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An attempt to reconstruct the natural and cultural history of the webbing clothes moth *Tineola bisselliella* Hummel (Lepidoptera: Tineidae)

Abstract - It is generally accepted that the natural habitats of most pest insects can be found outside the synanthropic environment in layers of leaf litter, under bark, as well as in rodent or bird nests. Indeed, most of the common pests have been reported as being facultative nidicolous. Therefore infestation of commodities by pest insects out of these reservoirs is one considerable possibility. However, the likelihood of a pest´s occurrence and survival out-doors largely depends on its ecological potential and competitiveness against other species of the same ecological guild. Some pest species are rarely found in wild habitats, especially in those regions where they are not native and where they have been introduced by man.
The fabric pest *Tineola bisselliella* serves as a good example. Most likely originating in Central or Southern Africa this insect was introduced into Europe probably not earlier than the late 18th century. Being more tolerant to dry environments than other fabric pests its economical importance increased during the 20th century when in-door climates changed because of central heating systems. Its occurrence in out-door natural habitats must be regarded as accidental. Reported founds of webbing clothes moth larvae in bird nests e.g. have been largely overstated in the literature. *T. bisselliella* should be regarded as an eusynanthropic species.

Key words: evolution, pest insect, phylogeny, synanthropy.

BRIEF DESCRIPTION OF MORPHOLOGY AND PHYSIOLOGY

The adult webbing clothes moth is a small moth that ranges in size from 4 to 9 mm and weighs up to 16 mg (Kemper, 1935; Hannemann, 1977; Becker, 1983). The head and the rest of the body are covered with long hair. The rusty yellow head hairs point towards the front. The eyes are black. The mouth parts are reduced, the mandibles are rudimentary, the maxillary palps are very short or missing, and only the labial palps are apparent and well developed (Fig. 1). The wings are lanceolate and are fringed at their ends and rear edges. The forewings are yellowish, and the hind wings are grayish-yellow. There are no striking markings on the wings. The wingspan ranges between 12 to 16 mm. In flight, the hind wings are interlinked through a setaceous frenulum to the retinaculum of the forewings. The male moths are generally smaller than the female moths and have a few small tufts of hair on the last three abdominal segments.

The larva, which reaches 7 to 9 mm, has yellowish to yellow-whitish coloring (Hinton, 1956). The color of the food in the intestines often shines through the thin body covering. The head capsule is brown, sometimes with an almost black posterior border. Ocelli are missing. The back of the neck is light to yellowish-brown. The coxae are not fused through the median. The larvae create silk tubes in which they live and eat, which are securely interwoven with the substrate. Feces and substrate particles are integrated into the silk tubes.

Adult clothes moths do not take in any more nourishment. Only the larvae feed and are capable of metabolizing keratinous materials through the respective enzymes and special intestinal environment (Lotmar, 1942; Day, 1951a; 1951b; Powning *et al.*, 1951; Hinton, 1956; Gerard, 2002; Hughes & Vogler, 2006). The developmental time of the webbing clothes moth is related to the quality of its food, and is closely dependent upon temperature (Titschack, 1925; 1926). The moisture level also has a great impact on the length of the larval period. With good nourishment, a constant temperature of 28°C to 30°C, and relatively high humidity, the total development from an egg to moth takes from about 45 to 70 days. Under poor developmental conditions, however, this development can take years. The number of larval stages correlates with the length of development and can lie between four and ten, as well as up to 40 stages (Titschack, 1927; Griswold, 1944).

The guild of keratophagous insects incorporates only few species, including some moth as well as hide and skin beetle species. Usually the relative humidity of a habitat directly corresponds to the substrate moisture content, which strongly influences successful infestations by the various species. However, in contrast to the guilds of xylophagous wood damaging or granivorous stored product-insects, for keratin feeding insects substrate moisture is not a limiting factor for intra-guild competition. Because of high levels of the protein keratin in wool and feathers, this diet is by far less hygroscopic than the cellulose in wood or the starch in grain. The moisture level of keratinous material is therefore more or less constantly low and not influenced by the relative humidity of the surrounding. Since textile pests are all capable of utilizing the dry substrate, the adaptive status varies therefore with their ability to physiologically conserve water. In comparison with e.g. the case-making clothes moths (*Tinea pellionella* L.) or carpet beetles (*Anthrenus* spp.), the webbing clothes moth is more tolerant to low relative humidity of up to 20% (Griswold, 1944; Hinton, 1956), and due to changing living climates to drier homes, the importance of this pest has been constantly increasing. It has widely replaced the case-making clothes moth (Weidner, 1970; Klausnitzer, 1993), which used to be prevalent in homes but requires lower temperatures and higher levels of humidity (Cheema, 1956). Webbing and case-making clothes moths can, however, co-exist (Key & Common, 1959), when locally suitable microhabitats allow for different levels of humidity. The feeding tube of the webbing clothes moth which is tight to the substrate may serve better in the aspect of preventing water loss than the portable sacks by other tineid moths.

Geographic origin, global spread, and current habitats

The biogeographic origin of *T. bisselliella* is basically still undecided, but is conjectured to be in South to Central Africa (Hinton, 1956; Weidner, 1970; Robinson & Nielsen, 1993). Webbing clothes moths are not autochthon to Europe, as they were first explicitly mentioned there not before the 19th century. Neither Linné nor Frabricius described them in their systematic works, and in a report about controlling moths in textiles by Réaumur to the Paris Academy in 1728, the webbing clothes moth in its true sense was not mentioned (Weidner, 1970). Thus one can rightly assume that *T. bisselliella* arrived relatively late in Europe, possibly introduced accidentally with the trade of natural produce and game trophies from Africa, and later spread throughout the world. Mentioning of "clothes moths" in the classic literature of the Antiquities, e.g. in Aristotle and Aristophanes (Beavis, 1988), or in the Bible (Bodenheimer, 1960) clearly does not refer to *T. bisselliella*. The decisive evidence for this assumption comes from a description of the destructive larvae, which are described to live in a "mobile enclosure" of a sack. This is not the case for *T. bisselliella,* as the larvae of this species live in immobile silk tubes, which are securely woven into the substrate (see above). Portable woven sacks are created, for instance, by *Tinea* spp. and *Monopis* spp. In the citations from the Antiquities, they are thus more likely describing an entire group of diverse facultative synanthropic keratophagous moth species (Robinson, 1979).

Although *T. bisselliella* today is more or less globally distributed, it is a neozoon in most parts of the world. Its cosmopolitan propagation is strictly synanthropic and it is one of the most economically significant textile pests (Kemper, 1935; Becker, 1960; 1983).

New species, introduced into new environments usually do not outcompete naturally occurring species within their ecological guild because the latter are ecologically well adapted to their habitats. However, factors may exist in the close vicinity of humans which favour or even enhance the establishment of introduced species over native species.

Reports of damages caused by *T. bisselliella* to wool, feathers, hair, and fur, as well as clothing and basic commodities made from these materials inside households and museums are numerous (Hinton, 1956; Hammers, 1987; Parker, 1990; Pinniger, 1994; Rajendran & Parveen, 2005). Reports in the literature regarding the presence of webbing clothes moths in natural habitats away from human housings are, in contrast, rare and confusing. For example, in his summary of bibliographies on nidicolous insects Hicks (1959) lists 15 references to *T. bisselliella* findings in bird nests. Thus, in secondary and tertiary literature, it is often listed as a common species in bird nests (Niethammer, 1937; Uhlmann, 1937/1938; Hinton, 1956, Petersen, 1969; Hannemann, 1977; Klausnitzer, 1988; Pinniger, 2001; Cox & Pinniger, 2007). Our own studies of the listed original references, however, do not allow for this general conclusion. First one notices duplications of citations as well as generalized faunistic reports from secondary literature without specified data. This limits the number of works reporting the presence of webbing clothes moths in bird nests to only six original references. In addition, the abundances of individuals in these finding are very small. According to Kemper (1938), while 63% of the 64 nests studied (nests of house and tree field sparrows, great and blue tits, barn swallows, house martins, and "city pigeons") contained moth larvae or moths, only 10% of them contained webbing clothes moths with a total of 24 individual specimens. The largest portion (95%) housed the so-called "case-bearing moths" (s. below) with over 2000 individual specimens. Furthermore, after a yearlong study on numerous common swift nests, Büttiger (1944) also reported on only finding one moth and one pupa. According to Boyd (1936), while webbing clothes moths, case-bearing clothes moths, and other moths are commonly found in swallow nests, there is no differentiation as to what species are found, so that the actual percentage of *T. bisselliella* remains unclear. In their studies of nests of various species of birds, Woodroffe & Southgate (1951/1952) and Woodroffe (1953) only found a very small quantity of webbing clothes moths in only 3% of the nests studied, exclusively in house sparrow nests. Herfs (1936) also does not include any absolute data, but does report on a very small number of webbing clothes moths compared to the high number of case-bearing clothes moths. In addition, an updated literature search revealed, that Weidner (1961) found only one webbing clothes moth larva in one out of six pigeon nests. The larvae of case-making clothes moth (*T. pellionella*) and the brown house moth (*Hofmanophila pseudospretella* Stainton), as well as the "pigeon moth" (*Tinea columbariella* Wocke), all "case-bearing" moth larvae, were more frequently found. On the other hand, indirect negative reports on *T. bisselliella* exist: Nordberg (1936) did not find any webbing clothes moths in a total of 422 nests of various bird species, while he did find large numbers of case-making clothes moths, brown house moths, and brown-dotted clothes moth (*Niditinea fuscipunctella* Haworth), and Hinton (1956) never found any webbing clothes moth in bird nests. Similarly, the webbing clothes moth is not listed in the results of the faunistic investigations by Green (1980) and Krall (1981).

T. bisselliella must then be considered to be an exception and a seldom to very seldom occurrence in bird nest biocenoses. The females' very poor flight ability (Hinton, 1956), as well as the strong competition from other species in natural habitats may be the causes. Other tineids, especially the case-making clothes moth and the "pigeon moth", as well as the Oecophoridae brown house moth and several species of *Anthrenus* and *Attagenus* dermestid beetles are the most common keratinophagous nidicolous insects found in mild climate zones. In tropical regions of Asia, away from human settlements, the known bird nest inhabitants are not webbing clothes moths, but rather other kinds of tineids (Robinson, 1988a).

The seldom occurrence of webbing clothes moths as nidicolous insects in birds nests is thus certainly tied to secondary infestation from housing or businesses in urban spaces, as for all of the positive instances listed above the few nests in which webbing clothes moths were found had direct contact to human living quarters. Infestation the other way around, from the bird nest to human dwellings, is unlikely – the economically relevant new infestations by webbing clothes moths do not usually occur through natural habitats, but rather through the displacement and receipt of infested materials (Kemper, 1935).

These general and rather theoretical considerations of *T. bisselliella* being a eusynanthropic species are supported by out-door pheromone trapping results carried out in the year 2008/2009. In and near Berlin (Germany) several trapping locations outside houses were set up inside and outside the city limits. Trapping was performed from August to July with sticky traps containing a pheromone lure for *T. bisselliella* provided by Insects Limited (Indianapolis, USA). Traps were checked and lures were changed

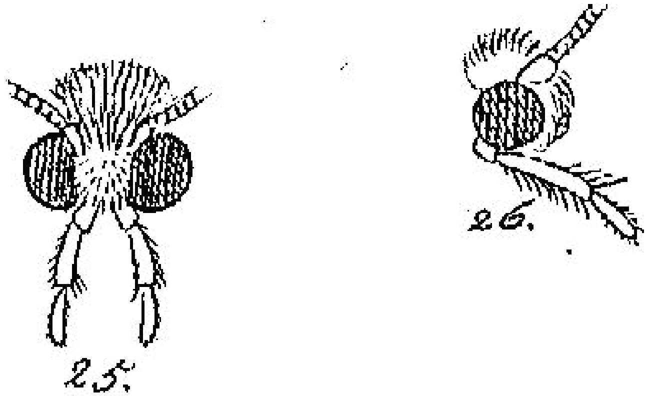

Fig. 1 - Original drawings by Herrich-Schäffer (1853) of systematic details regarding *Tineola bisselliella* labial palps.

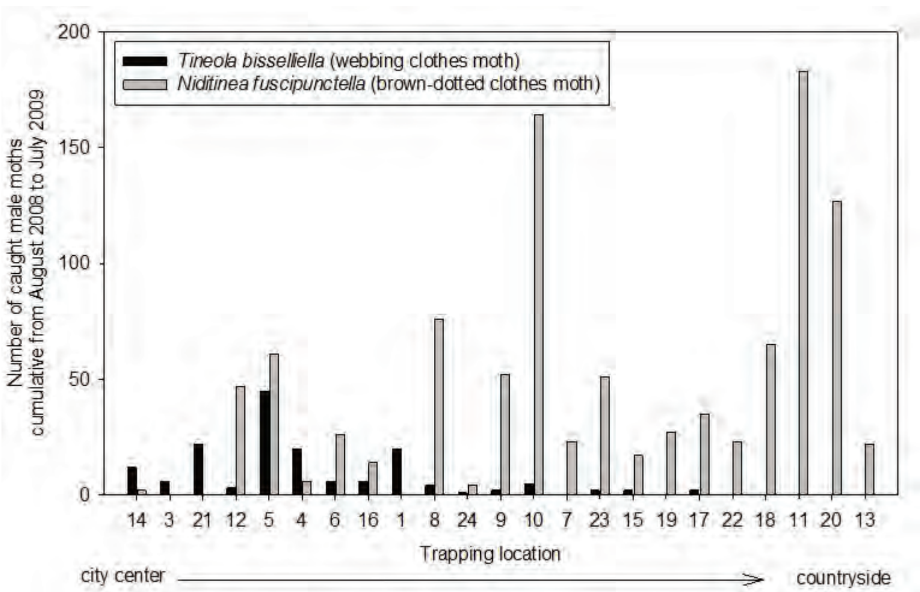

Fig. 2 - Trap captures of webbing clothes moths and brown-dotted clothes moths at different trapping locations in and around Berlin, Germany, sorted from city center to countryside. Numbers of trapped male moths are cumulative for 1 year.

on a biweekly basis. Fig. 2 shows catch data arranged from city center to country side. The further away from the city the fewer was the number of *T. bisselliella* captures up to total absence of this species in the country side. Interestingly, another tineid moth, the brown-dotted clothes moth (*N. fuscipunctella*), was also caught in high amounts. It is known that males of this species are attracted to alcohol compounds (Hwang *et al.*, 1978), and most likely they were lured into the trap by the webbing clothes moth pheromone´s solvent. The brown-dotted clothes moth is a well documented and typical species from bird nests in Central Europe (see above) and frequently trapped with alcohol based lures (Trematerra & Fiorilli, 1999). Trap catches of *N. fuscipunctella*, however, were reciprocal to those of *T. bisselliella* with highest numbers in the country side.

Biosystematics and annotations on phylogenesis

The first scientific description of the webbing clothes moth (in its classic sense) as *Tinea bisselliella* comes from Hummel in the year 1823 (Herrick & Griswold, 1933). Zeller (1852) produced the first detailed description on the morphology and dispersion. Due to morphological characteristics, including the lack of maxillary palps and a reduced glossa (Fig. 1), Herrich-Schäffer (1853) established the genus *Tineola* with *Tineola bisselliella* and three additional species, which were later reallocated to different taxa, due to the characteristics of the genitals. Currently, but with reservations, only one other species, *Tineola anaphecola* Gozmány, is included in this genus (Gozmány & Vári, 1973) but the authors do not explicitly specify whether or not both species truly form a sister clade. Due to newer genital morphological traits (Petersen, 1957) as well as biochemical traits (Cook *et al.*, 1997), *Tineola* spp. likely should be included within the "*Tinea*-group" and should no longer be considered to be the sister-taxon to the "*Tinea*- and Monopis-group" (Hannemann, 1977) (Fig. 3). Due to the unclear status of *T. anaphecola*, one could consider other Tinea species as potentially the most closely related taxa to *T. bisselliella*.

Tineola anaphecola is so far known to exist only in tropic West Africa, where it was found nidicolously and entomophagously in caterpillar nests. As it has frequently been conjectured, it is possible that the natural origin of *T. bisselliella* can also be found in the same region (see above), where it may have had an entomo-nidicolous lifestyle, under mummified conditions or possibly also living on cadavers. Their presence has been proven both in nests of social hymenoptera (four separate cases) and on a cadaver (singular incident) (Linsley, 1944; Weidner, 1952 cited in Petersen, 1963).

Feeding behavior among Tineidae is very divers and can best be described as detrito-mycetophag (Robinson & Nielsen, 1993, Davis & Robinson, 1999). Taking the phenogram by Cook *et al*. (1997) (Fig. 3 right side), which is based on similarities of cuticular fatty acids, as a blueprint for phylogenetic relationships among the *Tineidae*, and incorporating feeding ecology into this phenogram, the following evolutionary scenario regarding food exploitation could occur (Fig. 4): The common ancestor of the *Tineidae*, including Hieroxestinae (with *Amphixystis* ssp.), Scardiinae (with *Morophaga* ssp.), Nemapogoninae (with *Nemapogon* ssp.) and Tineinae (with *Monopis* spp. *Tineola* spp. and *Tinea* spp.) was feeding more or less on rotten plant detritus

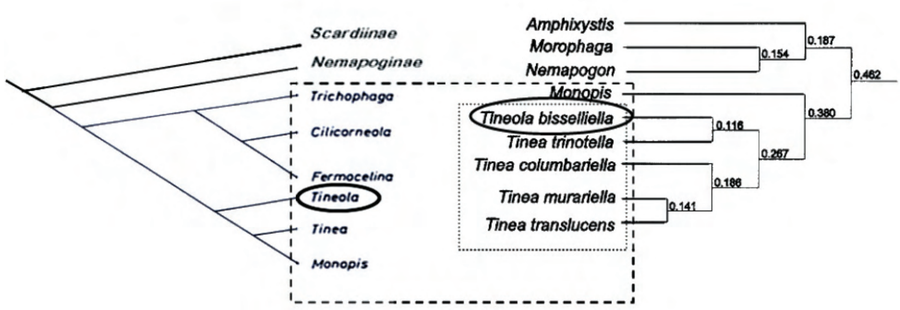

Fig. 3 - Comparative relationships of *Tineola bisselliella* within the Tineidae which are comprised of the Tineinae (dashed box) + Nemapoginae + Scardiinae, based upon Hannemann (1977) according to morphological genital traits (left) and upon Cook *et al.* (1997) according to data analyses of cuticular fatty acid percentages "centroid cluster analysis" (right).
(Note on the right phenogram: *Morophaga* represents the Scardiinae and *Amphixystis* stands for the Hieroxestinae, which Hannemann (1977) did not discuss).

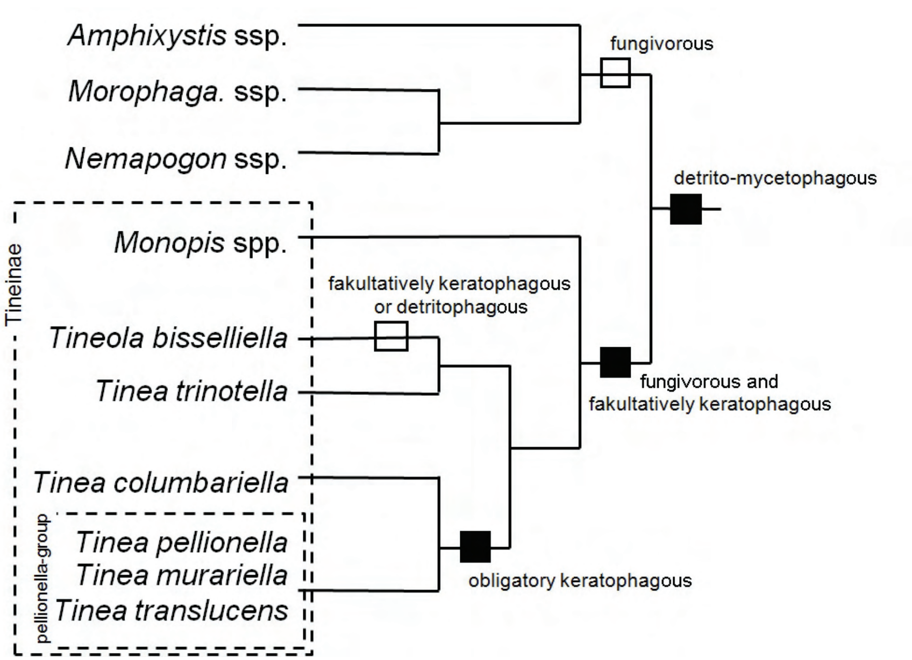

Fig. 4 - Relationship among the Tineidae (according to Cook *et al*. (1997), see also Fig. 3), with added feeding ecology.

which includes facultative feeding on various fungi and lichen (Hannemann, 1977). For *Amphixystis* ssp., *Morophaga* ssp. and *Nemapogon* ssp. decomposing fungi are still the preferred food source (Petersen, 1969). The common ancestor of the Tineinae (Fig. 4 large dotted box) also fed on fungi but was able to partly consume keratin as well, maybe through the enzymatic synergism of keratinases by fungi. Finally, in the Tineinae some taxa like the "*pellionella*-group" (Fig. 4 small dotted box) specialized and shifted obligatory on keratinous food, while others including *T. bisselliella* (which is not part of the "*pellionella*-group") remained oligophagous. Interestingly, among all described subtaxa in the Tineinae, the specialized "*pellionella*-group" hosts the majority of species being known as pests on textiles (Robinson, 1988b). Compared to those, *T. bisselliella* is not restricted to food of animal origin. It can successfully live not only on cholesterol but also on pure phytosterol containing food sources (Becker, 1980; Sellenschlo, 1990; Stejskal & Horak, 1999), whereas *T. pellionella* e.g. cannot survive on botanical materials (Ishii & Kawahara, 1966).

Other behavioural characteristics in tineid moths, like the differences in constructing frass-tunnel or making cases, certainly reflect different strategies to prevent desiccation by minimizing water loss because of shelter tubes. However, case building and their structures are by no means consistent within phylogenetics (Davis & Robinson, 1999).

CONCLUSION

The summary of autecological, behavioral, and historical data in combination with critically analyzed published faunistic records make the webbing clothes moth appear to be a true synanthropic species in most parts of the world. Its local spread is favored only by trade and exchange of infested commodities. New infestations from natural reservoirs are most unlikely. Preventive pest control strategies should therefore focus on proper quarantine measures.

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