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Long-tailed silverfish (*Ctenolepisma longicaudata*) – biology and control

Revised edition - 2019

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Foreword

The Norwegian Institute of Public Health (NIPH) has written this document in cooperation with Norsk Hussopp Forsikring, and it summarizes the level of knowledge in 2019 regarding the long-tailed silverfish (*Ctenolepisma longicaudata*). NIPH acts under the Health and Care Ministry of Norway as a national competence institution for governmental authorities, the health service, the judiciary, prosecuting authorities, politicians, the media and the public independent of commercial interests. The principle of substitution is a recurring theme in the management of and research on urban pests in Norway. It states that preventive and control measures must be carried out in an efficient way, but also pose the least possible harm on human health and the environment. Therefore, it is imperative to promote least-toxic methods as an alternative to pesticide use in indoor environments – it is indeed an important public health topic. The Department of Pest Control at NIPH is the national competence centre for prevention and control of indoors pests.

The long-tailed silverfish has shown a considerable increase in Norway the last years without any apparently good explanation. A sensible initial approach is to summarize the current level of knowledge of this species through a literature review to illuminate its strengths and weaknesses, and to identify potential control options. The present review is part of a larger project that aims to develop control- and management routines for the long-tailed silverfish. This species is clearly understudied and all scientific literature identified under the species name *Ctenolepisma longicaudata* in the literature databases Web of Science, SCOPUS and PUBMED have been reviewed. Additionally, the literature list of all these papers have been used to find older, non-searchable literature. Chosen scientific publications on the related, indoor species the common silverfish (*Lepisma saccharina*), the firebrat (*Thermobia domestica*) and the four-lined silverfish (*Ctenolepisma lineata*) have also been conferred as extended references for control and behaviour, and to enlighten biological aspects not yet studied in the long-tailed silverfish. The literature review is available at www.fhi.no free of charge. This is the second version, the first edition was published in 2018 (only in Norwegian). It is likely that updates will occur regularly as we expect new knowledge regarding control to become available. It is considered important to get such information to the pest control companies and their technicians.

Oslo, March 2019

Anders Aak ***Bjørn Arne Rukke*** ***Preben S. Ottesen*** ***Morten Hage***

Content

1 – The long-tailed silverfish and other relevant species

The long-tailed silverfish (Zygentoma; Lepismatidae - *Ctenolepisma longicaudata*) belongs to the bristletails and is among the oldest known insects (Truman & Ball, 1998; Whitington et al., 1996). Evolutionary they appeared before the insects developed wings and are therefore considered primitive insects (Hasenfuss, 2002). Among the bristletails there are approximately 550 described species (Elven & Aarvik, 2018). Most of them are ventrally flattened with an elongate and tapered body, small eyes, long antennae and caudal (tail-like) filaments, and many of the body parts are often covered with hair or scales (Sturm, 2009b). The bristletails are divided into the families Lepismatidae, Nicoletiidae, Ateluridae, Lepidothrichidae and Maindroniidae. The first two are found worldwide, but only members of the Lepismatidae are encountered indoors. The bristletails appearing in large numbers indoors belong to three genera, and the most typical representatives are the long-tailed silverfish, the common silverfish and the firebrat (Bennett et al., 2010; Mallis et al., 2011; Robinson, 2005). These three species have distinct differences in their preferred habitats (Heeg, 1967b; Lindsay, 1940; Sweetman, 1939; Tremblay & Gries, 2006), and it is consequently important to distinguish between them to allow rational and efficient control.

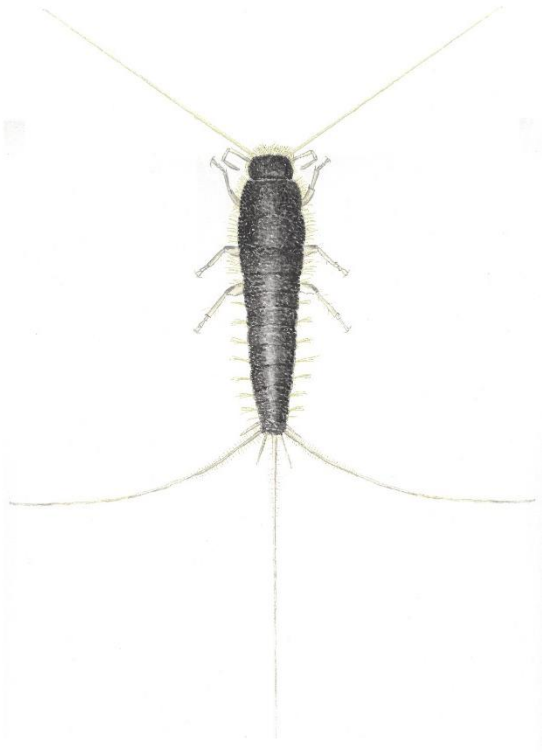

Figure 1. Long-tailed silverfish (*Ctenolepisma longicaudata*). Illustration - Preben Ottesen, © NIPH

1.1 – Long-tailed silverfish (*Ctenolepisma longicaudata*)

The *Ctenolepisma*-genus contains about 100 species, and many are found indoors (Goddard et al., 2016; Molero-Baltanas et al., 1997; Molero-Baltanas et al., 2012). Only the long-tailed silverfish and *Ctenolepisma calva* are registered this far in Norway (Mattsson, 2014; 2018). The long-tailed silverfish may become large if they live under good conditions, and maximum length without the antennae is expected to be 18 mm (Pape & Wahlstedt, 2002). Normal size for the adults is approximately 12 mm (Robinson, 2005). Here we describe the general appearance of the adult long-tailed silverfish (Figure 1), while the small discrepancies between the nymph stages and gender differences are described in parallel with the lifecycle (Chapter 2.1). The long-tailed silverfish is mottled in its coloration. The scales are in both grey and brown colour tones. They appear less silvery and shiny when compared to the common silverfish. Three strikingly long tail-like filaments are found at the end of the flat, elongate and clearly tapered abdomen. The middle one points directly backwards and is as long as the body, while the two other filaments often point directly to the sides. The head has two long antennae and two small maxillary palps. When

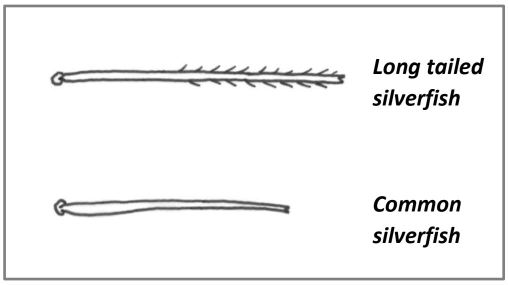

Figure 2. Difference in the morphology of the largest hairs of long-tailed silverfish (*Ctenolepisma longicaudata*) and silverfish (*Lepisma saccharina*). Illustration - Preben Ottesen, © NIPH

seen from above, the head and edges of the long-tailed silverfish will appear much more hairy when compared to the common silverfish. The shape of the larger hairs (Figure 2) and placement of bristle combs are decisive characters for species identification of the long-tailed silverfish (see identification key in Appendix A).

1.2 – Common silverfish (*Lepisma saccharina*)

The *Lepisma*-genus has many known species, but only the common silverfish is found indoors. Adults of the common silverfish will normally reach a maximum length of 10-12 mm (Robinson, 2005). The common silverfish is evenly coloured and silvery in its appearance (Figure 3). The colour may range from dark grey to light and silver shimmering. The common silverfish has shorter tail-like filaments, and the side-filament are often pointing backwards and to the sides. The middle filament is shorter than half the length of the body. The head and the sides of the body appear less hairy when compared to the long-tailed silverfish, but the head and the anterior parts carry some protruding hairs. Species specific details are given in the identification key (Appendix A).

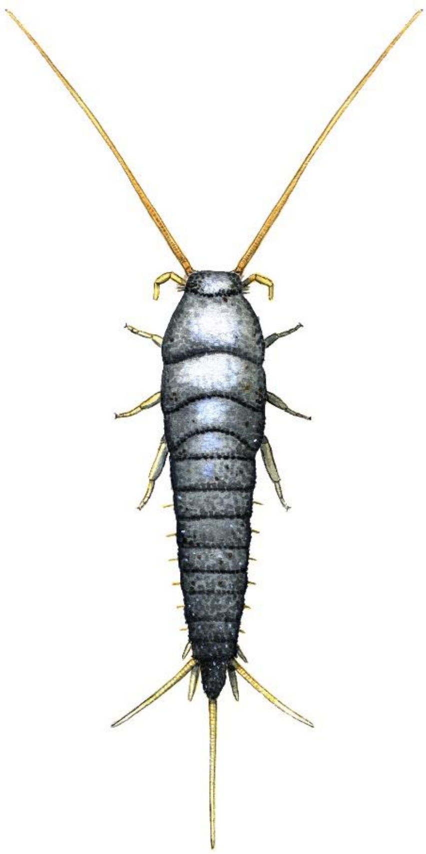

Figure 3. Silverfish (*Lepisma saccharina*). Illustration - Hallvard Elven, digital colour adjustment- Preben Ottesen, © NIPH.

1.3 – *Ctenolepisma calva*

Ctenolepisma calva appears similar to the long-tailed silverfish, but is white coloured. The middle caudal appendage is as long as the body, while the two lateral appendages are 2/3 of the body length. Adult body length is 8 mm.

1.4 – Firebrat (*Thermobia domestica*)

The *Thermobia*-genus also holds many species, but the firebrat is most commonly encountered indoors. It is large, and the appearance resembles the long-tailed silverfish by colour and their long tail-like filaments. The firebrat will normally appear to have a slightly darker thorax, and they are described as more parallel sided and less evenly tapered towards the end (Lillehammer, 1964). To distinguish firebrats from the long-tailed silverfish a combination of coloration and species specific placement of hairs and bristle combs is required (described in identification key in Appendix A).

1.5 – Other species

In other parts of the world, several other bristletails species are encountered indoors (Mallis et al., 2011). *Ctenolepisma lineata* and *Acrotelsa collaris* are relatively common in the US, *Thermobia campelli* is found in stored food and *Nicoletia meinerti* in greenhouses. *Ctenolepisma ciliata*, *Ctenolepisma diversiquamis* and *Ctenolepisma targionii* have also been occasionally encountered indoors (Mallis et al., 2011; Molero-Baltanas et al., 1997; Robinson, 2005). As a curiosity it should also be mentioned that Norwegian buildings positioned very close to the shoreline sometimes get visits from the Machilidae (jumping bristletails) *Petrobius brevistylis* and *P. maritimus* (NIPH_Pest-Statistics, 2019).

2 – Biology of the long-tailed silverfish

The long-tailed silverfish is an understudied species, and no scientific description of its natural biology exists. The long-tailed silverfish may be considered a true anthropocore as they are present in manmade habitats on most continents and depend on human-assisted dispersal for reproduction across discrete populations (Goddard et al., 2016; Molero-Baltanas et al., 1997; Wygodzinsky, 1972).

2.1 – Life cycle

The long-tailed silverfish is an ametabolous insect. It means that the individuals that emerge from the eggs are small, but relatively similar to the adults and they have a gradual growth through moulting. Insects that grow through moulting become passive before they shed their old skin. They go through many internal physiological changes before they break down their old exoskeleton, split the cuticle lengthwise and emerge as renewed and slightly larger individuals (Gullan & Cranston, 2014). The growth rate between the stages in the long-tailed silverfish is 10-25 %, but depends on access to nutrition and the environmental conditions (Lindsay, 1940). Continuous poor conditions may consequently result in smaller individuals than expected. The long-tailed silverfish become adults with fully developed genitalia at stage 14 (Lindsay, 1940).

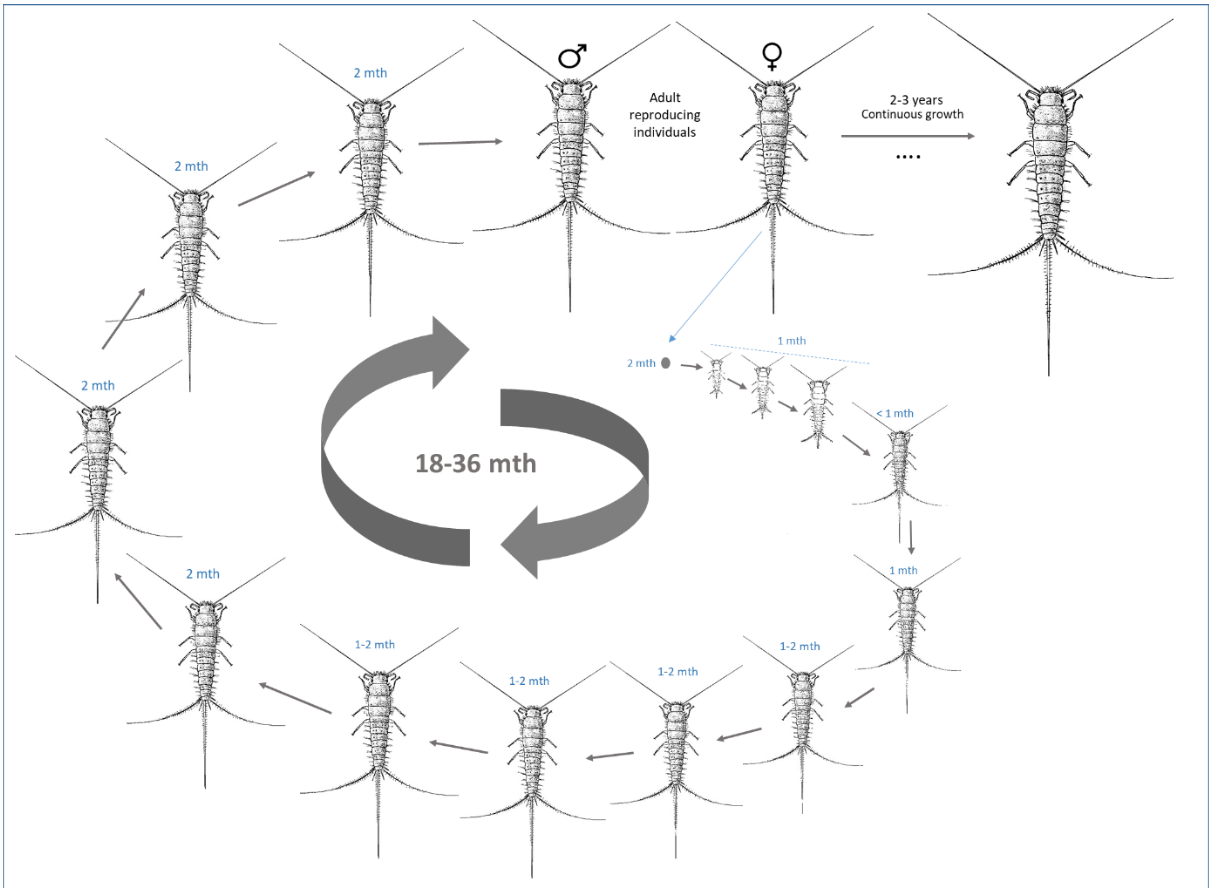

Figure 4. Illustration of the development of the long-tailed silverfish (*Ctenolepisma longicaudata*) from egg to the adult stages. Time of development of the different stages is according to Lindsay (1940) and indicates this under constant and ideal conditions, while the indication of a span in life cycle length is based on expected suboptimal and variable temperature conditions. Illustration – Preben Ottesen © NIPH

Moulting and growth continue after maturation, but the increase in size diminishes as resources are allocated from growth to survival, reproduction and repairs of damage (Delany, 1957; Lindsay, 1940). When bristletails shed their skin, they are able to repair damage and regenerate lost appendages (Buck & Edwards, 1990). The time they spend at each stage depends on temperature and access to nutrition, but it is assumed that they may develop to adults within 18 months if conditions are optimal (Delany, 1957; Lindsay, 1940). Even if our indoor environment is stable, day- and annual fluctuations in temperature and moisture levels will constrain the favourable conditions, and by doing so prolong the lifecycle (Figure 4). There has for example been an observation of a doubling in length in the lifecycle of the common silverfish when variable and more natural conditions are compared to stable laboratory conditions (Delany, 1957). In a variable environment it is likely that the lifecycle of the long-tailed silverfish will require approximately 3 years for completion. Adults may live for a few years (Lindsay, 1940). This gives the long-tailed silverfish a remarkable long life-span among the indoor pest insects.

Figure 5. Eggs of long-tailed silverfish (*Ctenolepisma longicaudata*). Photo; Morten Hage, © NIPH.

The **eggs** may be deposited separately or in groups. 10 eggs are normally deposited at a time (Delany, 1957). They are oval with a smooth surface, cream coloured to yellow-brown, (Figure 5), 1.15 mm long and 0.83 mm wide (Lindsay, 1940). The females probe with her egg laying tube into cracks and crevices (Video-link in Appendix D), to hide the eggs at protected locations with favourable conditions for survival and development. The long-tailed silverfish and other bristletails are offered cotton for egg deposition in laboratory cultures (Whitington et al., 1996; Woodbury & Gries, 2013a). At room temperature, 20-22 °C, the egg hatches in about 2 months (Lindsay, 1940).

Figure 6. First instar of long-tailed silverfish (*Ctenolepisma longicaudata*). Photo; Morten Hage, © NIPH.

The **first instar** nymphs (about 2.9mm) emerge from the egg. They differ from later instars by being lightly coloured and partly transparent, and they have short antennae and tail-filaments (Figure 6). To open the egg they also have a hatching organ in the shape of a tiny edge at their forehead. At room temperature, this stage only lasts for a few days. The first stage is also described as sluggish, and it is capable of moulting into the next stage without feeding (Lindsay, 1940). The first stage is assumed to be a passive stage as it carries enough nutrition from the egg and is therefore rarely observed.

The **second and third instars** (about 3.4 to 4.4mm) have a shape that resemble larger individuals, but they have fewer hairs, lack scales and are not as evenly tapered towards the tail-filaments (Figure 7). Under ideal conditions they only spend 1-2 weeks at each of these stages (Lindsay, 1940). The second instar is white and only slightly yellowish coloured, while the third instar is more cream coloured to yellow-brown with a purple tint around the edges of the carapace and the tail.

Figure 7. Second instar of long-tailed silverfish (*Ctenolepisma longicaudata*). Photo; Morten Hage, © NIPH.

Figure 8. Morphology of long-tailed silverfish (*Ctenolepisma longicaudata*) in instars 4 to 8. Photo; Morten Hage, © NIPH.

In the **fourth to the seventh instar** (about 4.8-5.5mm), the nymphs become very similar to the adults, but they lack any structures connected to reproduction (Figure 8). They are best described as miniatures of the adults as they are covered in scales, have the characteristic bristletail shape and have long antennae and tail filaments. In good conditions these stages will last from 2 to 7 weeks, and the time spent at each stage increases stepwise (Lindsay, 1940).

Figure 9. Morphology of long-tailed silverfish (*Ctenolepisma longicaudata*) in instars 9 to 13. Visible styli indicate start of development of sexual organs. Photo – Morten Hage, © NIPH.

Maturation occurs gradually from **stage eight to thirteen** (about 5.7-9.7mm) and these nymphs become even more similar to the adults (Figure 9). Internal structures develops, and styli and reproductive organs become visible at the end of the abdomen. These characters are located on the ventral side of the insect and may be hard to observe without good magnification. The time spent in each stage becomes longer during the development and reaches 5 to 9 weeks per stage (Lindsay, 1940). It is possible to separate the genders at stage eight. The differences grow more and more distinct through the development, but are not truly relevant until stage 14 when reproduction starts.

The long-tailed silverfish become adults from **stage 14** (10-18mm, Figure 10) when the reproductive organs are fully developed. Males and females are largely similar, but females have a narrow V-shaped opening at the ventral side of the abdomen and a clearly visible egg laying tube, while males have a more U-shaped opening and a penis (inset in Figure 10).

The total reproductive potential of insects is connected to the abiotic conditions, nutritional status and aging (Chapman, 2013; Price et al., 2011). The long tailed silverfish may live for a long time and deposit many eggs under good conditions. This allows them to produce large infestations. A mature long-tailed silverfish female can probably produce eggs for most of her life, but the total lifespan production has never been thoroughly studied. In large laboratory cultures an average of 50 eggs per female per year has been noted (Lindsay, 1940). This indicates a maximum production of 100 to 150 eggs if they survive for up to 3 years after maturation, and if the fertility remains high. Other bristletails show seasonality in reproductive effort, but the long-tailed silverfish has a constant production throughout the year (Delany, 1957). It is therefore reasonable to expect a relatively stable population growth in year-round heated buildings.

Figure 10. Adult long-tailed silverfish (*Ctenolepisma longicaudata*). Photos of the genital opening of females and males are inserted. Photo; Morten Hage, © NIPH.

Figure 11. Long-tailed silverfish (*Ctenolepisma longicaudata*) on a piece of wood in a laboratory culture. Photo; Morten Hage, © NIPH.

2.2 – Natural distribution and habitat

In the early 19th century, the long-tailed silverfish was described as an indoor nuisance pest in South-Africa and Australia (Heeg, 1969; Lindsay, 1940; Womersley, 1937). Descriptions from outdoor habitats consist of simple observations from cavities under rocks close to human activity (Heeg, 1969; Molero-Baltanas et al., 2017). Other bristletails and the jumping bristletails (Archaeognatha) have a better described biology. They often live in the transition between soil and the vegetation and are found in the litter and under rocks, in small caves and animal dwellings in addition to an association with ant and termite nests (Delany, 1957; Molero-Baltanas et al., 2017; Molero-Baltanas et al., 2010; Molero-Baltanas et al., 2012; Robinson, 2005). They may feed on simple diets consisting of green algae, moulds lichen, pollen or other plant material, or by utilization of a wider and more general diet when they act as detritivores that contribute to decomposition and recycling of nutrients (Robinson, 2005; Sturm, 2009a; b). Indoors the long-tailed Silverfish appears to be among the generalists as they are reported to feed on starches, sugar, proteins and fat (Bennett et al., 2010; Gold & Jones, 2000; Lindsay, 1940; Mallis et al., 2011). The long-tailed silverfish will not survive outdoors in Norway because of the cold winters and low summer temperatures, and its "natural" habitat is therefore heated buildings. The indoor insect fauna is variable, but it is often observed that parts of a buildings at or below ground level contains the largest number and diversity, and that furnishing and construction affect distribution (Leong et al., 2017; Robinson, 2005). These general patterns are likely visible within populations of long-tailed silverfish as well, but preferences and distribution inside buildings are poorly studied this far.

2.3 – Abiotic preferences

Most insects are capable of surviving in a range of environments, but outside of optimum conditions the environmental stress will increase to create weaker individuals and limit population development (Price et al., 2011). This causes patchily distributed individuals even though the possibility for activity in large areas is possible. The three most common indoor living bristletails is a nice example of this population dynamic in the urban ecosystem. The common silverfish prefers rooms with high humidity and is found in bathrooms, rooms with ongoing moisture damage or in environments with prevailing high relative humidity (Molero-Baltanas et al., 1997; Sweetman, 1939). Even if they may move out of these rooms for a limited time, the draught stress will become too large for establishment in bedrooms or living rooms. The common silverfish is considered an unproblematic pest, which is controlled or kept at bay with repair of moisture damage, humidity control or simple control efforts, such as limited use of sugar based baits. The firebrat, which demands high humidity and high temperatures (Sahrhage, 1954; Sweetman, 1938), is often found in warm regions far away from Norway, and it is doubtful that they will manage to develop in normal Norwegian buildings. The Firebrat is uncommon in Norway (Lillehammer, 1964) because they prefer temperatures around 35-37 °C (Tremblay & Gries, 2006). They may appear in special environments such as bakeries, in hot machine rooms or other special buildings, but control will only demand local temperature adjustments to prevent survival and reproduction. The long-tailed silverfish is now frequently found in Norwegian buildings because there is a substantial overlap between their preferred environment and our desired indoor conditions. The long-tailed silverfish may thus be found in all type of rooms in our year-round heated buildings (Figure 12).

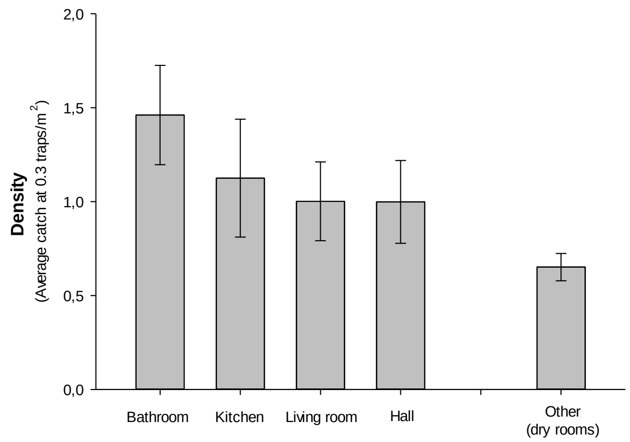

Figure 12. Distribution of long-tailed silverfish (*Ctenolepisma longicaudata*) in various types of rooms (n=354, Average catch ±SE) from Norwegian apartments and row-houses.

2.3.1 – Light

The long-tailed silverfish are nocturnal insects, which avoid bright light. The biological impact of light on the long-tailed silverfish is hardly investigated, with the exception of one behavioural study (Heeg, 1967b). It is however known from its close relative, the firebrat, that day-night activity is adjusted by a cyclic regulation of activity in its nervous system (Kamae et al., 2010; Kamae & Tomioka, 2012; Závodská et al., 2005). When combined with the difficulty of observing the long-tailed silverfish during the day, and a day-night activity in constantly lit experiments (Lindsay, 1940), it is reasonable to assume that the long-tailed silverfish uses similar mechanisms. Light consequently contributes to the local distribution of individuals. During the day, the long tailed silverfish is encountered at dark harbourages, such as inside furniture, shelves or bookcases, under different objects, behind skirting or in other small cavities. During the night they are more active in search of food (Lindsay, 1940) and move from their preferred harbourages.

2.3.2 – Temperature

The long-tailed silverfish prefers temperatures from 20 °C to 26 °C. Temperatures below 20 °C will delay the lifecycle because the time in each developmental stage will increase. The development stops at 16 °C, but as opposed to the smaller nymphs, that die after a few weeks at 10 °C, the larger individuals will survive temperatures down to 0 °C (Lindsay, 1940). There is no scientific information regarding tolerance of **temperatures below zero** and the time needed to kill the long-tailed silverfish by freezing. This is a research topic that needs investigation to reveal any adaptions or mechanisms behind a potential cold-tolerance. In the other end of the temperature scale some information exists, but exact limits for survival at **high temperatures** are also limited. The time needed for hatching and development is reduced as temperatures increases to 30 °C. This occurs in parallel with a decreased survival time among larger nymphs and adults in the range from 26 to 28 °C (Lindsay, 1940). Activity is also decreased above 24 °C, just before the tipping point between fast development and survival time (Lindsay, 1940). This indicate that the optimum temperature may be close to 24 °C, while behavioural studies with free movement across a temperature gradient indicate a preference for 20 °C (Heeg, 1967b). Compared to bed bugs, who also appear as pests in indoor environments, the tolerance against heat stress appears to be poor (Lindsay, 1940; Rukke et al., 2015; Rukke et al., 2018). Heat stress experiments indicate that the long-tailed silverfish will experience considerable mortality if exposed for some time to 35-40 °C, and they will only survive for hours at temperatures above 40 °C (Lindsay, 1940). These observations coincides with a shortened survival between 30 °C and 35 °C, but since survival during heat stress often is connected to interactions between temperature, humidity, behaviour and physiology (Chown & Nicholson, 2004) thorough studies need to be conducted before the true negative impact for both individuals and the population may be revealed.

2.3.3 – Humidity

The long-tailed silverfish is considered much more draught resilient compared to the other bristletails encountered indoors. Both the common silverfish and the firebrat have their optimum development in environments with a relative air humidity above 75 % (Sahrhage, 1954; Sweetman, 1938; 1939), while the moisture demand is lower in the long-tailed silverfish. The long-tailed silverfish will survive for some time during dry conditions, but in the long run they will need 55 % air humidity. Even with access to food, they will not survive for more than a few weeks at 45 %, maximum one month at 50 % and more than 3 months at 55 % (Lindsay, 1940). Eggs and the early stages have stricter moisture demands and die even faster at levels below 55 %. Microclimatic conditions in cracks and crevices will be crucial for survival as the long-tailed silverfish has the opportunity to move to places with good conditions for development. It is uncertain if silverfish are capable of drinking water or only obtain liquids through their food. On the other hand, the long-tailed silverfish has the ability to absorb water from the air (Heeg, 1967a) and may consequently have a better survival than suspected from measures of air humidity. They may also replenish their body with water by spending time close to free water, or if the humidity increases for a short time (Heeg, 1967a; Lindsay, 1940). It may be difficult for the long-tailed silverfish in dry conditions, but access to free water is likely a key for their survival in suboptimal conditions.

2.4 – Nutritional demands and metabolism

The long-tailed silverfish and several of the other indoor bristletails have been reported to utilize starch and carbohydrates from paper (Delany, 1957; Lasker, 1957; Lindsay, 1940; Treves & Martin, 1994; Zinkler & Gotze, 1987). The long-tailed silverfish appears to have less cellulolytic enzyme activity compared to the firebrat (Pothula et al., 2019) and microorganisms in the bristletails digestive system are a somewhat unclear factor. They are probably contributing to breakdown and digestion, or as nutritional supplements (Pothula et al., 2019; Woodbury & Gries, 2013a; b; c; Woodbury et al., 2013). In spite of the adaption, paper is not optimum nutrition for the long-tailed silverfish. The long-tailed silverfish requires proteins for full development (Lindsay, 1940), and smaller stages are not capable of moulting when supplied a simple carbohydrate diet. The ability to survive for a long time on paper is probably restricted to the later stages. Insect egg production is also connected to a high intake of proteins, and central insect hormones are based on resources such as amino acids and cholesterol (Chapman, 2013; Gullan & Cranston, 2014). To ensure fast and complete development in laboratory cultures, bristletails are held on a complete diet consisting of proteins, carbohydrates fat and other essential nutrients (DeVries & Appel, 2013; Wang et al., 2006; Whitington et al., 1996; Wijenberg et al., 2013).

The long-tailed silverfish may move long distances to find food, but if a good source is encountered they tend to remain in the vicinity of it (Mallis et al., 2011). There are also several observations of long-tailed silverfish feeding on dead insects. This is probably an important source of proteins in indoor environments. Cannibalism is also common (Delany, 1957), and dead individuals of their own species are probably not only eaten for energy, but also to get hold of essential nutrition and symbionts (Woodbury & Gries, 2013a; c; Woodbury et al., 2013). Carbohydrates, mostly used as energy, may originate from paper, grain or sugar, but even minor leftovers such as fat, breadcrumbs, cereals, seeds and such may constitute important nutritional supplies and provide essential trace elements. Close relatives to the long tailed silverfish also show variation in the diet as a result of temperature. The common silverfish prefers sugar at low temperatures and fat and proteins at higher temperatures when growth and population development is most intense (DeVries & Appel, 2014). Adult individuals of both the common silverfish and the firebrat also have a low basal metabolism (low energy use at rest) and consequently good abilities to survive long periods of time without food (DeVries & Appel, 2013). Observations of long survival on limited resources in the long-tailed silverfish (Lindsay, 1940) indicate similar abilities with respect to distribution of energy and resources.

2.5 – Behaviour and sensory system

All animals depend on a well-developed sensory system to perform essential tasks that lead to survival and reproduction (Stevens, 2013). The bristletails are primitive insects (Sturm, 2009a; b), but have all basic senses such as vision, olfaction, taste and mechanic sensors for registration of moisture, temperature, touch and vibrations (Berg & Schmidt, 1996; 1997; Farris, 2005; Hadicke et al., 2016; Hasenfuss, 2002; Heeg, 1967b; Lindsay, 1940; Missbach et al., 2014; Woodbury & Gries, 2007). Among higher insects the sensory organs have developed further to highly specialized organs, while the bristletails probably hold a somewhat simpler perception and evaluation of the environment in which they reside (Christensen, 2005; Hansson & Stensmyr, 2011; Haverkamp et al., 2018).

2.5.1 – Eyes and vision

The eyes of the long tailed silverfish consist of 12 facets, and may therefore be described as small and simple. Their ability to perceive visual input and orient according to them has not been studied, but other nocturnal insects such as the firebrat and bed bugs, which have simple eyes of comparable structure, are able to discriminate objects' light intensity and colours (McNeill et al., 2016; Tremblay & Gries, 2006). The firebrat also shows preference for black or dark objects in a way that indicate that vision contributes to location of harbourages (Tremblay & Gries, 2006). As the long-tailed silverfish does not have point eyes, it is likely that the facets acts as light measure and, as for the firebrat, probably contributes to regulation of circadian rhythms (Kamae et al., 2010; Kamae & Tomioka, 2012; Závodská et al., 2005). It has also been observed that the level of perceived light affect preference for temperature and moisture to accept less beneficial conditions as long as it is dark (Heeg, 1967b).

2.5.2 – Olfaction and taste

The ability to register chemicals through sensory organs on the antennae is believed to be as old as the insects and depend on the capability of capturing volatiles in the air or chemicals on a substrate in addition to interpretation of this input (Hansson & Stensmyr, 2011; Haverkamp et al., 2018). The antennae of most bristletails have many sensory structures (sensillae) characteristic for both contact and remote detection of chemicals (Berg & Schmidt, 1996; 1997; Hadicke et al., 2016; Hansen-Delkeskamp, 2001; Missbach et al., 2015), and the brain contains structures needed for handling of such signals (Farris, 2005). These structures are poorly studied in the long-tailed silverfish, but it has been shown that contact with specific chemical signals affect behaviour and lead to aggregation (Woodbury & Gries, 2007; 2013b). Long range detection of volatiles such as odour from food has not been studied, but description of the antennae of the most common indoor bristletail species point at taste (contact) and olfaction (long range) as behaviour modifying components (Hadicke et al., 2016; Hansen-Delkeskamp, 2001; Missbach et al., 2015).

2.5.3 – Mechanical senses, moisture and temperature

At the antennae and the tail-like filaments there are also several sensory structures connected to temperature and moisture registration as well as motion detection (Berg & Schmidt, 1996; 1997; Hadicke et al., 2016). These organs are not well studied, but in general they are used for choice of habitat, movement and registration of touch (Chapman, 2013). For the firebrat the ability to detect temperature is crucial for establishment in harbourages (Tremblay & Gries, 2006), and mechanoreceptors in the tail and the antennae are likely to contribute to avoidance of danger (Berg & Schmidt, 1996; 1997; Hadicke et al., 2016). A curious observation is also done among both the firebrat and the common silverfish. They have the ability to detect weak electrical currents and show tendencies to stop and aggregate on objects that contain an electrical field (Wijenberg et al., 2013).

2.5.4 – Aggregation and mating behaviour

Aggregating insect behaviour means that individuals cluster together to obtain advantages. This kind of behaviour is present among the long-tailed silverfish, the common silverfish and the firebrat and is based on species specific signals (Tremblay & Gries, 2003; Woodbury & Gries, 2007; 2008; 2013a; b). The long-tailed silverfish gain advantages through the aggregation signal as it indicates beneficial microclimatic conditions and short distance to food. An assembly of individuals also reduces the predation risk, increases drought resilience, provides access to mating and increased growth (Gullan & Cranston, 2014; Price et al., 2011; Sweetman, 1938). An aggregation will get strengthened gradually when foraging behaviour combines with aggregation signals, if both food and beneficial abiotic conditions are present simultaneously (Bennett et al., 2010; Mallis et al., 2011). This may explain the observations of elevated densities in bathrooms and kitchens (Figure 12). The signal that creates the foundation for the aggregation is based on microorganisms in the long-tailed silverfish's intestinal system. The bacteria *Enterobacter cloacae* and the fungi *Mycothypha microspora* evoke aggregation in the firebrat, while only the fungi does so in the long-tailed silverfish (Woodbury & Gries, 2013a; b). Further details are not studied in the long-tailed silverfish, but in the firebrat the microorganisms are transferred by ingestion of faeces or other materials contaminated by conspecifics, and the substances may act as nutrition and supplements for the early juveniles (Woodbury & Gries, 2013c; Woodbury et al., 2013).

Mating also occur in the aggregations. The bristletails have mating rituals that are specific for the individual species. The «mating dance» of the firebrat and the silverfish is described, and it consists of a sequence of contact and movements before silk threads are produced to lead the female towards a sperm capsule (spermatophore) which fertilises the female without direct contact between the genders (Sturm, 1997). The ritual is not described in the long-tailed silverfish, but silk threads and spermatophores have been found (Walker et al., 2013).

3 – Damage

The mechanical damage caused by the long-tailed silverfish is limited and partially connected to nutrient uptake. As they are capable of chewing on many substrates, they may gnaw on several products such as paper, pictures, books and most dried food. Cloth produced from cotton, linen or other plant materials may also be chewed on, but wool, silk and fur is rarely ingested (Bennett et al., 2010; Mallis, 1941; Mallis et al., 2011). It is important to highlight that mechanical damage in a private setting is very limited. Serious damage only occurs if objects of high value are damaged, and it is therefore much more problematic with long-tailed silverfish in libraries, museums and art collections where irreplaceable objects may become degraded or destroyed (Szpryngiel, 2018).

Bad publicity in media may also impair reputation and create economic loss for shopkeepers, the accommodation industry and other service providers if businesses are connected to dispersal of the long-tailed silverfish. This is also relevant for housing cooperatives, landlords, schools and kindergartens who likewise may get a bad reputation if they house the nuisance pest. In Norway, the long-tailed silverfish has also played a part in an increasing number of residential sales disputes. In addition to large economic demands from byers of infested apartments, these legal problems hold a societal factor as resources in the legal system become occupied.

The psychological distress of sharing residence with the long-tailed silverfish is a major factor in a private home. The cool climate in Norway with fairly closed buildings will normally only allow a limited number of indoor insects. When this is combined with a high standard of living and good hygienic conditions, the general opinion in Norway is a zero-tolerance for indoor pests. This has created the notion of an invasion of our private sphere when the long-tailed silverfish becomes established, even though they are hardly observed and the physical damage is marginal. The psychological distress is further strengthened by an unjustified fear of social stigma and a misunderstood connection to unhygienic conditions. A high density of the long-tailed silverfish is clearly unacceptable, but low density populations in parts of a building will probably be acceptable for some time. It is also important to be aware of the fact that control efforts likely need to be carried out for an extended time, and that rebounding populations from failed control attempts may strengthen the unease related to this nuisance pest.

Allergic reactions to insects may occur. It is common to respond to bites or stings, but reactions may also appear after ingestion or inhalation of insect proteins (Arlian, 2002). The connection between asthmatic reactions and insects is unclear, but allergens in excrements and insect parts are a potential factor in sensitisation and worsening of asthma (Arlian, 2002). Cockroaches are well studied according to insect induced allergy, and the typical observation is that individuals of lower social status have a higher incidence of cockroaches and thereby more allergic problems (Gore & Schal, 2007). Reduced exposure is only achieved by control of the cockroaches and removal of allergens (Rabito et al., 2017). The bristletails may also contribute to this kind of problem as they moult and leave behind insect hairs, fragments, scales and excrements, but a direct connection between bristletails and allergic problems has not been shown (Barletta et al., 2005; Barletta et al., 2002; Boquete et al., 2008). Small insect populations play a lesser part in a total situation with many allergy regulating factors (Arlian, 2002; Bonnefoy et al., 2008), and the risk of development of hypersensitivity and asthmatic problems is therefore low in Norwegian buildings with high standards and generally low levels of insect-allergens. People who already are allergic or experience asthmatic problems released by insect allergens, should pay attention to these problems and avoid contact with indoor pests (Arlian, 2002).

4 – Control and handling of the long-tailed silverfish

The long-tailed silverfish has been found in Norwegian homes for some years, but the last three years have shown a numerical escalation. In 2016 there was 511 registered control cases, while this number increased to 1516 in 2017 and 3433 in 2018 (NIPH_Pest-Statistics, 2019). It is likely that there has been an intermediate activity in Norway in the years before this, and in addition to the numbers found in the statistics it is known that the long-tailed silverfish has been present for some years. The long-tailed silverfish was officially registered in 2014 through 9 infestations (Mattsson, 2014). There is also one possible case from Oslo in 2004, and 3 confirmed cases from Bærum (Mattson, 2018 pers. comm.), Årstad and Godvik (Djursvoll, 2017) in 2006, 2008 and 2009, respectively. As a curiosity it is also worth noting that among some old firebrat observations from Norway, we also found the long-tailed silverfish collected at the Zoological Museum of Oslo in 1979 (NIPH_Pest-Statistics, 2019). Reported insurance cases regarding the long-tailed silverfish (Norsk Hussopp Forsikring) show a distinct excess of new buildings in the claims (Figure 13). Buildings constructed after year 2000 appear to be hardest hit by this new problem, and an increasing number of reports from office buildings kindergartens, schools, museums, libraries and other official buildings has appeared in recent

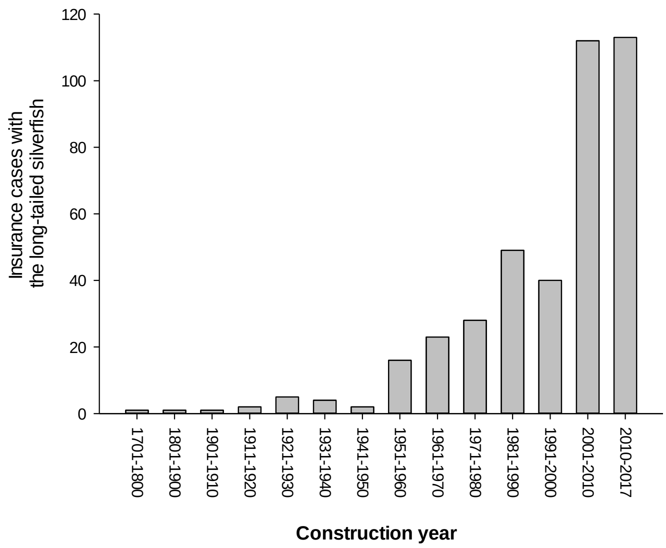

Figure 13: Reported insurance cases regarding the long-tailed silverfish (*Ctenolepisma longicaudata*) according to year of construction.

years (NIPH_Pest-Statistics, 2019). First observations of the long-tailed silverfish and a similar escalation of the problem are also described from the Netherlands, Great Britain, Belgium, Sweden, Germany and the Czech republic (Bujis, 2009; Goddard et al., 2016; Kulma et al., 2018; Lock, 2007; Meineke & Menge, 2014; Pape & Wahlstedt, 2002; Schoelitsz & Brooks, 2014). The pest control industry in Norway has met a new challenge through the long-tailed silverfish. This far it has been case-to-case treatment, but the extent of the problem the last years highlight the need for thorough control with many approaches, building-wide management and identification of sources of introduction and dispersal.

International literature on silverfish control point at the long-tailed silverfish as more demanding to control when compared to the other bristletail species. Strategies should consequently include a more complete and integrated pest management approach (Bennett et al., 2010; Mallis et al., 2011). Recommendations include reduction of moisture and removal of as many hiding places as possible. This also includes attics and basements where cardboard boxes, suitcases, bags and stored clothing may create favourable microclimatic conditions (Bennett et al., 2010). Vacuum cleaning of potential harbourages in furniture, small cavities, crack and crevices and underneath objects is recommended (Mallis et al., 2011), and dried food should be kept in closed containers. Conventional pesticides should only be directed towards areas of aggregation and potential daytime hiding places (Bennett et al., 2010; Gold & Jones, 2000; Mallis et al., 2011).

5 – Integrated Pest Management (IPM)

The most rational approach to control the long-tailed silverfish is an **I**ntegrated **P**est **M**anagement (**IPM)** strategy where the customer handles general population limiting efforts and a pest control technician conducts the technical evaluation and adjusts the control methods according to local conditions. An IPM-solution utilizes many control elements to achieve the desired control and includes preventive measures, inspections and identification, mapping of extent and evaluation of the effect. It may also be necessary to increase knowledge and understanding of the problem among users to improve the quality of own efforts. In large buildings, it may also be crucial with an open minded and collaborative approach between all stakeholders to maximize prevention and limit dispersal and re-infestations.

5.1 – Introductions, dispersal and preventive measures

It is important to differentiate between building types when the risk of introduction and preventive measures are evaluated. Problems with the long-tailed silverfish will typically be discovered in private homes, office buildings, schools, libraries and museums. All these places hold a responsibility for reducing the probability of further spread. In addition to this, it is very important to be aware of storage facilities for merchandise, distribution terminals for cargo and goods, second hand stores and flea markets, and their potential as distribution terminals for the long-tailed silverfish. These kind of commercial handlers operate with a large flow of goods, temporary storage and distribution, and it is very easy for the long-tailed silverfish to hitch a ride with pallets, crates, cardboard boxes or furniture to establish in new places. Without investigations and mapping of dispersal routes it is difficult to pinpoint the path of introduction. They do not live outdoors in Norway and must consequently be transported into buildings. Product packing, crates and boxes are the most likely candidates because wood, corrugated cardboard, polystyrene, plastic and its like provide a multitude of hiding places. It is not known if specific products stand out, but since there is a fast increase in the number of cases, it is likely that we have a continuous introduction or dispersal. Central stakeholders within merchandising should therefore take responsibility and perform systematic inspections, detection and control within their facilities. New buildings are overrepresented in control cases (Figure 13). This might be explained by a temporary elevated risk of introduction because new buildings will experience an increased influx of objects when all apartments are inhabited simultaneously. A large number of boxes with interior, construction materials, furniture, inventory and electronic equipment will in combination with many moving loads, elevate the risk in new buildings with synchronous housewarming. In older and established buildings, it is likely that the introduction will occur more sporadic when people move in or refurbish older apartments. The dispersal mechanisms will also in these cases be through objects, and it might be possible that we will observe a more even distribution according to year of construction in the future.

It is difficult to prevent sporadic introductions of the long-tailed silverfish. It will require a constant surveillance and inspection of all boxed items being brought into a building. It may be worthwhile to get rid of packaging quickly to slightly reduce the chance of infestations. There is also a minor risk of hitchhiking with handbags, briefcases, bags and backpacks from offices, schools, kindergartens or other apartments. The long-tailed silverfish is passive during the day. This reduces the chances of accidentally getting unwanted guests in objects brought back and forth on a daily basis. If handbags, briefcases or backpacks are placed off the floor and in well-lit locations, the risk is close to zero. Objects left over night in infested buildings will have a higher risk, and it may be beneficial to inspect them visually before bringing them home. If the long-tailed silverfish has been observed at the accommodation during vacations, an inspection of suitcases or backpacks may be beneficial when arriving at home. Moving loads are particularly demanding when it comes to dispersal of the long-tailed silverfish, as large volumes provide many potential hiding places. Precautions should be made if moving from infested buildings, but 100% prevention will require heat- or cold-treatment of the entire moving load, and this is costly and logistically challenging.

The long-tailed silverfish has a good dispersal ability inside buildings if they are established. They are small with a flattened body and are capable of walking between rooms, squeezing through tiny openings, and they may use pipe penetrations, air- and cable ducts as dispersal paths (Mallis, 1941; Mallis et al., 2011). Limitations of the freedom of movement may contribute in an IPM-strategy by reducing the possibility of finding suitable microclimatic conditions. To maintain a completely sealed building is not feasible, but to leave as few options for movement between units, by use of sealants and fine meshed screens in air ducts, may limit dispersal.

5.2 – Building wide strategies and population threshold values

It is very likely that the long-tailed silverfish will be able to move between apartments in the same building, and through time it is expected that a population will produce enough individuals to create a significant risk of internal dispersal. This situation makes individual treatment of apartments inefficient in the long run because re-infestation from neighbouring units will maintain the infestation. Treatment of the long-tailed silverfish should therefore be handled more in line with pharaoh ant, cockroach or bed bug infestations where dispersal between units is accounted for. The use of detection traps in neighbouring units is a minimum demand to obtain a reasonable overview of the infestation, and a total mapping of the building may often be necessary to allow a systematic and coordinated control effort.

Because a truly cost-efficient control method is currently not available and because the damage is limited, it is not expedient to use zero-tolerance in complex buildings. This will probably also lead to excessive use of pesticides. A second problem with zero-tolerance is that the risk of reintroduction currently appears to be high in Norwegian buildings, and a distinction between failed treatment and a new introduction will be very blurred. It is also important to point out that too high tolerance is unfortunate as the risk of dispersal increases with the number of individuals present. An acceptable threshold should be low enough to avoid both psychological distress and risk of dispersal. It is therefore important to elevate knowledge among users of the building. This will increase the understanding of the biology of the pest, probably improve own effort towards control and reduce mental distress and fear (Bennett et al., 2016). Pest control technicians handling the long-tailed silverfish consequently need to have extended knowledge about the pest and the ability to disseminate this knowledge in an easy and understandable way. A thorough and complete knowledge-based approach is likely to optimize the effects on all levels to achieve control success. An acceptable infestation level will depend on personal opinions, but low levels, which practically means no object damage and few visible insects, is probably something most people will accept.

5.3 – Inspection, detection and evaluation

A suspected infestation needs to be confirmed by species identification. This might be difficult as dead and dried silverfish may lack species specific characters such as hair and scales. Living individuals of long-tailed silverfish may also have broken appendages and lack hairs and scales and consequently resemble the common silverfish. Size is not a good character, but if large individuals are found (more than 12 mm) the suspicion is directed towards the long-tailed silverfish. It is important to get hold of complete individuals for species identification. The long-tailed silverfish is nocturnal and may be difficult to find during the day. By moving furniture, boxes or bookshelves it might be possible to encounter hidden individuals. The long-tailed silverfish are also often found behind skirting, under doorsteps and inside boxes for embedded lights.

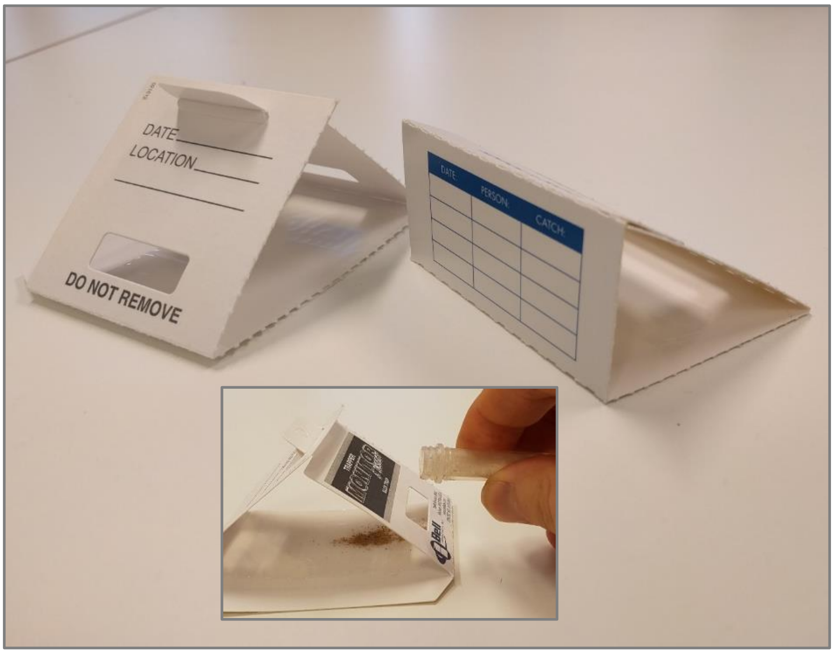

Figure 14: Examples of sticky traps used to catch the long-tailed silverfish (*Ctenolepisma longicaudata*), and addition of milled cricket powder. Photo; Morten Hage and Anders Aak, © FHI.

By opening such permanent cavities, one can expect to discover day-resting individuals. The owner of an apartment may also conduct night-inspections as it will be easier to find individuals moving about to find food. The use of sticky-traps for 14 days is also efficient for detection (Figure 14). The placement of traps in areas with suitable conditions and access to food will quickly collect individuals for species identification to allow the distinction between the long-tailed silverfish and the common silverfish. Bathrooms, kitchens and laundry rooms are hot-spots for the long-tailed silverfish. It is important to find more than one individual as the common silverfish and the long-tailed silverfish often occur together, and investigations should include more than the bathrooms alone to prevent catches of common silverfish only. The use of traps under and after control is also important to allow adjustments of strategies and to evaluate success. A small number of sticky-traps used for 14 days every 2nd or 3rd month is probably sufficient for evaluation.

5.4 – Cleaning and reduced access to nutrition

The long-tailed silverfish can feed on most of our food, and even tiny leftovers on the floor or behind stoves or refrigerators can be utilized. Thorough cleaning routines will consequently prevent access to food for the long-tailed silverfish and may contribute to limit the population growth. Cleaning will not solve the problem, but is an important contributor in an IPM-strategy. Leftovers should be removed, and thorough vacuuming of the floor and furniture as well as behind more permanent installations such as ovens and refrigerators, will remove the majority of available food in an apartment. Vacuuming may also move some of the long-tailed silverfish present. The vacuum cleaner bag should be thrown away or frozen to prevent individuals from crawling out again. It is also beneficial to store dried food in containers to make sure that they do not provide the long-tailed silverfish with a constant supply of food. Dried food for dogs and cats may also provide a major food source and should always be kept in closed containers.

5.5 – Environmental adjustments

Adjustments of the indoor environment may be beneficial as a part of a complete IPM-strategy. Dry conditions will give the long-tailed silverfish fewer options for reproduction, because the eggs and the early stages require higher moisture levels (Delany, 1957). Dry conditions in all cracks and crevices are difficult to achieve, but it is probably beneficial to limit the use of water during cleaning. Excess water may easily run underneath skirting, kitchen cabinets and cavities underneath furniture to provide the long-tailed silverfish with the moisture they need. Desiccant dusts are also a possible mean to create dry conditions in small cavities and consequently worsen conditions for the long-tailed silverfish (Gold & Jones, 2000; Mallis et al., 2011). This kind of approach will not be beneficial in areas with consistently high moisture where more permanent solutions, such as dehumidifiers, heat and aeriation, may provide better results.

A generally lowered temperature in a building will also prolong the time of the lifecycle, and decreased temperatures during the night may be beneficial both with respect to the long-tailed silverfish development and energy saving. There is however little scientific knowledge regarding the practical effect of such measures, but environmental adjustments have the potential to limit the available space with beneficial conditions and «buy» more time to succeed with eradication.

5.6 – Killing of established individuals

It should be possible to get rid of the long-tailed silverfish, but it is necessary to conduct a cost-benefit evaluation of the control measures in parallel with a health and environmental risk assessment connected to the users of the building. The long-tailed silverfish causes limited damage, and the control measures should reflect this. Control efforts must also account for building type, damage potential, potential control effect and risk of dispersal from the building. A storage facility will for example allow a completely different approach as compared to a kindergarten, and a kindergarten will demand a much higher responsibility with respect to information.

Many indoor pests may be controlled by removal of the sustenance of the population to make it collapse. The long-tailed silverfish may not be controlled this way because they live for a long time and have a substantial overlap with our environmental- and nutritional preferences. They also lead a particularly cryptic life, and in most situations the population has been allowed to fully establish before detection. This slow and hidden establishment of many and widely dispersed individuals requires an extra thorough approach towards control.

The time demands for a successful eradication is also expected to be longer than with most commonly occurring indoor pests encountered in Norway. It will be hard to reach all individuals quickly in a fully established population, and the slow development of the eggs is an important and delaying element. Eggs may hatch for as long as 2 months after removal of the last female, and these new individuals also need to be removed by the control measures. Individuals escaping the treatment may also become adults and deposit new eggs. However, with a thorough treatment in a long term IPM-programme there should be room for a successful outcome. In this respect, it may be considered beneficial that the long-tailed silverfish has a 2-year lifecycle as it provides plenty of time to succeed. If a constant numerical reduction is achieved the population will eventually die out.

5.6.1 – Mass trapping

Sticky traps are suitable for detection and monitoring. The removal of individuals from the population is also beneficial, and although mass trapping is unlikely to be a single solution, the traps will contribute towards control. Sticky traps for the long-tailed silverfish are basically a passive catch, but Norwegian field experiments show that the addition of small amounts of finely milled cricket powder (100% *Acheta* crickets, Figure 14) increases the catch as compared to un-baited traps (Figure 15). The attraction towards such a protein rich substrate may also point at proteins as a limiting resource in infested buildings. An attractant is useful as it has the potential to provide higher catch rates and better detection. Mass trapping is also a potential control method because the long-tailed silverfish has a very long lifecycle and is confined to a single area (building) with a low rate of new introductions (El-Sayed et al., 2006), but the effect of trapping is this far limited compared to other methods (Figure 16). The need for many traps used for a long time makes people perceive this approach as unpractical.

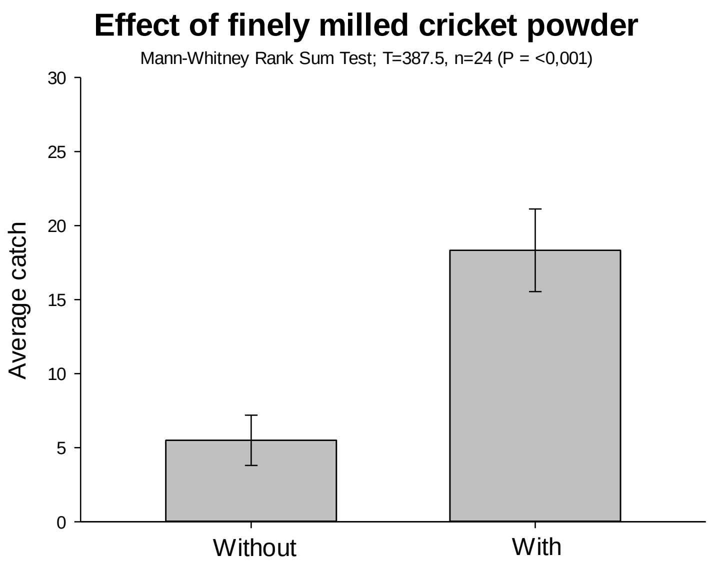

Figure 15: Average catch (±SE) of long-tailed silverfish (*Ctenolepisma longicaudata*) in sticky traps with or without a milled cricket powder.

5.6.2 – Toxic baits

There are many toxic baits intended for use against insects in buildings, and the low dose of harmful substances and the option of controlled placement with small amounts of bait make this strategy preferable to conventional spray application. Care should anyhow be taken to ensure that bait does not end up astray to increase risk of unintended ingestion by children. Buildings such as schools and kindergarten offer less possibilities for safe application, and it is harder to reach all individuals with toxicological information and advice. Children are also more susceptible for toxins compared to adults. Treatment in these kind of places, therefore requires the bait to be placed hidden to avoid unintended ingestion. Several commercially available baits, tested against the common silverfish and the firebrat, are consumed as well as competing food sources, and the active ingredients indoxacarb, fipronil and abamectin induces significant mortality (Sims & Appel, 2012). Baits with indoxacarb, already in use against cockroaches and ants in Norway, provide good control effect against the long-tailed silverfish (Figure 16 and Appendix B). These baits also have low chronic toxicity in humans (ADI; indoxacarb = 0.01mg/kg body weight), and are therefore most relevant. By means of bait with indoxacarb, Norwegian field trials have shown more than 90% population control within 10 to 12 weeks (Appendix B). Comparable field results have been observed in the Netherlands when using Maxforce Platin (Gutsmann, 2019). An important success factor in both the Norwegian and the Dutch bait tests has been to use many, evenly distributed, small droplets of baits to increase the probability of ingestion by the long-tailed silverfish. Positions where aggregations are expected, are obviously important (according to cockroach strategies (Mallis et al., 2011)) because bait drops close to harbourages also will increase the probability for ingestion. The use small cracks and crevices

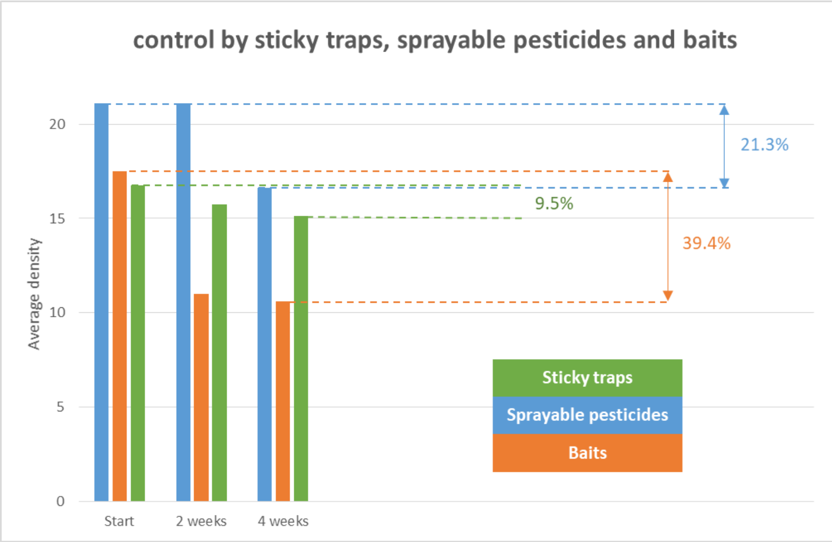

Figure 16: The effect from sticky traps (high density of traps baited with ground cricket), spray application (permethrin – 0.95%, Pyrethrin II – 0.34%) and bait (indoxacarb – 0.05%) used against the long tailed silverfish (*Ctenolepisma longicaudata*) in 30 apartments.

Figure 17: example of natural bait stations where silverfish may get hold of the bait at the same time as risk of unintended exposure is reduced. Photo; Anders Aak, © FHI.

as natural bait stations (Figure 17), is expedient since these places overlap with areas of movement and hiding. Such placement also reduces the probability of unintended contact with the bait. A nutritious bait will appear attractive for the long-tailed silverfish if encountered and consequently get consumed. It is also important to remove competing food sources to increase probability of ingestion. Addition of nutrients attracting the long-tailed silverfish has the potential of increasing the effect of toxic baits. The cricket-powder (described under mass trapping) is in this respect interesting and a possible x-factor capable of improving bait as a control strategy.

5.6.3 – Conventional pesticides

The use of conventional spray pesticides should be limited in environments with risk of user exposure as the effect of baits is better and safer (Figure 16). Typical examples where **extensive use should be avoided** is in schools, bedrooms, kindergartens and hospitals (Dhang, 2011). Resistance against pesticides is not known, and the preferred pesticide choice should be products with low human toxicity. Repeated and/or preventive application should in general be avoided to limit chronic exposure of users of the building and to limit the risk of resistance development (Devine & Denholm, 2009; Radcliffe et al., 2008; Zhu et al., 2016). The effect of different active ingredients is not studied in the long-tailed silverfish, but the common silverfish is knocked out by permethrin in low doses (Faulde et al., 2003), and it is expected that the effect is the same for the long-tailed silverfish. Pesticides should only be a minor part of an IPM-solution, and application should be directed towards aggregations and hiding places. This means the use of small amounts in cavities, cracks and crevices, behind skirting and other objects. A possible risk of spray application of pesticides is avoidance of treated areas by the insects and subsequent increased dispersal to new areas. This may limit the effect substantially.

5.6.4 – Heat and cold treatment

Heat treatment appears to have a control potential against the long-tailed silverfish. Mortality occurs within 2 hours at 42-44 °C (Lindsay, 1940), and tolerance towards heat stress appears low when compared to other relevant indoor pests (Fields, 1992; Pereira et al., 2009; Rukke et al., 2017). The long-tailed silverfish will quickly die at temperatures above 50 °C (Lindsay, 1940) where proteins start to denature (Chown & Nicholson, 2004). The ability to withstand heat stress has not been studied in the long-tailed silverfish, but their low temperature tolerance indicates poorly developed heat resilience mechanisms. Treatment of buildings will be difficult as the long-tailed silverfish probably will find spots inside wall voids, behind skirting or other objects where heat will not penetrate. Local use of hot air in cavities will probably be most cost beneficial and should be used as part of an IPM-solution. Steam treatment may provide elevated local moisture and create damp conditions inside constructions and cavities. This may provide improved local conditions for the surviving individuals. Heat treatment will only kill the long-tailed silverfish if the individuals are exposed to direct heat.

Knowledge regarding cold tolerance is absent, but if the cold resilience is found to be weak, the possibility of using winter temperatures is present in Norway. Storage facilities may utilize the low winter temperatures to knock down or eradicate populations.

5.6.5 – Desiccant dust and biological control

Desiccant dust may be a valuable tool against the long-tailed silverfish, but knowledge regarding mortality and field effects is limited. Desiccants may destroy the cuticle and kill the long-tailed silverfish, but mechanisms and effect have not been studied. However, experiments with the common silverfish show that populations will succumb to desiccants (Faulde et al., 2006). The common silverfish is more dependent on moisture, and the results are consequently not directly transferrable, but they indicate that desiccants may contribute in an IPM-strategy against the long-tailed silverfish (Mallis et al., 2011).

Insect pathogenic fungi have not been evaluated against the long-tailed silverfish, but this is an interesting approach because the long-tailed silverfish is found in distinctly defined populations, shows aggregating behaviour and has a long lifecycle (Lindsay, 1940; Woodbury & Gries, 2007). They consequently fulfil several of the success criteria for an attract and kill strategy (El-Sayed et al., 2009). They also prefer relatively high temperatures and moisture, and since they eat each other (Lindsay, 1940) dead and dying individuals may act as a source of infection. The long-tailed silverfish therefore also fulfil many of the general criteria for use of fungi as a biological control method (Hajek & Shapiro-Ilan, 2018). Their active search for nutrition may also allow bait stations as a primary source of infection to limit the amount of fungal conidia initially introduced to the indoor environment (Lacey et al., 2015). Possible solutions in this direction are ahead of us, but if an infectious fungus species or strain is found, further studies are warranted.

5.6.6 – Methods for vulnerable objects of high value

There are several examples of long-tailed silverfish in Norwegian museums and collections (NIPH_Pest-Statistics, 2019). This type of environment requires a full IPM-approach (Appendix C) where the control measures are adapted to the local conditions (Querner, 2015; Querner et al., 2013; Szpryngiel, 2018; Åkerlund, 1991; Åkerlund et al., 1998). There are also many special control methods for vulnerable objects of high value (Beiner & Ogilvie, 2005; Hansen et al., 2011). Common strategies are freezing at -30 °C, micro-wave or gamma-ray treatment and chambers with modified atmospheres (Querner, 2015; Åkerlund et al., 1998). All these methods will probably also kill the long-tailed silverfish because survival is prone to normal insect physiology. The poor resilience to heat in the long-tailed silverfish (Lindsay, 1940) may be beneficial for treatment of valuable artefacts. If an object can withstand 36-40 °C for extended time, such «low temperature treatment» may be utilized without risk of damage to the objects.

6 – Suggested IPM-protocol against the long-tailed silverfish

These recommendations will quickly change if new knowledge is acquired through research or experience in the pest control industry. The strategy of choice must also be adapted to the infested building, and most control programmes will require a substantial own effort from the buyer of the pest control service to keep the cost at acceptable levels. A thorough and complete strategy should contain as many of the preventive measures below as possible:

- *Inspection, detection and evaluation (Chapter 5.3)*
- *Knowledge elevation among residents or users through information and meetings (Chapter 5.2)*
- *Reduced probability for new introduction and further dispersal (Chapter 5.1 and 5.2)*
- *Removal of food sources and hiding places (Chapter 5.4 and 5.1)*
- *Reduction of potential hiding places in the attic, storage rooms and basements (Chapter 5.1 and 5.2)*
- *Reduction of heat and moisture in technical rooms (Chapter 5.3 and 5.5)*
- *Identification and reduction of moist conditions in the entire building (Specialist required)*
- *Sealing and closing of open transitions between rooms (Chapter 5.1)*
- *Lowered temperatures in the building (Chapter 5.5)*
- *Lowered air humidity in the building (Chapter 5.5)*

The preventive measures will make it more difficult for the long-tailed silverfish and provide a slower population growth. This is however not sufficient to remove established populations, and control should therefore be attempted by use of bait (Chapter 5.6.2) with the following strategy:

- *Use small amounts of bait (1-2 g per 100m^2)*
- *Place tiny droplets of bait (10-20 mg) evenly distributed along the walls instead of few larger drops*
- *Place the droplets as safely as possible by utilizing natural bait stations in cracks and crevices, underneath skirting and behind objects.*

Bait treatment may be supplemented by traps, local heat treatment and cautious spray application of pesticides. Such a supplemented bait strategy will severely affect the long-tailed silverfish population (appendix B and C), but the possibility of isolated survivors will demand a thorough and extended period of follow-up visits and evaluation. Such evaluation should be a collaboration between the customer and the technician and include:

- *Maintenance of the preventive measures (listed above)*
- *Follow up treatments with baits (Chapter 5.6.2)*
- *Evaluation with traps (chapter 5.3)*

If no long-tailed silverfish are found during two consecutive evaluations, the control should be considered a success and treatments terminated.

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Appendix A – Identification key to indoor living bristletail species

Ctenolepisma longicaudata

Ctenolepisma lineata

Ctenolepisma calva

Lepisma saccharina

Thermobia domestica

This identification key is mainly based on two earlier keys for the species in question (Gorham, 1991; Pape & Wahlstedt, 2002), together with a more general insect identification key (Landin, 1967).

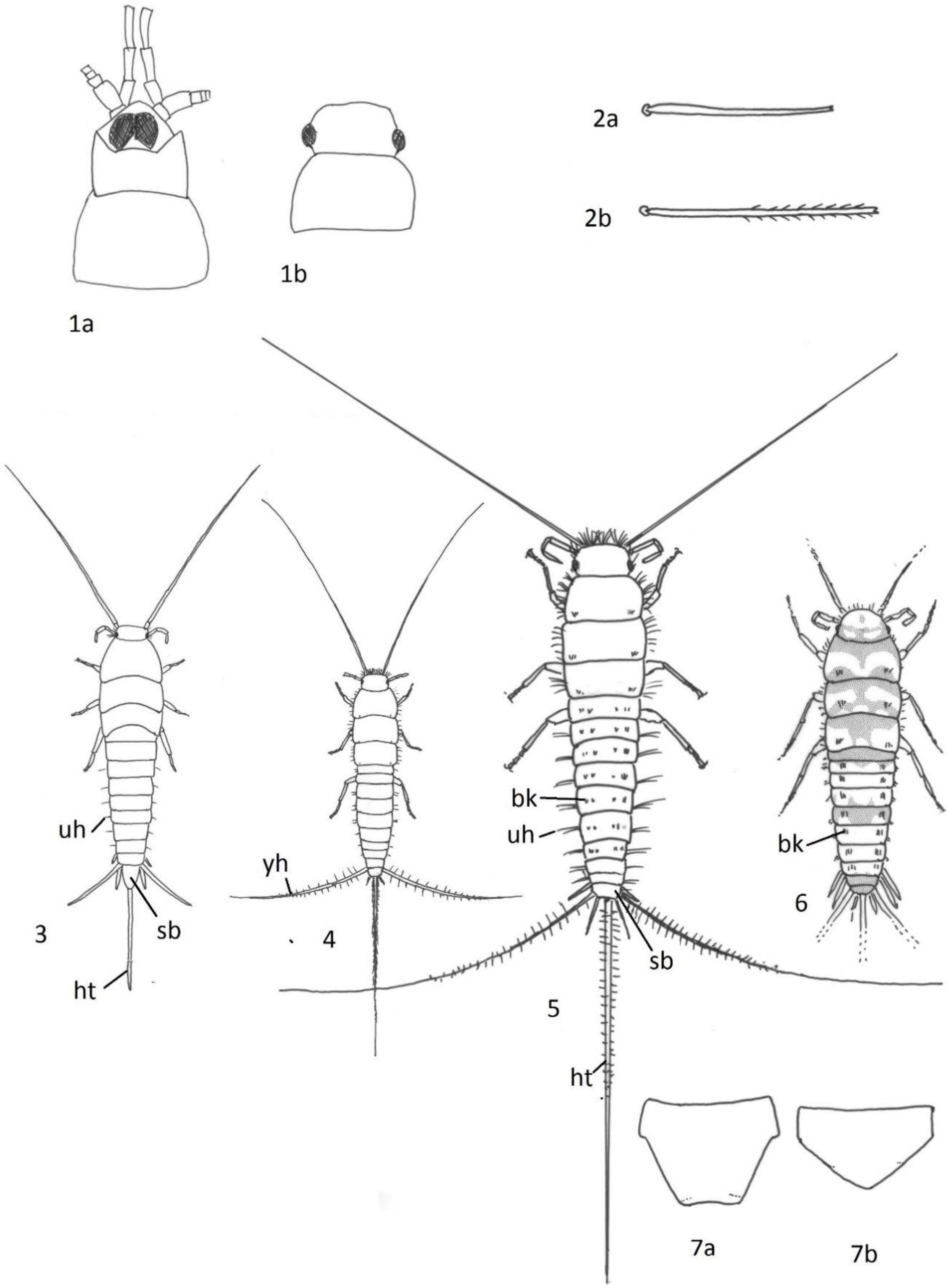


Fig. 1a: Head of a jumping bristletail (order Archaeognatha), 1b: head of a bristletail (order Zygentoma). 2a: The larger setae of silverfish (*Lepisma saccharina*) (cf. 3 og 5, uh), 2b: Larger setae of the long-tailed silverfish (*Ctenolepisma longicaudata*). 3: Silverfish with larger setae (uh) and the caudal (tail-like) appendages (ht) and the last abdominal segment (sb). 4: *Ctenolepisma calva* with lateral caudal appendages (yh). 5: Long-tailed silverfish with bristlecombs (bk). 6: Firebrat, only body with dark spots are drawn, otherwise resembling long-tailed silverfish. 7a: Last abdominal segment of long-tailed silverfish, cf. 5, sb. 7b: last abdominal segment of *C. lineata*

1 Large, overlapping eyes (fig. 1a). Can jump. (Order Jumping bristletails, Archaeognatha, family Machilidae, genus *Petrobius*)

Two Norwegian species, *P. brevistylis* og *P. maritima*. Living on rocks and beaches in the intertidal zone along the coastline. Sometime entering buildings in these areas. Common all along the coast of Norway.

- Small, not overlapping eyes situated on each side of the head (fig. 1b). Do not jump. (Order Bristletails, Zygentoma) …………………………………………………………………… 2

2 Caudal (tail-like) appendages about half as long as the body length (fig. 3, ht). Head sparsely haired (fig. 3). Last abdominal segment elongated, longer than wide (fig. 3, sb). The largest, erect setae on the side of the body (fig. 3, uh) are smooth, seen with at least 60 x magnification (fig. 2a). Without bristlecombs at the abdominal, dorsal plates (fig. 3). One-coloured, but individuals varying from silvery to dark grey ……………………………………………………………………………… Silverfish, *Lepisma saccharina*

- Caudal appendages longer than half of the body length (fig. 5, ht), (NB! They easily break off and therefore may appear shorter). Head densely haired with «beard» (fig. 4, 5). Last abdominal segment short, shorter than wide (fig. 5, sb). The largest, erect setae on the side of the body (fig. 5, uh) are saw-toothed, seen with at least 60 x magnification (fig. 2b) ….......................... ……………………………………………………… 3

3 The two lateral caudal appendages (fig. 4, yh) are 2/3 of the body length. The middle caudal appendage is approximately as long as the body. The abdominal, dorsal plates without visible bristle combs. Up to 8 mm long, excluding antennas and caudal appendages. Shimmering white, one-coloured ……… *Ctenolepisma calva*

- All caudal appendages as long as the body. The abdominal, dorsal plates with bristle combs (fig. 5,6, bk). Dark coloured ……………………………………………………………. 4

4 Body scales with a clear, mixed beige and black pattern on the dorsal side (fig. 6). The abdominal, dorsal plates on the second to sixth abdominal segment with two bristle combs on each side – one dorsally and one laterally (fig. 6, bk). Up to 12 mm long, excluding antennas and caudal appendages …. Firebrat, *Thermobia domestica*

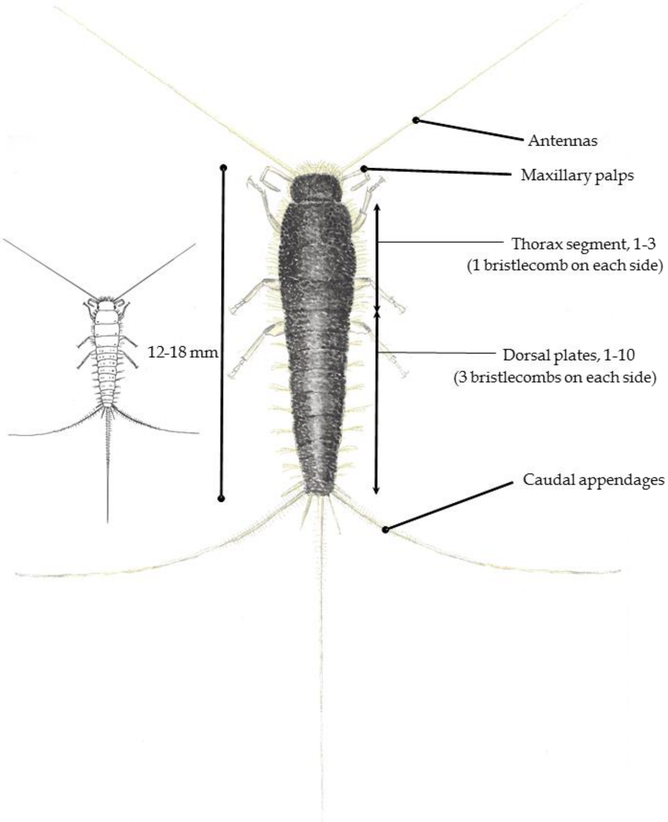
- Grey or beige dorsal side, dark scales on a silvery background can be seen in a stereo microscope (worn individuals that partly lack scales appear yellow or brass coloured). The abdominal, dorsal plates on the second to sixth abdominal segment with three bristle combs on each side – two dorsally and one laterally (fig. 5, bk). Up to 18 mm long, excluding antennas and caudal appendages 5

5 Last dorsal plate (=abdominal segment X) trapezoidal (fig. 7a). Three bristle combs, of which two dorsally, on each side of the abdominal segments II – VI (fig. 5) ……… ……………………………………. Long-tailed silverfish, *Ctenolepisma longicaudata*

- Last dorsal plate triangular (fig. 7a). Three bristlecombs, of which two dorsally, on each side of the abdominal segments II – VII …………………….. *Ctenolepisma lineata*

Detailed description of the **long-tailed silverfish** (*Ctenolepisma longicaudata*)

The long-tailed silverfish grows large in good conditions, and maximum body length without caudal appendages and antennas is assumed to be 18 mm (Pape & Wahlstedt, 2002). Normal adult length is around 12 mm (Robinson, 2005). The long-tailed silverfish appear somewhat speckled as the scales vary in grey and brown colour tones. Therefore, they appear less silvery than the silverfish. Positioned at the end of the flattened, elongated and tapered abdomen, three conspicuously caudal appendages are as long as the body. The middle one points straight backwards, while the laterals point perpendicular from the body. The head has two antennas in addition to two shorter maxillary palps. From above, the forehead and sides of the head appear much more hairy than in the common silverfish. The shape of hairs and specific location of bristlecombs are good species characteristics. Contrary to the common silverfish, the long-tailed silverfish has a pair of bristlecombs on the dorsal side of each thorax segment, and it has three such bristlecombs on each side of the abdominal, dorsal plates. One of these three bristlecombs is placed laterally on the abdomen. An important characteristic that can be used to differentiate between worn specimens of the two species is that the largest setae of the long-tailed silverfish are saw-toothed, while those of the common silverfish are smooth. To see this, a magnitude of at least 60 x is needed. Additionally, the last abdominal segment is shorter than wide, while this among the common silverfish is longer than wide. In English literature, the long-tailed silverfish is also called *grey silverfish* or *giant silverfish* (Bennett et al., 2010; Gold & Jones, 2000; Mallis et al., 2011).



Detailed description of ***Ctenolepisma calva***

Ctenolepisma calva is white coloured, as the scales are white. The middle caudal appendage is as long as the body, while the two lateral appendages are 2/3 of the body length and points out perpendicularly to the body. *C. calva* is as hairy as the long-tailed silverfish, and the largest setae are saw-toothed. The last abdominal segment is shorter than wide. Maximum body length is 8 mm.

Detailed description of the **common silverfish** (*Lepisma saccharina*)

The common silverfish is uniformly coloured with individuals varying between silvery to dark grey. The common silverfish has caudal appendages shorter than half of the body length, and the lateral appendages point obliquely backwards. Compared to the long-tailed silverfish, the common silverfish do not appear hairy, but the head and anterior part of the body have some erect setae. These setae are smooth, not saw-toothed like in the long-tailed silverfish. The last abdominal segment of the common silverfish is longer than wide.

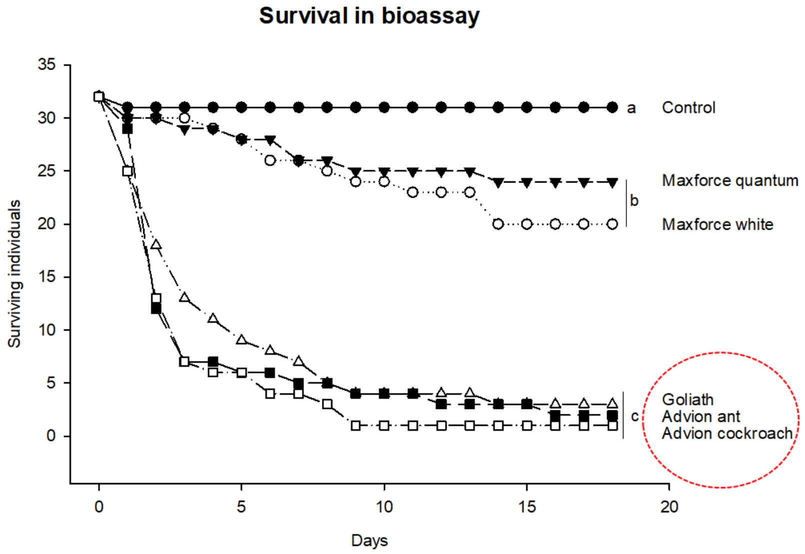
Detailed description of the **firebrat** (*Thermobia domestica*)

The firebrat resembles the long-tailed silverfish, as it is large and hairy with the lateral caudal appendages pointing perpendicular from the body. Normally, the firebrat have a darker thorax than the long-tailed silverfish. In addition, the species is described as more parallel sided as individuals are not as gradually tapered toward the end as the long-tailed silverfish (Lillehammer, 1964). To distinguish the firebrat from long-tailed silverfish, one must look at the colour pattern combined with species specific positioning of bristlecombs and setae. On the dorsal, abdominal plates, the firebrat has two bristlecombs on each side, while the long-tailed silverfish has three. The firebrat is not a relevant pest in Norway, but appears frequently in warmer countries (Mallis et al., 2011).

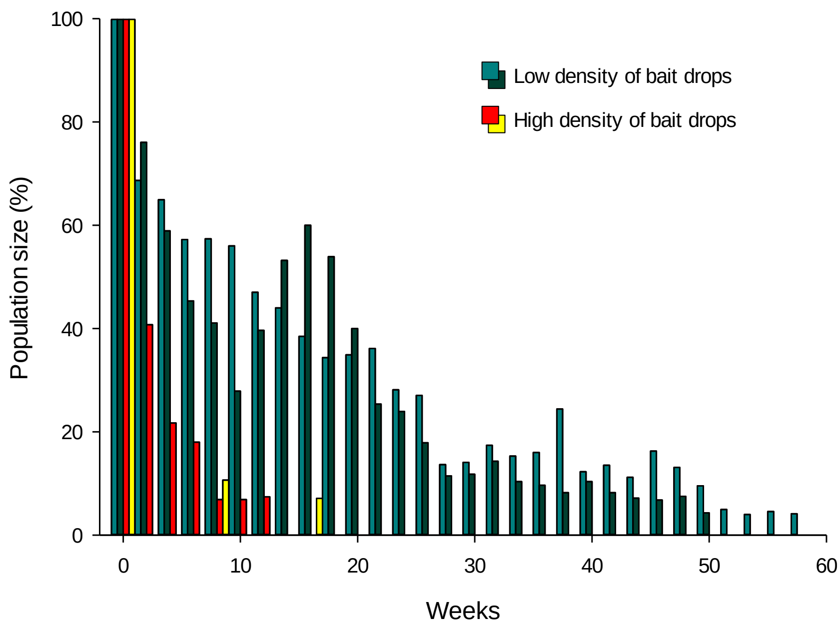
Appendix B – effect of bait in laboratory studies and field experiments.

These results is a part of an ongoing study conducted by the Norwegian Institute of Public Health (Department of pest control). The concluded results are expected to be published in 2019/2020

Bio-assay: The five most commonly used baits against insects in Norway were tested in small arenas with harbourages, free water and competing food sources. 16 adults and 16 juveniles were used per bait. Three of the baits were efficient. The Advion baits has lower toxicity for humans compared to the Goliath bait.



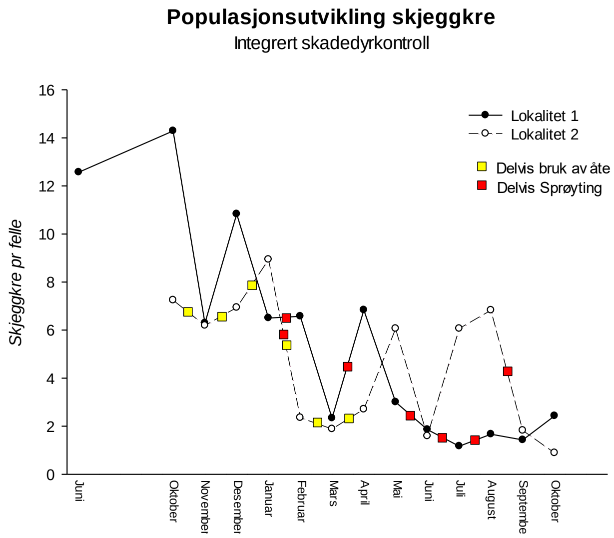
Field studies: This is an ongoing study and none of the experiments are concluded. The examples show control by use of bait in an office building (light green), single family house (dark green), Row house (yellow) and apartment building (Red). The initial density of long-tailed silverfish is set to 100% to show relative reduction of the populations. The experiments illustrate the effect of bait in general and an improved effect of high density of many small bait droplets (yellow and red) compared to low density of larger drops of bait (light and dark green).



Appendix C – Example of long-tailed silverfish control in library

Library with associated book storages: The long tailed silverfish was discovered in a library in 2016. Several measures were taken to limit the potential damage at all the locations of the library and sticky traps were used to monitor the situation. The library used an IPM-strategy containing the following elements:

1) *Discussions and constructive dialog with the building owner.*
2) *Openness regarding the problem among the employees.*
3) *Written information regarding biology, preventive measures and control.*
4) *Focus on thorough cleaning.*
5) *Total cleaning of areas with observations of long-tailed silverfish.*
6) *A tidy-and-throw-away campaign led to destruction of 12 metric tonnes of paper.*
7) *Avoidance of eating outside of the canteen to prevent leftovers and unnecessary available food.*
8) *Storage containers of cardboard was replaced with plastic containers.*
9) *Yearly inspections of collections and storage rooms.*
10) *Clear definition of storage zones and the remaining rooms.*
11) *Use of double-sided tape to prevent silverfish movement between zones.*
12) *Freezing of objects (-20 to -30 °C) before long-time storage.*
13) *Local use of toxic baits.*
14) *Local use of desiccant dusts.*
15) *Local use of spray pesticides.*



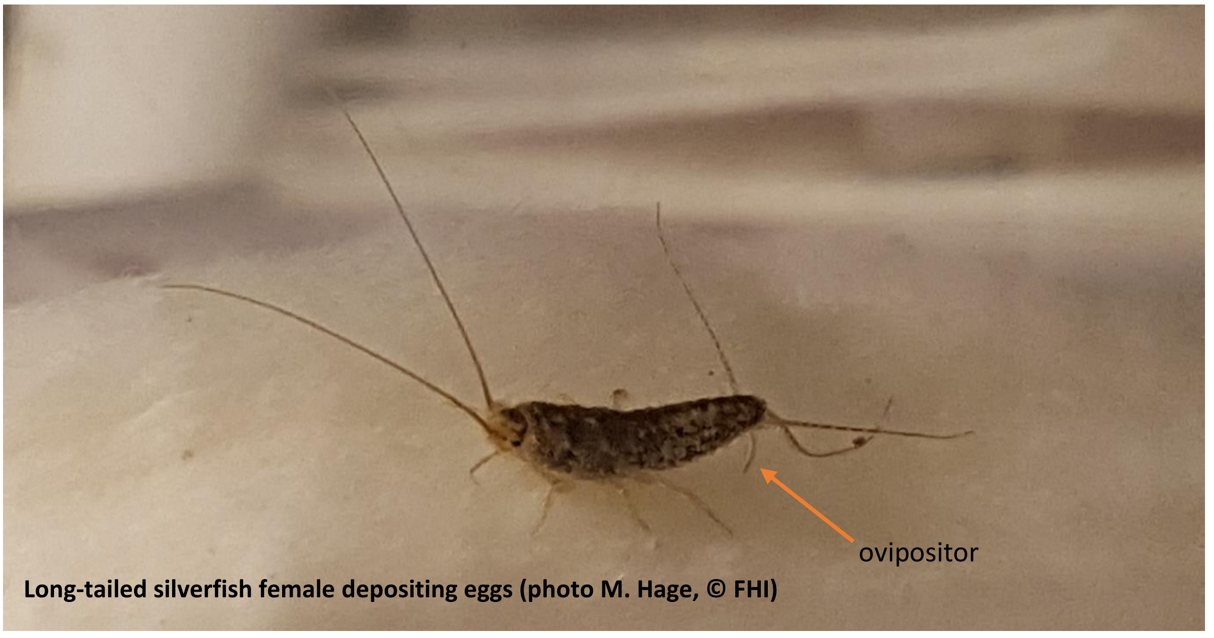
Long-tailed silverfish (*Ctenolepisma longicaudata*) population development during implementation of an IPM-strategy (data collected by the library and Anticimex and the figure is presented with permission from Gunhild Myrbakk). Yellow and Red squares represent partial use of bait and spryable pesticides, respectively

The development of the long-tailed silverfish population was very positive for the library and highlight the importance of many efforts pulling in the same direction. The approach was in line with recommended strategies for pest control in museums. (Querner, 2015; Querner et al., 2013; Åkerlund, 1991; Åkerlund et al., 1998) and point at the importance of IPM. It is hard to identify which element contributing most when many approaches are used in parallel, but this case-study show that it is possible to decimate the population even in highly complex and large buildings.

Appendix D – Video link and pictures

https://www.fhi.no/nettpub/skadedyrveilederen/smadyr-andre/skjeggkre/

Pictures of *Ctenolepisma longicaudata*:



Long-tailed silverfish female depositing eggs (photo M. Hage, © FHI)

Long tailed silverfish in natural habitat (photo A. Aak, © FHI)

Long-tailed silverfish in sticky trap (photo M. Hage, © FHI)