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THE GREY SILVERFISH AND OTHER SPECIES OF LEPISMATIDAE IN AUSTRIAN MUSEUMS

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Abstract Silverfish (*Lepisma saccarinum*) are described as a pest to museum and paper objects and mainly occur in damp and humid conditions. They can damage paper, starchy materials, wall paper, but in some cases also insect collections and textiles. The firebrat (*Thermobia domesticum*) is also described in the literature as a potential pest for museum paper objects, but needing higher temperatures. Since a few years reports form a new species, the grey silverfish (*Ctenolepisma longicaudatum*), increased in Europe (Netherlands, Norway, Germany) and therefore a systematic analysis of all Lepismatidae (Zygentoma) found on sticky blunder traps and pheromone traps for moths was made in different locations (museums, historic buildings and new storage depositories) in Vienna, Austria in 2019. The animals were counted, pooled and the species identified. Five different Lepismatidae species were found, with *Ctenolepisma longicaudatum* being the most abundant and larges species and occurring mainly in new storage or museum buildings. *Lepisma saccarinum* was found mainly in historic buildings and in ground floors or basements with damper conditions. We also found the four-lined silverfish, *Ctenolepisma lienatum*, occuring in a few sites and *Ctenolepisma calvum*, a new introduced species of silverfish in Germany and Austria. The results are discussed with examples of damage to museum objects and different IPM strategies applied: mass trapping, deep cleaning, quarantine of packaging materials, humidity control, application of diatomaceous earth and experiments with poison bait gels. These new pests cause new threats especially for archives, libraries, but also modern art collections.

Key words Paper, archives, libraries

INTRODUCTION

Silverfish (*Lepisma saccarinum*) are found in many buildings where they live in bathrooms and other damp areas, usually in the basement, in crevices or under furniture. If conditions are favorable with high humidity (70% or higher) they can occur in large numbers. They are considered to be a hygienic and material pest and can damage museum objects, paper, books and archive materials (Pinniger, 2015; Querner, 2015). Materials containing starch and sugars, but also flour or oatmeal, serves as food and they can also feed on dust, dead insects and microscopic fungi. Damage by feeding on cellulose-containing materials such as paper, tissue paper, cardboard, wallpaper (and textiles) is the biggest problem for the museums. They also eat hair and skin remains of humans. At humidity >70%, silverfish can multiply and paper-based materials are at risk. The firebrat (*Thermobia domestica*) is also described as a museum pest but needs higher temperatures to survive. It is also known to be a pest in bakeries and warmer countries .

In the last years another species was reported from the Netherlands and is now spreading across Europe: The grey silverfish (*Ctenolepisma longicaudatum*). Often this species is still identified as "silverfish" by museum staff and professional pest contractors. Since a few years *C. longicaudatum* regularly appear also in museums in Germany, Austria and other countries. *C. longicaudatum* numbers increased over time as they reproduce over a long period (multiple years). Mainly adults are spreading in the building and soon lead to the first damage of paper objects, photographs or graphics in Austria, Germany and the Netherlands. Also tissue and pergamin paper can serve as a food source. This pest is a new challenge for pest prevention and Integrated Pest Management (IPM). They differ in their much larger body size from the silverfish and are not bound to a humid indoor climate, this results in a much higher potential for damage.

In this article five species of Lepismatidae occurring in buildings in Vienna, Austria are described. The biology of the pest species, its identification features and prevention and treatment methods, when infestations with *C. longicaudatum* are high, are discussed.

Table 1. Overview of papers on *C. longicaudatum* in different European countries.

NL	Beine Nierop and Hakbijl, 2002; Schoelitsz and Brooks, 2014; Knoop, 2016
UK	Moore and Steer, 2016; Goddard et al., 2016, Pinniger et al., 2016
Germany	Sturm, 2001; Sellenschlo, 2007; Meineke and Menge, 2014; Landsberger and Querner, 2017; Wagner et al., 2021
Austria	Christina, 2002; Querner, 2019; 2015; Landsberger and Querner, 2017, Querner and Hassler, 2016; Querner et al., 2017; Brimblecombe and Querner, 2021a; 2021b; Querner and Sterflinger, 2021
Belgium	Lock, 2007
Sweden	Pape and Wahstedt, 2002
France	Fabien Fohrer (oral communication)
Norway	Aak et al., 2019; 2020; 2021; Mattson, 2014; 2018
Faroe Islands	Thomsen et al., 2019
Czech Republic	Kular et al., 2018

MATERIAL AND METHODS

The monitoring data from different museums, storage depositories and historic buildings was analyzed for the presence and dominance of the different species of Lepismatidae for 2019. Identification was possible with a hand lens on site in most cases or with a stereo microscope (identification keys used: Weidner and Sellenschlo, 2010).

RESULTS AND DISCUSSION

Four different Lepismatidae species were regularly found (Table 2), with *C. longicaudatum* being the most abundant and larges species, and occurring in all buildings. *C. longicaudatum* is found mainly in new storage or museum buildings. The silverfish *Lepisma saccarinum* was found mainly in historic buildings and in ground floors or basements with damper conditions. Since 2017, a new introduced species in Germany and Austria, *Ctenolepisma calvum,* was also found in many museum buildings, historic and new, sometimes also in large numbers. We also found the four-lined silverfish, *Ctenolepisma lienatum*, but it occurs in few sites and in low numbers. On very few traps single individuals of *Atelura formicaria*, a small species associated with ants, could also be identified as a fifth species.

DESCRIPTION OF THE SPECIES FOUND

Silverfish *(Lepisma saccharinum)*

Silverfish were once the only species of Lepismatidae found in our buildings. They are still found in many buildings, but mostly in humid rooms like bathrooms or toilets, in cellars or basements of historic houses. Due to the central heating, their living conditions have been worsened in most museums, libraries and archives and usually only few individuals are found. Active infestations or damage of objects were not reported in Austrian museums in the last years. The animals are between 6 to 10 mm long, with a max. of 11 mm. The larvae develop within 1-3 years and the imagines live another 2 years.

Grey silverfish *(Ctenolepisma longicaudatum)*

These animals are often also active during the day and can be found moving vertically on the walls. Large individuals (15 mm) are also often found behind objects leaning against the wall or behind hanging paintings. *C. longicaudatum* is adapted to a "normal" room climate. Observations indicate that they are the most frequent and dominant species in our buildings. The origin of *C. longicaudatum* in the buildings cannot easy to determine, transportation with objects, packaging materials, hygiene articles for the toilets (Weidner and Sellenschlo, 2010), cleaning materials or building materials from the outside is likely the mode of introduction. Animals reach sexual maturity within one year and still live up to five more years, with a reproduction rate of around 80-90 eggs per year (Lindsey, 1940). In the time of a few years the population develops exponentially if conditions are right and enough food is available.

Table 1. Pooled results from the different species of Lepismatidae on the sticky blunder and pheromone traps in the museum buildings in Vienna, Austria (March until October 2019).

Location	*Lepisma saccarinum*	*Ctenolepisma longicaudatum*	*C. calvum*	*C. lienatum*	*Type of building and collection*
Museum 1 Storage A	**25**	**323**	**5**	**-**	new building, modern art
Museum 1 Storage B	**2**	**373**	**-**	**-**	new building, modern art
Museum 2 KHM	**139**	**1041**	**87**	**3**	historic building, historic art
Museum 2 Storage	**-**	**279**	**1**	**-**	new building, historic art
Museum 3 NHM	**34**	**10**	**53**	**80**	historic building, natural history
Museum 4 LM	**5**	**1**	**11**	**3**	historic building, historic art
Museum 5 LM		**2**	**29**	**1**	historic building, historic art
Museum 6 BEL	**65**	**105**	**23**	**16**	historic building, historic art
Museum 6 BEL Storage A	**-**	**21**	**5**	**-**	historic building, historic art
Museum 5 BEL Storage B	**1**	**106**	**-**	**-**	new building, historic art
Museum 5 BEL Storage C	**-**	**59**	**1**	**-**	new building, historic art
Museum 6 21er	**1**	**65**	**-**	**-**	new building, modern art
Museum 6 21er Storage	**1**	**392**	**-**	**-**	new building, modern art
Museum 7 AK Storage	**-**	**15**	**1**	**-**	new building, historic art
Museum 8 AK Storage	**1**	**27**	**-**	**-**	new building, historic art
Museum 9 SB	**126**	**64**	**212**	**22**	historic building, historic art

The grey silverfish (*Ctenolepisma longicaudatum*) is not a new pest in Europe or Austria (it was reported for the first time 2001 by Prof. Christian, BOKU) but it is now reported from many museums in Europe and damages occur where populations are high. This is always a result of bad housekeeping and lack of regular cleaning. In the last years the spread of this new species poses new challenges to the IPM in many museums, libraries and archives. Because of its large body size, long life span, high reproduction, survival and tolerance towards humidity and temperature, it is now occurring on many buildings with paper-based collections, where it poses a high threat to the collection.

Ctenolepisma calvum

Ctenolepisma calvum was recently discovered in Germany in Chemnitz (Erlancher, 2017). In German it is called the "ghost fish" because of its small appearance and white colure. It was first described in 1910 from Ceylon, today's Sri Lanka. At the beginning of the 70s they were found in Central America, where they were one of the most common species of human habitation, especially in Havana. Little is known about this biology.

Four-lined silverfish *(Ctenolepisma lineatum)*

This species is less common in buildings in Vienna and is probably found only in the south of Germany and Austria (Zimmermann, 2016). This species spreads rapidly in recent years in Vienna (in 2012 it was only known from one location). In Vorarlberg (western Austria) large numbers of animals were also found also outside of buildings where they were found hiding in behind wood panels. It can easily be recognized by the dark brown lines on the abdomen.

Atelura formicaria

This small and yellow species between 4-6 mm lives in ant nests and is rarely found in museums or buildings. The ant nests are probably outside and the animals are only found by chance inside of buildings. It was found in the last years on two occasions in two buildings in Vienna (data not presented in Table 2).

COUNTERMEASURES AND INTEGRATED PEST MANAGEMENT (IPM)

The following measures can be carried out as prevention or as a first response if large number of *C. longicaudatum* (or the other species) are found. Vacuuming gaps along the walls, sealing them, general improvement of cleaning and housekeeping, application of diatomaceous earth, double-sided tape to stop the spreading of the insects, placing additional sticky blunder traps, or live traps and treatment of individual objects in severe cases was tested in 2016 and 2017 in different museums and collections in Austria and Germany. Humidity control in the room should be applied. Mass trapping is not a preferred strategy as most of the times not all animals can be captured with traps, especially if no specific bait or pheromone is available. Observations in different institutions show that *C. longicaudatum* cannot overcome smooth metal surfaces. This results that many objects are safe in metal shelves and metal plan chests.

Vacuuming the joints between the wall and the floor helps to remove the animals, other dead insects and dust from these gaps and cracks.

Application of diatomaceous earth. It is advisable to apply enough diatomaceous earth along the walls in the storage rooms (an average 2 cm wide track is ideal), where the animals live and hide. Diatomaceous earth can be of very different quality. The success in this pest control measure is that the material adheres well to the surface of the insects and causes the animals to dry out. The product Killgerid Fossil Shield 90.0S showed good results .

Sealing the joints and gaps. Gaps along the walls which were not sealed or by expansion may be filled with diatomaceous earth after vacuuming. A permanent seal with silicone, cork or other materials is recommended.

Double-sided adhesive tape as barriers. Double-sided adhesive tape can prevent the spread of these animals between rooms and also works as a large sticky traps around storage furniture. It can be used only in areas with low visitor activity and has to be replaced 1-2 per year.

Setting up additional glue- or live traps. Sticky blunder traps work well to monitor the activity of all species of silverfish, if they manage to reduce individual populations is not jet clear (and unlikely). Some toxic or food baits are available, but from personal experience sticky blunder traps placed along the wall work sufficient by Landsberger and Querner (2017) describe also live traps (large paper tubes with a plastic lid) where *C. longicaudata* and also *C. calvum* are trapped in large numbers. These traps need to be emptied from time to time not to attract other pests.

Poison bait gels. Poison bait gels were tested by Aak et al. (2019, 2020, 2021). Most gels were developed for ants or cockroaches, but when applied correctly and in a silverfish specific way, they seem to reduce the population by 80-90%. In about 10 museums, libraries and storage facilities bait gels are being tested at the moment and the results can be compared with Aak et al. (2019) and Querner (2022).

Possible control by object treatment. According to (Brokerhof et al. (2007) silverfish and its relatives are category 3 pests found inside of the room, and not living *in* or *on* the material or objects. Brokerhof suggests cleaning measures focusing on the room and not treating the objects. This priority should also be applied for *C. longicaudatum* but in some cases heavily infested objects and its packing material should be treated for example with anoxia, nitrogen or thermally with freezing and heat, as eggs and small animals can also hide in three dimensional objects (Wagner et al., 2021). Only treating objects as a single measure without cleaning makes no sense, because most individuals of *C. longicaudatum* are very mobile, hidden in dark places during the day and can escape the object treatment. Quarantine and/or treatment of packaging materials like paper is already discussed.

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