration did not give sufficient time for colonisation of urban spaces abandoned by humans [7]. Additionally, rodents increased in cities as restaurant were closed and pest control was limited.

UNESCO [1] suggests that some 90% of museums were closed in 2020, which meant no visitors over long periods. Moreover, international tourism was minimal, which contributed to a loss of revenue [8] for many institutions and cities. Many heritage organisations had to shift away from direct face-to-face activities, with special exhibitions often cancelled or postponed [9]. Some had to change format and expand their online exhibitions, which may arguably impose longer term changes to museum practice [10]. However, lower staffing levels were characteristic, and some furloughed staff did not return even after the incidence of infection became less frequent [11]. Some heritage organisations used the time for additional maintenance or research [11]. A few museums were concerned about insect pests, but there were also worries about invading birds and rodents in historic houses and museums [12]. Quiet and unoccupied heritage interiors created a potential for increased activity among museum pests [13,14]. Changes in interior climate, lack of regular cleaning, or just reduced occupancy levels in galleries can influence pest activity. Thus, there was the potential that insect infestations during closures would enhance the forms of damage that are typical in museum collections, affecting organic materials such as wood (e.g., holes in furniture and frames), wool (holes in clothing, carpets, and tapestries, along with associated frass), paper (fragmentation of books and archive documents), and herbaria and zoological specimens.

In Austria, museums, galleries, and other historic sites were shut for just over two months in the spring of 2020 (16 March 2020–15 May 2020), so the heritage sector saw no visitors across this period, and also staffing levels were greatly reduced. Later in 2020, museums had a second period of closure to visitors (3 November 2020–3 May 2021); although some staff worked onsite, others worked from home. Museum management during the first and second COVID-19 closures was different. During the first lockdown, only security staff were present onsite, and few were allowed to work. In the second closure, many curators and administrative staff were still at home, but conservators were allowed to work with the collection in the museum, usually in separate rooms to reduce contact. Cleaning was not widespread across the first closure and often remained reduced in the exhibition spaces during the second closure. In general, the second period had much higher staff activity with the collection, but the exhibition rooms remained quiet, although some museums used this time for specific cleaning operations.

Insect pests have been on the increase in recent years. Some have argued that this might be the result of climate change [15–19], increasing exhibitions of loaned objects [20] or the use of safer, but less effective pesticides [21] in addition to the potential for transport by large visitor flows. Central Europe has witnessed a notable increase in *Zygentoma* with some novel species such as (i) the long-tailed silverfish, *C. longicaudatum*, [22] once not common but now very abundant at some locations and (ii) the ghost silverfish (*C. calvum*) which has an expanding range in Europe [23], with the four-lined silverfish (*Ctenolepisma lineatum*) also found [24].

Zygentoma numbers were observed to increase in the first COVID-19 closures [13]. There were also some increases in the summed catch of *Tineola bisselliella* (webbing clothes moth) from three museums in Vienna, following the closures of 2020, but the change was not as obvious as for *Zygentoma* [14]. This current work examines the catch of different insect pest species in more detail over the period 2018/2022. It extends earlier work, by (i) covering two lockdown periods in Austria, where heritage institutions were closed to the public and (ii) examining a larger number of museums, as Hofburg Palace, Schönbrunn Palace, and Technisches Museum Wien have been mentioned in previous studies [13,14]. Here, we compare 10 museums with associated storage and a further five museums without associated storage areas in and around Vienna, to assess the breadth of the changes in insect pests during closures, and implications for pest management.

2. Materials and Methods

2.1. Sites

Ten museums and some associated storage areas were chosen as sites from Vienna and its surroundings as they had good records of insect catch. Some of their characteristics are listed in Table 1, along with abbreviations occasionally adopted in the paper.

Table 1. List of museums and storage facilities in this study. Notes: LA are museums in Lower Austria, within an hour of Vienna. Trap number includes both pheromone and sticky traps.

Museum	Site Code	Type	Age	Traps
21er Haus	21e	Museum	modern	14
Altenburg Library (LA)	Alt	Library	historic	32
Oberes Belvedere	BeO	Museum	historic	70
Unteres Belvedere	BeU	Museum	historic	20
Dom Museum	Dom	Museum	historic	36
Feuerwehr Museum	Feu	Museum	historic	24
Franzensburg (LA)	Fra	Castle	historic	135
Heeresgeschichtliches Museum	HGM	Museum	historic	110
Hofburg	HOF	Museum	historic	122
Museum 1	MN1	Museum	historic	39
Museum für angewandte Kunst	MAK	Museum	historic	55
Museum Niederösterreich (LA)	MNO	Museum	modern	62
Museum 2	MN2	Library	historic	116
Schönbrunn Palace	Sch	Palace	historic	166
Technisches Museum Wien	TMW	Museum	historic	199
Storage				
21er Haus	X21	Art store	modern	81
Belvedere-Oberes	XBO	Bunker	historic	27
Belvedere-Unteres	XBU	Cafe/study	historic	40
Feuerwehr Museum	XFe	Archive/depots	historic	19
Heeresgeschichtliches Museum	XHG	Store	historic	207
Museum für angewandte Kunst	XMA	Three depots	historic	94
Museum Niederösterreich (LA)	XMN	Depots	modern	159
Museum 2	XN2	Manuscripts	historic	70
Schönbrunn Palace	XSc	Depots	historic	160
Technisches Museum Wien	XTM	Archive	historic	59

Figure 1 illustrates two sites from the study: (i) the Technisches Museum Wien with a large collection and many visitors and (ii) the Altenburg Library, a historic library with fewer visitors.

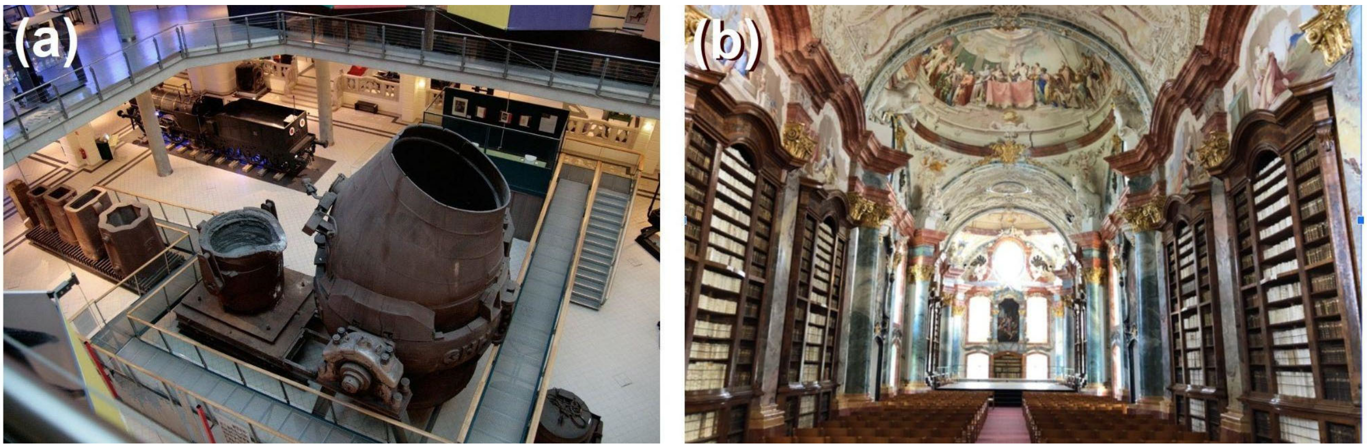

Figure 1. Pictures of (**a**) the Technisches Museum Wien and (**b**) the Altenburg Library. These sites revealed the largest and smallest catches of insects. Photographs Manfred Werner—Tsui—File: LD-Tiegel, Technisches Museum Wien, Juni 2009.jpg) and P.Q.

2.2. Insects and Traps

The trapping data used in this study come from sticky (Catchmaster: 6.5 cm × 6.3 cm) and pheromone traps (FINICON: 20 cm × 6.5 cm) for the webbing clothes moth. These were set out at the museums described in Section 2.1. The insects caught were identified as part of a yearly pest monitoring and IPM programme to alleviate the potential threat to Austrian museums. Traps were placed at floor level and replaced with new traps in the early parts of the year; usually in February or March. The first data were collected in late spring (typically May). Further observations were made in the autumn: October to represent the summer catch. Traps were replaced at this time and left out over the winter and collected in February or March of the new year. The sampling period was five years (2018/2022) and covered the two periods of museum closures (lockdown I and II) in Austria which stretched 16 March 2020–15 May 2020 and 3 November 2020–03 May 2021. Museums and all other heritage institutions were closed nationally to visitors by the government. In large institutions conservation staff, supervisors, or curators were home over the first lockdown, with many on paid leave (*Kurzarbeit*).

The project recorded the numbers of insects found on traps, specifically noting the presence of *Tineola bisselliella* Hummel, 1823 (*Tineidae*; webbing clothes moth) [15,25], *Plodia interpunctella* Hübner, 1813 (*Pyralidae*; Indian-meal moth) [26], *Anthrenus verbasci* Linnaeus, 1767 (*Dermestidae*; varied carpet beetle), *A. olgae* Kalík, 1946 (*Dermestidae*), *A. scrophulariae* Linnaeus, 1758 (Dermestidae; common carpet beetle), *A. fuscus* Olivier, 1789 (*Dermestidae*), *A. museorum* Linnaeus, 1761 (*Dermestidae*), *Attagenus smirnovi* Zhantiev, 1973 (*Dermestidae*; brown carpet beetle or vodka beetle) [27], *Attagenus unicolor* Brahm, 1971 (*Dermestidae*; black carpet beetle), *A. pellio* Linnaeus, 1758 (Dermestidae; fur beetle), *Thylodrias contractus* Motschulsky, 1839 (*Dermestidae*; odd beetle) [28], *Gibbium psylloides* Paweł Czenpiński, 1778 (*Ptinidae*; hump beetle), *Ptinus fur* Linnaeus, 1758 (*Ptinidae*; white marked spider beetle) [29] and *Stegobium paniceum* Linnaeus, 1758 (*Ptinidae*; biscuit beetle). Additionally, *Zygentoma* were recorded including: *Ctenolepisma longicaudatum* Escherich, 1905 (*Lepismatidae*; long-tailed silverfish) [30,31], *Ctenolepisma calvum* Ritter, 1910 (*Lepismatidae*; ghost silverfish) [23], *Ctenolepisma lineatum* Fabricius, 1775 (*Lepismatidae*; four-lined silverfish) [24], and *Lepisma saccharinum* Linnaeus, 1758 (*Lepismatidae*; common silverfish). Some other insect pests and other arthropods were also found, but will not be discussed in this paper, as the numbers trapped were too small for statistical analysis (typically <10). Identification was based on morphology using descriptive keys [23,32–34].

2.3. Data Analysis

In general, this study has pooled catches of individual species or groups of similar insects, rather than using the numbers found on individual traps as so often they are zero (i.e., empty traps). *Anthrenus* sp. consisted mainly of the varied carpet beetle *Anthrenus verbasci* and *A. olgae*, but occasionally other species of this genera, and also the larvae, which are hard to differentiate on sticky traps. The same pooling was undertaken for *Attagenus* sp., including *Attagenus smirnovi*, *Attagenus unicolor*, *Attagenus pellio,* and their larvae (these are also very hard to differentiate) and the *Zygentoma*: *Ctenolepisma longicaudatum*, *Ctenolepisma calvum*, *Ctenolepisma lineatum,* and *Lepisma saccharinum*.

However, pooled catches need to be used with some caution as they are likely to be sensitive to the number of traps set out [15]. At the point where we needed to compare museums in a quantitative way, we used catch rate, which can be thought of as the average number of insects in the trap (i.e., number of insects/number of traps set out). This rate can also be biased if large numbers of traps are set out (e.g., because the museum has experienced infestations in the past), as it might yield a lower catch rate, despite the abundance of insects being high. As with pooled totals, the catch rate needs to be interpreted with some care although the museums studied here have a similar intensity of monitoring, with the number of traps loosely proportional to their size.

The typical insect catch varies year-to-year. As insects are often trapped in small, often zero, necessarily integer numbers and the catch typically varies year-to-year, we have most often used non-parametric tests. The Friedman test (statistic Q) as a non-parametric equivalent to the correlated ANOVA) is used to detect differences in treatments across multiple test attempts. Here, it was adopted to test the significance of differences between multiple blocks (a season or a year at a site) of data. The Kendall rank correlation (statistic τ) is a measure of ordinal association and was used to assess the correlation between catches, while similar to the conventional Pearson correlation statistic, it is well suited to the integer numbers of insects trapped.

3. Results

3.1. Catch in Museum Galleries

The total catch of different species of insects from all sites is listed in Table 2. The Technisches Museum Wien reveals the largest total catch 2018/2022 of the insects from the species discussed (5728, i.e., almost 29 per trap), while only 238 of these insects (fewer than eight per trap) were trapped at Altenburg Library. Additionally, 3173 insects were caught in the storage areas at Museum Niederösterreich. It is clear that large numbers of *Zygentoma* were trapped from the museums, with almost twelve thousand caught across the five years. These were spread evenly among three species *C. longicaudatum*, *C. calvum*, and *L. saccarinum*, with few examples of *C. lineatum*. The Kendall rank coefficients suggest that there was little correlation among the *Zygentoma* catches from different museums, with the exception of a weak correlation (τ = 0.4156, p~0.05) between *C. calvum* and *L. saccarinum*. Although *C. lineatum* was not common, it was rather abundant at Oberen Belvedere (BeO), where more *C. lineatum* (152) were caught than *C. calvum* (119). *Zygentoma* dominated the catch with more than 60% belonging to this order at 21e, Dom, Feu, and MN2. The moth *T. bisselliella* was also abundant in these museums, with more than a thousand caught at BeO, HGM, and TMW over the five-year period. More than half the catch at BeU and HGM represented this moth. *Anthrenus* sp. (largely *A. verbasci* and *A. olgae*) were also common, and most abundant at Schönbrunn Palace and *Attagenus* sp. In the Hofburg.

The change over five years for the most abundant groups of insects is shown in Figure 2. Traps were examined three times a year, and the catch typically rises through the year to a maximum in the late summer [15], which results in a sawtooth pattern over time and is especially noticeable for *T. bisselliella* and *Anthrenus* sp. The annual patterns were compared across all years for the museums with high catches (BeO, BeU, HGM, Hof, MN2, ON2, Sch, TMW). These showed a significant (Friedman test $p < 0.0001$) trend in mean ranks for the three seasons (up to March, March–May, June–October): 1.3, 1.7, and 2.9, and 1.3, 1.7, and 3 for *T. bisselliella* and *Anthrenus* sp., respectively. Even examining the more scattered *Zygentoma* numbers reveals an evident trend towards higher catches throughout the year; successive catches have a mean rank 1.3, 2.2, and 2.6 ($p < 0.0001$).

The less common species seem to show some of the same behaviour. *Gibbium psylloides* was found at Hofburg (1608) and occasionally at ÖN2. Figure 3a shows that the catch grows with each of the three catches through the year with the last four summer catches (i.e., since 2019) being in excess of 300. *Plodia interpunctella* was frequently trapped at both HGM (69) and TMW (74), which show a growth in catch through the seasons of most years (Figure 3b). The insect is a food-pest, so may have found food in the offices of these larger museums. *Thylodrias contractus* is a rare beetle for museums and in our surveys was found only at Museum 1, though present in relatively large numbers (150), and at the Hofburg, where a single individual was caught in May 2020.

Table 2. Total catch at the sites over the period 2018/2022. Note, abbreviations for insects are: Tine., *Tineola bisselliella*; Anth., *Anthrenus* sp.; Atta., *Attagenus* sp.; Zyge., four species of *Zygentoma*; Gibb., *Gibbium psylloides*; Plod., *Plodia interpunctella*; Thyl., *Thylodrias contractus*; Ptin., *Ptinus fur,* and Steg. *Stegobium paniceum*.

Code	Tine.	Anth.	Atta.	Zyge.	Gibb.	Plod.	Thyl.	Ptin.	Steg.
21e	165	51	6	316	0	0	0	0	2
Alt	22	70	23	104	1	8	0	5	5
BeO	1067	140	103	1783	0	7	0	8	3
BeU	321	55	10	132	0	2	0	1	0
Dom	28	21	33	282	1	1	0	0	1
Feu	101	29	8	488	0	2	0	0	0
Fra	27	258	131	174	0	38	0	162	5
HGM	1354	168	89	809	0	69	0	1	16
HOF	286	194	282	1108	1608	6	1	5	18
MN1	32	19	17	141	0	0	150	0	0
MAK	33	71	89	749	0	1	0	0	2
MN2	509	15	2	1043	0	2	0	3	1
ÖN2	87	140	81	136	38	2	0	0	19
Sch	565	489	172	1551	0	0	0	25	14
TMW	2598	77	153	2833	0	74	0	1	2
X21	2	1	1	1089	0	1	0	0	0
XBO	1	1	0	52	0	13	0	0	1
XBU	24	22	4	412	36	56	0	0	0
XFe	23	1	0	406	0	0	0	0	0
XHG	796	326	23	738	0	126	0	1	31
XMA	6	61	3	587	0	1	0	0	0
XMN	132	7	1	3028	0	2	0	3	0
XON	16	91	43	804	0	2	0	1	1
XSc	484	272	4	779	0	47	0	26	6
XTM	108	49	7	495	0	7	0	9	5

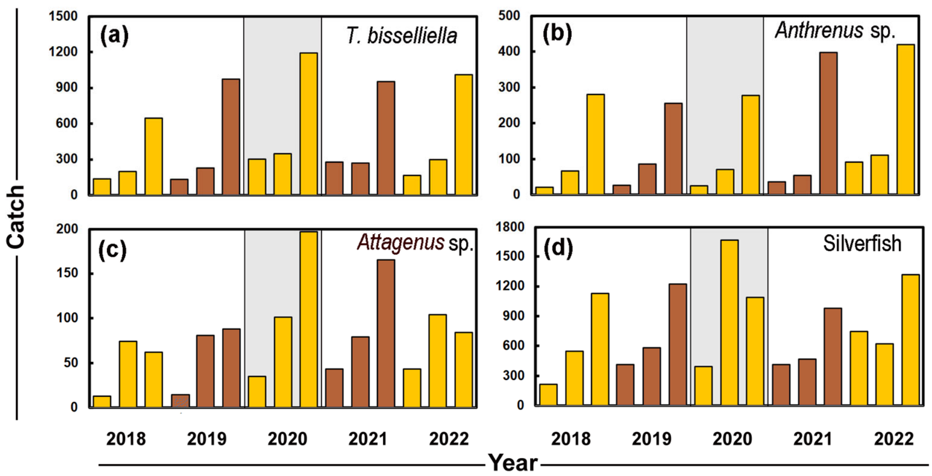

Figure 2. Triannual catch of (**a**) *T. bisselliella* (**b**) *Anthrenus* sp, (**c**) *Attagenus* sp., and (**d**) *Zygentoma* from all the museums. The shaded area denotes the year with COVID-19 closures and different shadings to the bars denote successive years. The three samples each year are (i) October–March, (ii) March–May, and (iii) June–October.

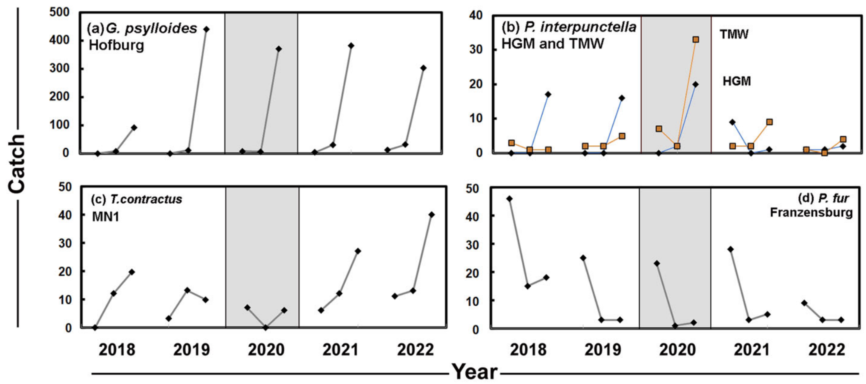

Figure 3. Triannual catch of (**a**) *G. psylloides* at Hofburg (**b**) *P. interpunctella* at HGM and TMW (**c**) *T. contractus* at Museum 1 and (**d**) *P. fur* at Franzensburg. The shaded area denotes the year with COVID-19 closures.

3.2. Catch in Storage Areas

Insects were also trapped in storage areas at a number of museums (Table 2), with more than ten thousand caught over the sampling period. There were infestations of *C. longicaudatum* in storage areas at the 21er House, the Feuerwehr, and Niederösterreich museums, with just on three thousand of this *Zygentoma* caught at the latter site. *Zygentoma* represented more than three-quarters of the catch in most storage areas, except at Heeresgeschichtliches Museum, Schönbrunn Palace, and Technisches Museum Wien, where there were substantial numbers of the other dominant insects (*T. bisselliella*, *Anthrenus* sp. and *Attagenus* sp.). *Plodia interpunctella* was abundant in the storage areas at XHG (catch 126) although more than found in the museum (69), while 36 *G. psylloides* were caught in the storage areas at Belvedere Unteres, though none were captured in the museum. There was little systematic change over time with the most abundant groups of insects in the storage areas (Figure 4), although there is a typical pattern of growth through the three seasonal catches, especially clear with *T. bisselliella* (Figure 4a). There are no obvious increases in the numbers caught during the closures as was apparent for the museum galleries (Figure 2a,b,d). *Stegobium paniceum* were caught in small numbers (40) in storage areas across the period, but more than three quarters were found in the storage areas at Heeresgeschichtliches Museum.

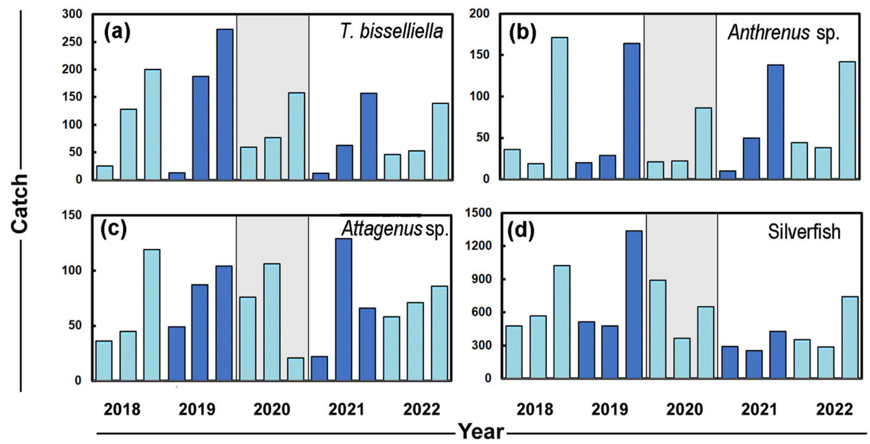

Figure 4. Triannual catch of (**a**) *T. bisselliella* (**b**) *Anthrenus* sp, (**c**) *Attagenus* sp., and (**d**) *Zygentoma* from storage areas. The shaded area denotes the year with COVID-19 closures and alternate shadings to the bars denote successive years. The three samples each year are (i) up to October–March, (ii) March–May, and (iii) June–October.

3.3. Catch during Closures

3.3.1. Lockdown I

Increased *Zygentoma* populations were observed during the first closure of museums as part of attempts to reduce COVID-19 infections [13]. The insects are shy, so they were able to range more freely in unoccupied visitor spaces. The Friedmann test was used to determine the difference in mean rank for the years 2019, 2020, and 2021, restricting the analysis to museums where more than 50 silverfish were caught. For *Zygentoma* at the museums studied here, it amounts to 24 sets of observations: 9 *C. calvum*, 8 *L. saccarinum*, 6 *C. longicaudatum,* and a single one for *C. lineatum*. The statistical analysis gives 2019 a mean rank among the catch across the three years of 1.7, with 2020 as 2.4 and 2021 at 1.9, suggesting that the year of COVID-19 closures had the highest *Zygentoma* catch (p~0.025).

The Friedman test was repeated for all other species in this study that have high abundance in museum galleries. There were ten cases where *T. bisselliella* had catches of more than 50 and these had the following ranks for the three years 2019/2021: 1.6, 2.6, and 1.8; suggesting that the year of the COVID-19 closure had the highest catches. In fact, these were higher in 2020 for seven of ten instances, but the differences were barely significant (n = 10; p~0.06). The same was true for *Attagenus* sp. (1.5, 2.6, and 1.9; n = 8; p~0.07), but not for *Anthrenus* sp. which revealed the highest catches in 2021 (1.8, 15, and 2.8; n = 6; p~0.07). Although statistically barely significant, the ranks determined here are in line with what can be seen with the overall catch numbers presented in Figure 2.

Storage areas, along with some historic libraries [35], are rarely visited, so might be less likely to show changes from closure as they would have insect environments that were not much different during the pandemic. These locations are dominated by the *Zygentoma*, as almost three quarters of the catch in storage areas were silverfish, compared with less than half in the other museum spaces (see data Table 2 and Figure 4d). Unfortunately, there were only a small number of instances from the storage areas where there were catches of more than 50. The silverfish showed no pattern of increase (2.1, 2.1, and 1.8; n = 16; p = 0.56) across the years 2019/2021. Removing the data from the storage areas where there were infestations of *C. longicaudatum* that were subject to treatment with insecticide led to no improvement (1.9, 2.2 and 2.0; n = 13; p = 0.78), suggesting little evidence of change in the storage areas. There were insufficient data to detect interannual changes for *T. bisselliella*, *Anthrenus* sp., and *Attagenus* sp. (Figure 4a–c). Although Figure 4 might hint at a small reduction in the total catch of *T. bisselliella* (Figure 4a) and *Anthrenus* sp. (Figure 4b), it is not very convincing and certainly not statistically valid. It is also possible to compare this situation with the catch of insects at the Klosterneuburg Library as it does not have large numbers of visitors, so they neither act as a vector or drive insects from the interiors. In this way, the library is rather like the museum storage areas. Two insect species were caught in reasonable numbers at Klosterneuburg [35]: *Zygentoma* (mostly *L. saccharinum*) and *Anthrenus* sp. Over the years 2019/2022, they revealed pooled catches from all traps as: 16, 14, and 5 for the Zygentoma and 30, 32, and 32, respectively, presenting no evidence for dramatic change during the COVID-19 closures.

There were a few other changes following the closures, although their relevance is hard to ascertain. *Plodia interpunctella* increased dramatically in 2020 in the summer following the closure of the castle at Franzensburg, TMW and a little less notably at HGM. Large numbers of *T. contractus* were caught at Museum 1, but the catch during 2020 was very low compared with other years (Figure 3c). The numbers here were too small for a convincing statistical test, although the possibility that the closures reduced abundance of *T. contractus* is an interesting one, though difficult to explain. Three quarters of the *P. fur* were found at Franzensburg, a romantic castle in extensive grounds at Laxenburg, Lower Austria to the south of Vienna. The beetle seems to behave unusually, with the catch declining through the year rather than increasing as is the case for other species. Less than a hundred *S. paniceum* were caught at the sites across the period, but even though the numbers were small (Supplementary Materials, Figure S1), here the catch grew through the three seasons. This beetle is also a food pest so may be rapidly attracted if a small amount of food is left out. At low numbers, it is unlikely these insects are causing damage to objects in the museums or storage areas.

The difficulty In establishing changes in the year-by-year catch made it useful to look for changes in the seasonality of the catch in 2020 for evidence of an effect due to the museum closures. *Zygentoma* tend to be caught earlier in the year, and the years 2018, 2019, and 2022 (unaffected by COVID-19 closures) show that 20%, 26%, and 54% of the catch from all 15 museums was caught in early spring, late spring, and summer, respectively. In contrast, *T. bisselliella* tends to be found in traps later in the year with 11%, 19%, and 69% found in the early spring, late spring, and summer catches. There is evidence that the catch of *Zygentoma* increased dramatically in the late spring (2nd collection of 2020) and declined by the summer suggesting that the Zygentoma behaviour was affected by the museum closures (as seen in Figure 2d). This is supported by the 17 sets of traps catching more than 50 Zygentoma species, as these show a trend in mean ranks for the three seasons: 1.3, 2.7, and 2.1 (Friedmann test $p < 0.0001$), whereas looking at this over three years without closures gives 1.6, 1.7, and 2.7 ($n = 35$, $p < 0.0001$). This suggests that when museums are open, *Zygentoma* have a similar seasonal profile to most other insects, with the highest catch at the end of summer. Repeating the same calculations for other insects is more difficult because only nine had a catch >50 in 2020, i.e., six *T. bisselliella* and one each of *Attagenus* sp., *Anthrenus* sp., and *G. psylloides*. Nevertheless, these show significant ($n = 9$, p~0.0006) differences in mean ranks for the three seasons of 1.2, 1.8, and 3, with the rank 3 meaning that the summer catch was the highest on all occasions in 2020. This suggests no change in the normal seasonal pattern for these insects (Figure 2) during the closures.

3.3.2. Lockdown II

The second closures (3 November 2020–3 May 2021) saw more staff present, but the museums remained closed to visitors. This period was also examined by comparing the catches for (i) November 2018–May 2019, (ii) November 2020–May 2021, and (iii) November 2021–May 2022, with the middle period being that of the partial closures. The data November 2019–May 2020 were not used to avoid overlap with the period of Lockdown I. Data were taken from all the museums, although used only where the numbers caught across the three periods were greater than 50. For silverfish, these high catches were almost evenly spread among six *L. saccarinum*, five *C. calvum*, five *C. longicaudatum*, and a single case of *C. lineatum*. The Friedman test suggested an increase in the catch during the final period with the ranks 1.7, 1.9, and 2.4 ($n = 18$, $p = 0.056$), but the partial closure period is not especially high being in the middle of the rankings. The test was run by pooling the catches of other species that were above 50 over the three periods. There were thirteen cases where *T. bisselliella* was the most common. The Friedman test suggested ranks of 1.6, 2.1, and 2.3; once more an increase over time, though in this case non-significant ($p = 0.2$). The middle-ranked period of partial closure does not suggest the catch rate was higher. Although one might have expected insects to increase in the exhibition areas over the partial closure, where there were no visitors, there is no evidence of increased catch.

4. Discussion

Most museums have a specific community of pests that are found year after year but differ between sites. This species composition in different locations is probably related to various features: (i) building history, use, and age, (ii) indoor climate, (iii) surroundings of the museum, (iv) materials stored in the collection, and (v) pests previously introduced with objects and materials. The pests found in this study appear not to be actively harming the collections or objects, but previous work shows that these may live in the museum galleries and storage areas, feeding on organic particles within dust, dead insects, and other organic materials [25]. None of the institutions investigated here showed any obvious damage to objects during or after the COVID-19 closures.

Changes in the catch of *Zygentoma* were easy to observe as their range increased during the first closure. However, any increased catch of *T. bisselliella* became apparent later in the year as they appear to be more readily caught through the summer of 2020. This might reflect population changes as they hatch much faster (4–10 days). In most museums in Vienna, *T. bisselliella* are present as larvae during the winter and adult moths hatch in spring. The reduced cleaning during the first lockdown might have resulted in an increase of adult moths, as the regular cleaning in early spring normally reduces the pests by removing moth larvae from cracks and dead spaces. None of the locations had very high numbers of moths caught on individual traps, and also no infested objects so had to use other food sources such as organic-rich dust [15,25].

Attagenus sp. may also have been caught more frequently in the summer of 2020, after the COVID-19 closures. The partial closures provided little evidence of changes in catch rate, but although there were few visitors at this time, there would have been more lighting, cleaning, and other activities, which might have discouraged insects from increasing their range.

Further evidence that the observed increases were a function of disturbance comes from the observation that there were no changes in the catch in museum storage areas or the little visited monastic library at Klosterneubug [35]. *Thylodrias contractus*, though only found in numbers at Museum 1, seems to dominate the catch at some locations in other countries, such as Division of Birds, U.S. National Museum of Natural History [28], so it may have arrived with exhibition materials. *Ptinus fur*, although not that common, is mostly found at Franzensburg, and the catch increased to 24 just after the closures of the castle in 2020, which may reflect a change in this less common insect. The catch of *P. fur* declines through the year, but it has a lengthy diapause (220 days) at lower temperatures [29,36].

In the years subsequent to the pandemic, a number of species reveal increased catches, perhaps most notably *Anthrenus* sp. Which showed larger numbers caught in 2021 and 2022, especially at Hof and Sch. We cannot really explain this result as *Anthrenus* sp. In buildings mainly feed on dead insects living inside the building or coming in from outside. Additionally, the hitherto little-known ghost silverfish (*C. calvum*) has been on the rise in Europe [23], though its spread is hardly a product of the pandemic restrictions. In 2022, it amounted to almost 30% of the *Zygentoma* catch in both exhibition areas and storage areas. There were no startling changes in outdoor climate over the period in question, so it is hard to explain the current high populations by climate [35]. However, it is likely that it is the indoor microclimate that affects indoor pests, and this might well be associated with small cracks, spaces between walls and furniture, or individual shelves and cupboards [35]. Some of the museums (21e, Beo, BeU, Dom, Feu, MN1, and MNO) have heating ventilation and air conditioning (HVAC), although there was no obvious relationship with insect catch. Potentially, HVAC can lead to a stable environment, but historic structures without climate control, such as Klosterneuburg library, can have an indoor climate that changes only slowly over the seasons, though still reveals a range of indoor pests [35]. When comparing the catch from different museum exhibition spaces there may be other explanations: museum size or visitor flow might be important in bringing insects into the museum, or they might be associated with the import of exhibition materials.

We found evidence that *Zygentoma* catch increased during the COVID-19-driven closure in early 2020, although when museums are open, the silverfish have a similar seasonal profile to most other insects, with the highest catch at the end of summer. This occurred while the buildings had very few visitors, probably allowing the insects to range more widely. As *Zygentoma* lifetimes are longer (~3 months or more) than the closure period, there was insufficient time to allow a change in population [13]. An increase of *Zygentoma* (*L. saccarinum* only) during the first lockdown was also found in other museums in Europe: e.g., the National History Museum in London (oral communication Armando Mendez) and the National Museum Liverpool (oral communication Christian Baars) reflecting these important changes in silverfish. Although not apparent in Viennese museums, further afield, an increase of rodents and cockroaches has been found [37] along with concern about science collections [38].

5. Conclusions

The closure of Viennese museums during the COVID-19 pandemic appears to have increased insect catch, most notably among silverfish (*Zygentoma*), but was also evident for *T. bisselliella* and *Attagenus* sp. *Zygentoma* catch increased dramatically in the late spring of 2020, the period when museums were fully closed. Increases in *T. bisselliella* and *Attagenus* sp. Came at the end of the summer. There was also some evidence that locations where the Indian-meal moth, *P. interpunctella*, was reasonably common, it showed increases by the end of summer 2020. No significant change was found for the catch of *Anthrenus* sp. In 2020. This study of insect catch during COVID-19 reminds us that populations in museums can be sensitive to minor changes in their habitat, yet these can be subtle, so hard to detect. Even when museums are closed, their exhibition spaces require attention through inspections as pests may increase. The quiet habitats of storage areas might need special attention, given the dominance of the shy *Zygentoma* species at these locations. Further work is also needed to understand the diversity and inter-species interactions in the museum environment. These may be well-buffered and stable with controlled climate, but risk in these environments deserves more research. These questions, along with the role of climate change in controlling the population of museum pests, are part of investigations under an Austrian Academy of Science funded project (Heritage_2020-043_Modeling-Museum). Lockdowns during the COVID-19 pandemic may have brought a quieter pace of life for those confined at home, but insects appear to have been more active.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/heritage6030150/s1, Figure S1: *Stegobium paniceum* catch from all the museums for the triannual samples 2018/2022.

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