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ORIGINAL PAPER

The preservation of cultural heritage damaged by anobiids (Insecta, Coleoptera, Anobiidae)

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Abstract.
The paper presents the research done in 61 locations (memorial houses, libraries, churches, monasteries, storage facilities for heritage objects), focusing especially on the species of Anobiidae that damage the heritage goods, the type of damage they do, as well as testing some methods of pest control in the context of preserving the cultural heritage. 9 anobiids have been identified: Anobium punctatum, A. pertinax, Lasioderma serricorne, Oligomerus ptilinoides, O. brunneus, O. retowskii, Ptilinus pectinicornis, Stegobium paniceum and Xestobium rufovillosum. In some churches Ernobius mollis and Priobium carpini have been collected too, without being identified in the damaged objects. The O. retowskii and O. ptilinoides species were discovered for the first time as pests that damage the heritage goods in Romania. The O. brunneus species was discovered as well for the first time in Moldova as a pest that damages the cultural collections. The Anobbidae attack on the heritage goods was found in all the locations, the most frequent species being Anobium punctatum in the objects made of wood and S. paniceum in the old book collections. Monitoring the S. paniceum species was performed by means of adhesive and pheromones traps. The pest control was done by means of mechanical, physical (freezing) and chemical methods (pyrethroids, basil and absinth essential oils).

Key words: anobiidae, cultural heritage, preservation

1. Introduction

Faunistic and taxonomic research

The study of anobiids was started by C. Linnaeus who in *Systema Naturae* (1758) included *Ernobius mollis, Anobium pertinax, Ptilinus pectinicornis and Stegobium paniceum* in the *Dermestes* genus. In 1767 Linnaeus transferred some species from the *Dermestes* genus to the *Ptinus* genus. In 1774 Charles de Geer describes the *Anobium punctatum* species and adds the *Ptinus rufovillosum* species to the genus.

Towards the end of the 18th and during the 19th centuries different authors enlarged the number and ranked the species and genera of this family. Müller (1764) was the author of the *Ptilinus* genus. In 1792 the *Dorcatoma* genus was created by Herbst. Latreille (1809) formed the *Xyletinus genus*, one of the richest genera of this family. Jaquelin du Val (1860), Mulsant & Rey (1863-1868), Kiesenwetter (1877), Oliveira (1894) contributed significantly to the *Anobiidae family*, recording 30 genera and numerous species of Anobiidae in the first catalogue of the coleopters in Portugal.

LeConte (1861-1878) and Gorham (1883-1886) recorded the anobiid species in the American fauna, Broun (1880-893) and Sharp (1882-1886) recorded those in the New Zealand and Hawai fauna and Blackburn (1891) in the Australian fauna.

At the beginning of the 20th century, Reitter (1911-1912) separated the Anobiidae from the *Teredilia* group. This order was also followed by Pic (1912).

In the 20^{th} century many authors contributed to the enlargement of the *Anobiidae* family. Fall (1905), Leng (1920) and R. White (1961-1990) added new species for the Nearctic zone. In 1971 R. White created the *Trycorininae* subfamily.

The coleoptera catalogues in the Palearctic region include the anobiids identified in several subregions. Therefore P. Kuhnt (1911), A.Winkler (1924-1932), F. Köhler, H. Freude (1968, 1969) and B. Klausnitzer (1998) presented the distribution of the species in Central Europe, Hickin (1963) presented the Anobiidae in Great Britain, H. Silfberg (1991), L. Kaila (1993), I. Rutanen (1995), R. Leinonen (1998), K.H. Thunes (1994) presented the Anobiidae in Finland and Norway, J.S.Claire Deville (1920), A. Viñolas (1993-1999), Karl & Riita Löyttyniemi (1988) noticed new species in the African fauna. Tenenbaum (1915), Bofill (1916), Garcia del Cid (1940), Viñolas (1993-2002) made their own contribution by presenting the Anobiidae in the fauna of the Iberian Peninsula, and A.T. Kaygin, (2004), S. Akbulut (2008), S. Unal (2009) recorded the existence of 66 species of Anobiidae in Turkey. Between 1960-1990 Fr. Español had the most prolific research on the Anobiidae, done in Europe, Africa, Equatorial Guinea, Asia, Australia, New Zealand, Chile, Macarenas Islands. Logvinovskyi (1985) published a monographic volume about the *Anobiidae* family for URSS Fauna.

It was towards the end of the 19^{th} century that the Anobbidae were mentioned in Romania for the first time, by Frivaldszky (1871), Szmolay Vilmos (1874) [1] and Ştefănescu (1885). In the 20^{th} century some species of anobiids were identified by Cosmovici (1901), Jaquet (1902, 1903), Fleck (1905), Montandon (1906,1908), Leon (1912), Marcu (1929, 1964), Negru (1967, 1968), M. Mustaţă & Gh. Mustaţă (1977-2009), C. Bucşă & L. Bucşă (2005).

Research on the damage caused to the cultural heritage and the control of anobiids

Swammerdam's information related to the Anobiidae and their biology, ecology and behaviour was among the first, writing in *History of Insect* (1672-1680) about the bugs that produce a clicking sound, a behaviour described both Allen (1695) and Derham (1701). Bouché (1834) mentioned the presence of different development stages of the woodworms in wood. Westwood (1839) and

Tachenberg (1879) recorded the fact that the development cycle of the *Xestobium rufovillosum* lasts 1-3 years.

In 20th century, the importance of the damage caused by the anobiids determined a series of scientists to research on their biology, ecology and ethology. H.M. Lefroy (1924) mentioned the fact that the *Xestobium rufovillosum* is attacked in the wood tunnels by predators. R.C. Fisher (1937-1941) wrote about the biology of this species, about the factors that influence the egg laying as well as the relation between the insects and the xylophagous fungi. Hickin (1963) presented in detail data on their spread, damage, morphology, biological cycle, metamorphosis, habitat, nutritional support, viability, predators, parasitoids, simbionts for the *Xestobium rufovillosum* and *Anobium punctatum*.

Papers on the anobbids digestion were presented by P. Buchner (1921), R.C. Fisher (1930); Campbell (1929) proved the fact that the larvae excrements have a lower level of cellulose than the wood, Heitz (1927) proved the presence of microorganisms in the digestive tube and Ripper (1930) wrote the fact that the larvae have enzimes able to breck down the cellulose, the hemicellulose, the starch and the sugar from wood.

Levy (1973) and Jurzitza (1970, 1977) wrote on the biology, nutrition, mating and laying eggs behaviour of the *Lasioderma serricorne*. J.A. Coffelt (1972-1973) described the mating behaviour of this species according to age and the pheromone quantity that the males are exposed to. A.J. Howlander (1995) proved that marking the egg laying area is done by dispersion pheromones. S.C.Papadopoulou (2003, 2004) presented the influence of the environmental factors on the species biological cycle.

W.G. Campell (1941), S.R. Belmain (1998-2002) and Goulson (1993, 2002) researched the mating behaviour, the preference for certain substrata and the influence of the climate on the *Xestobium rufovillosum*. Birch (1991) proved that the adults able to mate hit the wood with a frequence of approximately 11 Hz, and P.R. White (1993) proved that this acoustic communication replaces the pheromone communication when the degree of infestation is high.

Studies on the sexual pheromones of the *Stegobium paniceum, Anobium punctatum* and *Lasioderma serricorne* were published by Chuman (1981-1983), Kuwahara (1975), Mochizuki (1984), P.R. White and M.C. Birch (1987, 1988).

Research on the damage caused to the cultural heritage and the control of anobiids

Information on the damage the insects caused to the religious artifacts has been kept since the antiquity; really important data started to be recorded round the 18th – 19th centuries when significant insect attacks on the libraries and archives were noticed by Frisch (1721) and J. Herman (1775) in Germany, J.P. Meinecker (1785) in Belgium, M.L. Hiriart (1900) and C. Houlbert (1903) in France. Houlbert mentions other authors preoccupied by the study of book pests: Réaumur (1734), Buchoz (1781), P. Pompilio (1809), Poey (1851), E. Perris (1869) etc.

At the beginning of the 20th century numerous studies on pests that damaged historical monuments were published by: Sir Frank Baines (1914), Hickin (1963), S.R. Belmain (1999) and R.C. Fisher (1941-1959) for Great Britain, Tooke (1949) for South Africa. D. Pinniger (1989) and H.P. Sutter (2003) presented the anobiids that are responsible for biodeteriorating the museum collections. In Italy Gallo (1967), Liotta (1991), Caneva (1994), Uzielli (1994), Santacesaria (1999) published studies on the damage caused by the anobiids to the heritage goods as well as papers on methods of pest prevention and control.

Applying insecticides by fumigation, brushing or injection, are the most frequently mentioned in the 19th century papers, by authors such as Guérin (1858) and Hubbard (1880) who recommended the use of pyrethrin, Andrews (1870) who used bleach for pest control or H. du Buysson (1893) who used carbon disulfide fumigations. In the 20th century the chemically synthesized insecticides are frequent. Using high pressure carbon dioxide is recommended by P.S. Nielsen (2001). Rajendran S. (2004) studied the conditions for eradication by use of phosphine fumigations.

The use of vegetal insecticides or repellents for pest control has been mentioned since antiquity but only in the 20th century scientists performed studies on their efficiency: Deshpande (1974), Ahmed (1986) and Regnault-Roger (1997) mentioned the biocide effect of the essential oils of *Ocimum basilicum*, *Gaultheria*, *Eucalyptus* and thyme, and Soon-Il (2003) suggested fumigations with *Acorus calamus* caudices.

Physical methods of Anobiidae pest control were suggested by Kozulina (1971) who recommended gamma irradiation, Ulrichs (1997) and Xavier-Rowe (2000) present the advantages and disadvantages of thermal treatments, Valentin (1993) and S. Maekawa (2002) recommended anoxia with or without nytrogen or argon.

The effectiveness of pheromone traps in monitoring and control anobiids were studied by Arbogast (2003) and S. Rajendran (2005).

Biological methods of limiting the populations of Anobiidae were tested by Ambriz (1996) who studied the degree of infestation caused by the *Lariophagus distinguendus to Lasioderma serricorne* by means of substances extracted from the cocoon of the pupae, Kaelin (1999) and Tsuchiya (2002) who tested the effectiveness of the *Bacillus thuringiensis* over the *L. serricorne* larvae.

In Romania the first papers on this subject were published starting with the second half of the 20th century. Şt. Negru (1966), E. Vintilă (1978), F. Oprea (2006) mentioned the anobiids that cause damage to the museum collections in Romania. R. Georgescu (1977) presented vacuum as a method of disinfection. J. Păun (1977), C. Ponta (2003), M. Brăilean (2003) experimented on pest control in the museum collections by means of gamma rays. G. Iuga (1979), Corneliu & Livia Bucşa

(1978, 2005) suggested chemical methods of pest control as being the safest and the most frequently used. P.D. Pascu (1998) used plant extracts as an alternative to chemical treatments. Gheorghe & Mariana Mustaţă (1977 - 2010) have done a lot of research on the biodeterioration of the cultural heritage, and published numerous papers on pests, the damage they cause and effective pest control as well as the use of chemical gas or liquid. Important data was published by M. Moşneagu (2003-2010) for Moldova, by G. Gămălie (2005-2007) for the book collections in Moldova and Braşov, by B. Ungurean (2006-2009) for the village museums and by L. Axinte (2007-2009) for the historical monuments in Suceava.

2. Materials and methods

Methods of collecting the biological material. Adults, larvae, larval skin and pupae's houses, feces and biodegraded material were sampled from museums, libraries, archives, storing facilities, memorial houses, churches.

Collecting the insects by means of traps. Sticky pannel traps *Pherocon AM Trap* from *Trécé Inc*., transparent and coloured traps, sexual pheromone traps *Fuji Flavor Co*., Ltd. for *Stegobium paniceum*, electrical grid traps with UV light were used to identify and monitor the active attacs of the anobiids (figure 1).

Fig. 1 - Identification of active actack with sticky pannel traps (a), coloured trap (b), electrical grid trap with UV light (c) and sexual pheromone trap (d,e)

Preserving the collected biological material. The dry preservation of the adults has been done by fixing them on entomological pins or card points.

Preparing the biological material. Biological material were prepared in Canada balsam after maceration in KOH 10% solution for 12 hours, followed by repeated rinsing with water and neutralization by the use of acetic acid 10%. For the study under the SEM the dead larvae have been exposed to vapours of ethilic ether, dehidrated in 30' ethanol, immersed in 30' hexametildisilazan, dried and metallized.

Registering the images. The photographic registration were done in situ by means of the Olympus FE-120 camera. Macro and micro photographs were taken by means of the MSZ 5600 binocular microscope (Krűss Optronic Germany), the Optika trinocular optical miscroscope and the TESCAN Vega II SBN scanning electron microscope.

Growing the anobiids in the laboratory. The insects have been grown in glass jars of different sizes on paper, lime wood, fir-tree wood, cherry wood, textiles, bakery products, tea leaves. *Stegobium paniceum* and *Lasioderma serricorne* insects have been grown on bakery products and tea leaves at 18-30^{0}C şi 47-65% UR. The *Anobium punctatum* species has been kept in 7-year-old cherry and lime wood containers and 3-year—old fir tree containers.

Obtaining essential oils from plants for control anobiids attacks. Essential oils have been extracted from absinth by using the method suggested by the 10th edition of *Farmacopeea Română.* Flowers and leaves of *Artemisia absinthium* have been harvested in august, dried for a week at the room temperature and finally ground. 45 g of plant mixed with 450 ml of distilled water were boiled in the Clevenger device for 3 hours.

Analytic ecological indices. The F frequency of the pest insects was calculated according to the formula: $F = p/P \cdot 100$, F - frequency, p - the number of samples in which the studied species appears, P - the total number of the studied samples.

Sampling stations. The research was done in ten county: Alba, Bacău, Braşov, Iaşi, Neamţ, Prahova, Suceava, Tulcea and Vaslui, been studied libraries, memorial houses, churches, monasteries, storage facilities, museums, as well as numerous icons from private collections.

3. Characteristics of the *Anobiidae* family

3.1. The taxonomic and phylogenetic data.

The *Anobiidae* represent a family of small dimensions of about 1800 genera that are in close relationship with the *Ptinidae*, *Bostrichidae* and *Lyctidae* both by their morphology and their behavior.

The *Anobiidae* family belongs to the *Animalia* kingdom, *Arthropoda* phylum, the *Insect* class, *Coleoptera* order, *Polyphaga* suborder and

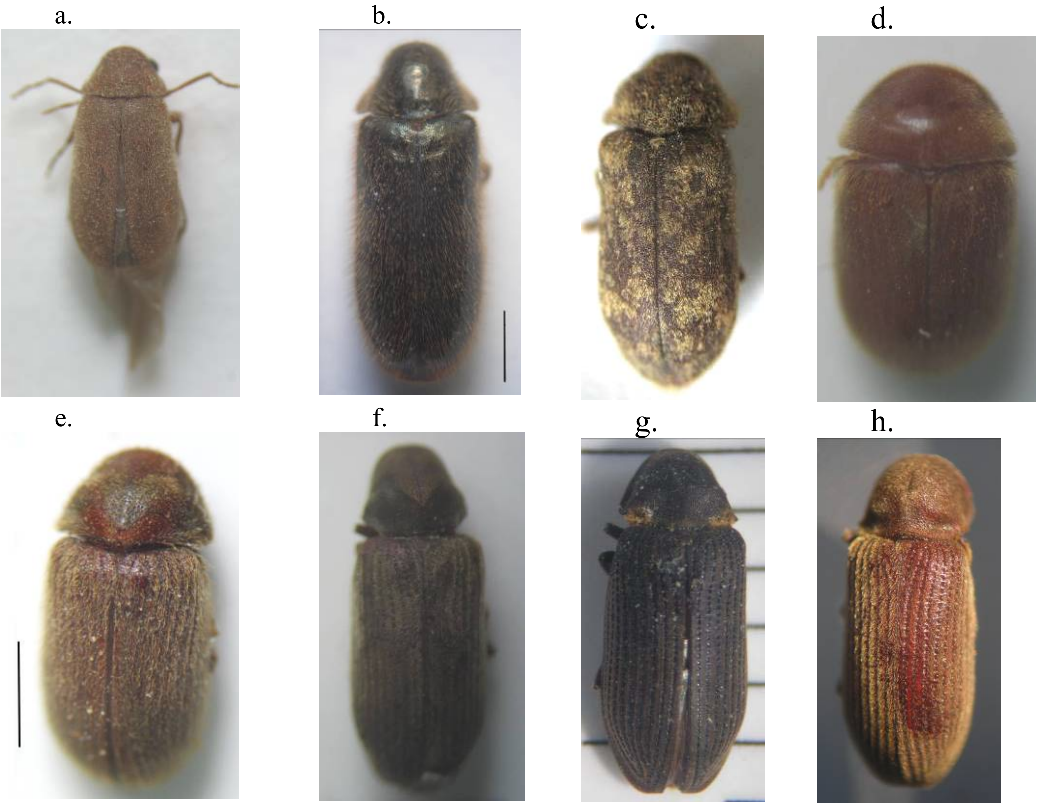
Bostrichoidea superfamily. It is divided into 8 subfamilies: *Hedobiinae, Dryophilinae, Ernobiinae, Anobiinae, Ptilininae, Xyletininae, Tricoryninae* şi *Dorcatominae* that reflect the different evolutional stages.

3.2.The morphological characteristics of the anobiids

The anobiids are small insects with a length that varies from 1,3-9 mm. The shape of the body is subcylindrical or oval. The colour varies from light to dark brown. The body is covered by whitish or golden hairs that can sometimes form spots. The hairs differ in terms of length, colour, thickness and orientation (figure 2).

The head of the anobiids is hypognathous, more or less semispherical, being covered on the back by the prothorax. In the case of the *Hedobiinae* the head is almost underhung and in the case of the evolved species it is almost opisthognathous. *L serricorne* can have fosets and the *A. punctatum* can have bumps. The eyes are complex with or without hairs (figure 3d).

a. b. c. d.



e. f. g. h.

i. j. k. l.

Fig. 2 - *Ernobius mollis* (a); *Xestobium plumbeum* (b); *Xestobium rufovillosum* (c); *Lasioderma serricorne* (d); *Stegobium paniceum* (e); *Anobium punctatum* (f); *Anobium pertinax* (g); *Priobium carpini* (h); *Oligomerus brunneus* (i); *Oligomerus ptilinoides* (j); *Oligomerus retowskii* (k); *Ptilinus pectinicornis* (l) (scale – 1 mm)

The antennae of anobiids have 8-11 segments, being club-shaped, filiform, either serrated or pectinated (figure 3 a-c). There are sensilla with mechanical, chemoreceptive, thermal and hidroreceptive roleson the antennae. There have been identified Böhm, trichoids, chaetica, baziconic (figure 4), stiloconic, capitulum and auricilica sensilla. The trichoid sensilla and chaetica of 50 µm are mechanoreceptors. The basiconic sensilla have chemoreceptive, olphactory or pheromonal roles (the flat stiloconic and coeloconic types). The auricilica sensilla are thought to have chemoreceptive role. The capitulum sensilla identified as *L. serricorne* seem to have thermal and hidric roles [2].

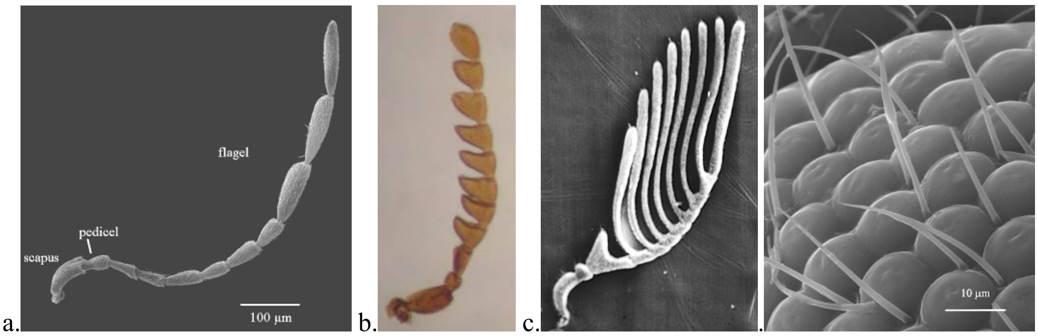


Fig. 3 - Types of antennae: a – club-shaped (*Ernobius mollis*), b – serrated (*Ptilinus pectinicornis* ♀), c - pectinated (*Ptilinus pectinicornis* ♂); the compound eye with hairs (d)

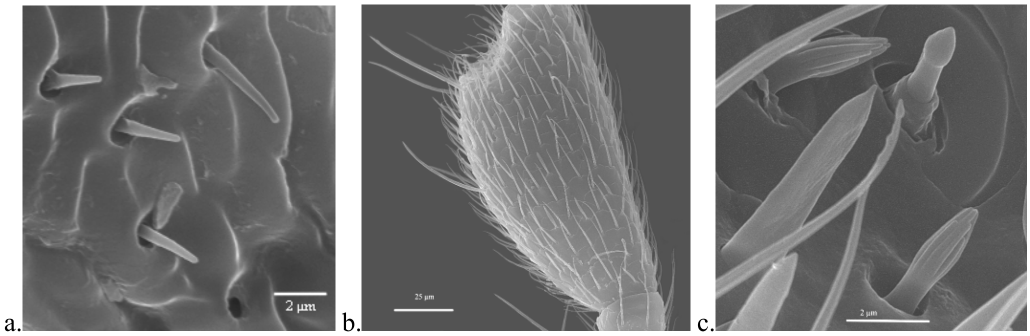


Fig. 4 - Types of antennal sensillla at the anobiids: a - Böhm (*Lasioderma serricorne*); b - chaetica, baziconic and trichoide sensilla, c - baziconic sensilla (*Stegobium paniceum* ♂)

The strong buccal apparatus is adapted to tearing and chewing (figure 5). On the buccal apparatus of the anobiids there are Böhm, trichoide, chaetica, stiloconic and placoide sensilla (figure 6). The Böhm sensilla were discovered on the internal side of the first articles belonging to the maxillary and labial palps (*L. serricorne, S. paniceum*), at the basis of the mentum (*L. serricorne, S. paniceum*) and next to the hairs of the galea (*O. ptilinoides*).

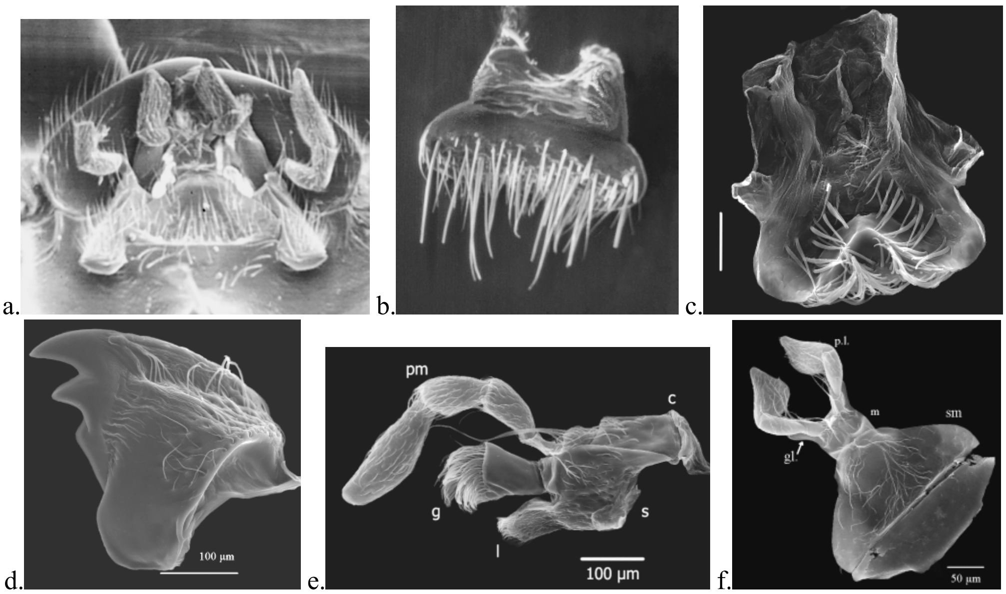
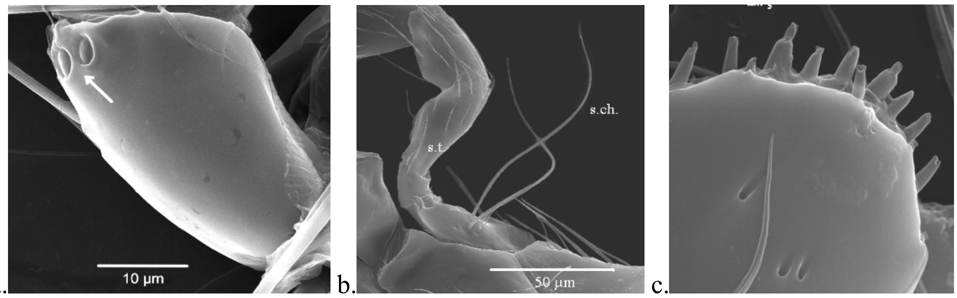


Fig. 5 - The buccal apparatus: ventral view(a), the labrum(b), epipharinx (c) (scale – 50 µm); the mandible (d), the maxillae (e) and the labium (f)



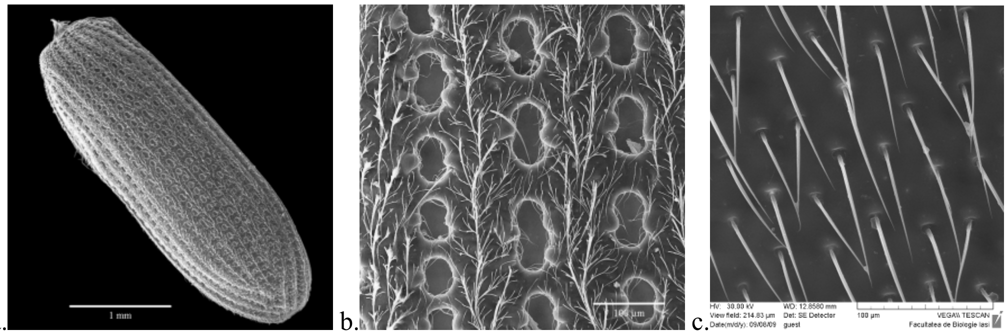
a. b. c.

Fig. 6 - Types of sensilla on the buccal apparatus: placoide (a), chaetica (b) and stiloconic (c)

The thorax is made up of prothorax, mesothorax and metathorax, to which the appendages involved in locomotion should be added. It is the prothorax that is characteristic to each species, presenting specific shape, sculpture, pubescence and granulation. The scutellum is obviously dorsal.

The elytra are red-chestnut brown; they can have spots placed in rows (*Anobium, Priobium, Synanobium*) or in no specific order (figure 7). The ernobiines and some tricorynines and xyletinines have no striations on their elytra.

The membranous wings have reduced innervations, with a single cell closed in the anal field. There are sets in a various number and positions in the area where the median and cubital areas join.



a. b. c.

Fig. 7 - Elytra with rows of ordered rows (a, b – *Priobium carpini*) and elytra without spots (c – *L. serricorne*)

The leg, adapted to walking, have long and thin femur, tibia and tarsus; they are covered by hairs (figure 8a). The anterior and median coxae are globular. The tibia have spurs or indentations. The tarsi are made of 5 articles and have two claws (figure 8c). There have been identified coeloconic sensilla on the pretars in the case of the *Ernobius mollis* (figure 8b).

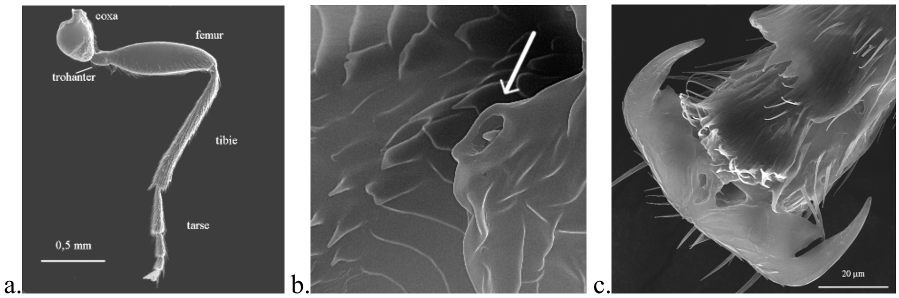


Fig. 8 - The leg (a) and the coeloconic sensilla (b) on the pretars of the *Ernobius mollis* (a); the claws of the *S. paniceum* ♂ *species* (c)

The abdomen is covered by elytra, but only the last tergit seems to be partially uncovered. It is made of five separate or joined sternites. The anal plaque of the male has a straight posterior margin but the one belonging to the female has a sinuous one.

The external genital apparatus of the male differs in the family, being important both for differentiating the similar species and for classifying them. The edeagus is trilobed, the only exception being the species belonging to the *Hedobiinae* subfamily [3].

The larvae's morphology. The anobiids larvae belong to the melolontoid type (figure 9a), being oligopodes and having in the last stage of development various lengths (4 - 11 mm). The colour of the larva is yellowish-white. The body is covered by fine golden or brown, thick or thin, long or short hairs.

The head is ortognated almost hemispherical and narrower than the thorax (figure 9b). The antennae are anterior – laterally oriented being made of 1 or 2 segments. They have olfactory cones and sensitive organs represented by tricoid, baziconic and coeloconic sensilla. The basis of the sensilla is free or surrounded by a developed basic ring (figure 9c).

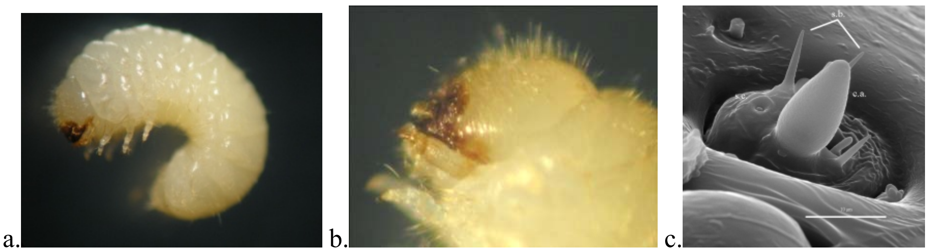


Fig. 9 - The *Xestobium rufovillosum* larva (a), the cephalic capsule of the *Stegobium paniceum* species (b) and the antennae of the *Anobium punctatum* (c)

The buccal apparatus is made for tearing and chewing (figure 10a). The maxillae are joined by a membrane that is submental to the labium. The maxillary palp is triarticulated (figure 10b). The sensory organs of the maxillary and labial palps are grouped at the end of the apical segment (figure 10c). There can be identified trichoid, basiconic and placoide sensilla.

The thorax is wider than the cephalic capsule and the abdominal segments and has three pairs of legs (figure 11a) with 3-5 articled that end in claws.

The abdomen is made of 10 segments of which the 9th and 10th are not folded. Except for the newly born larvae the anobiid larvae have short chitinized spinules (figure 11b) oriented towards the posterior side in rows of a various number, on the dorsal or lateral side of the 2nd and 3rd segments of the thorax and the 1st and 8th abdominal segments. The larvae spiracles are placed laterally, a pair for each segment of the thorax and abdomen, except for the caudal segment (figure 11c).

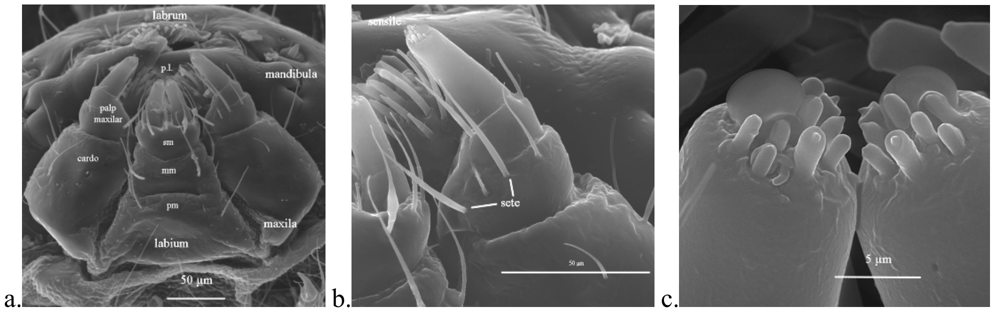


Fig. 10 - The buccal apparatus of the *Anobium punctatum* larva seen ventrally (a), maxilla of the *Xestobium rufovillosum* with trichoid sensilla (b) and basiconic sensilla (c)

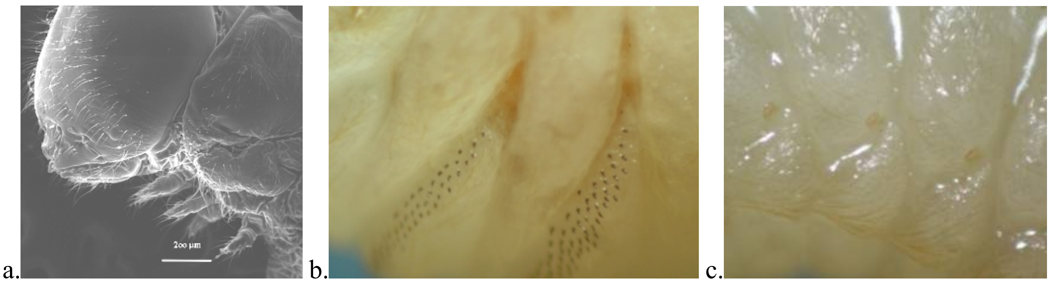


Fig. 11 - The legs of the larva (a), the dorsal spinules (b) and spiracles (c) of the *X. Rufovillosum larva*

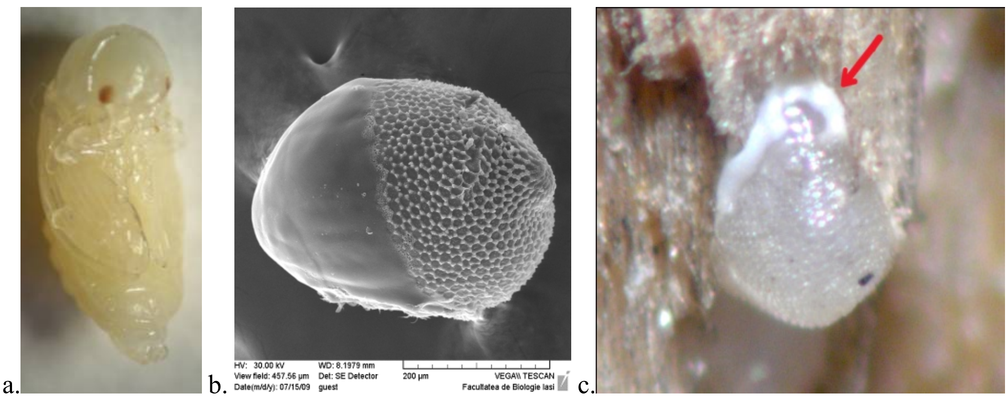


Fig. 12 - *Stegobium paniceum* pupa (a); *Anobium punctatum* egg (b) fixed in the support by means of a white secretion (c)

The pupae's morphology. The anobiid pupae have the segments of the body well individualised with separate appendices. Their colour is milky-white, gradually pigmenting their eyes then the mandibullae, tarsi and claws (figure 12a). The dimensions can indicate the gender of a pupa.

The eggs are white, translucent, with a smooth or sculpted surface (figure 12b). Their form can be ovoidal, elongated, with a length of 0,2-1,5 mm. The egg is fixed by the female on the wood by means of a whitish secretion (figure 12c).

3.3. The internal organization

The nutrition functions. The anobiids are capable of digesting only a small percentage of the complex substances from the wood composition; that is why they feed on the spare substances in the cells or consume the wood after the symbiont microorganisms (i.e. yeast, bacteria, protozoans, microscopic fungi) have degraded celulosis and lignin.

The excretion function is fulfilled by the tubes of Malpighi, the labial glands, the pericardic cells and the adipose body. Another characteristic of the anobiids is the lack of leptofragmates in the criptonefridial system.

The reproductive functions. There have been identified sexual pheromones such as the stegobinone for the *Anobium punctatum* species [4] stegobinone [5] and stegobiol for the *Stegobium paniceum* [6] and serricornin, serricorone and serricorole for the *Lasioderma serricorne*. Stereoisomers of the serricornin such as *erytro-serricornin* and *threo-serricornin* [7] that induce the males'sexual arrousal have been isolated and synthesized.

Biological Data. The anobiids have a holometabolic development with four clear stages of development: egg, larva, pupa and adult. The beginning of the flying depends on the thermal conditions. In Europe, the adults start to fly from March to September. The mating takes place either within the damaged substratum or outside. Females lay eggs in sheltered places such as the wood cracks. The embrio development takes 1-4 weeks. Hibernation takes place during the larva or pupa stage. Life cycle vary from a few weeks to a few years, according to the environment conditions and the quality of the nutritional environment. The adult lives for about a month. The adults' longevity differs according to their heredity, gender, the nature of their nutritional substratum, the environment factors [1].

3.4. Ecological and ethological data

The relative temperature and humidity of the air. Most of the anobiids develop in 45-70% UR and 17-30^{0}C, with the optimal values at 22-25 ^{o}C, a minimum of 11-14^{o}C and maximum of 29-35^{o}C.

The light. Before mating the adults have a positive phototropism being also attracted to light colour surfaces [8].

The nutritional support. The anobiids are insects that are mostly xylophagous, and living within the dead wood outside and inside. *Lasioderma serricorne* and *Stegobium paniceum* are polyphagous species that develop on various products: tea, food, dry plants, herbariums and insect drawers, etc. Some species such as *Nicobium castaneum*, *Falsogastrallus* sp., *Stegobium paniceum* sau *Tricorynus* sp prefer old books that they seriously damage. The dorcatomines are micetofiles and micetophagous. Species of *Xyletinus* have been found in the dry excrements of the herbivores [9]. Some species of develop within the tall and the fruit of plants such as the ivy, the mastic and the mistletoe.

The role of the biotic factors on the anobiids. The anobiids live in endosimbiosis with microorganisms that contribute to the use of the nutritional resources by providing the necessary enzimes for degrading or detoxifying their food. The anobiids have developed associations with the fungi in the *Ascoidea, Cicadomyces, Coccidomyces, Endomycopsis, Hansenula, Pichia, Saccharomyces* genera (O. *Saccharomycetales*). The *Stegobium paniceum* and *Lasioderma serricorne* have a symbiotic relationship with the *Symbiotaphrina kochii* and *S. buchneri* fungi (Cl. *Ascomycetes*). The predators of the anobiids are species of spiders, psocoptera, hemiptera and coleoptera. Clearing the anobiids larvae is done by the Himenoptera (*Pteromalidae, Bethylidae, Braconidae, Ichneumonidae*) and the acari.

Table 1 - The geographical areas of distribution of the anobiids (according to Logvinovskyi, 1985)

Subfamily	**Number of genera**					
	Region					
	Palearctic	Nearctic	Indo-malaesian	Ethiopian	Neotropical	Australian
Hedobiinae	2	3	-	1	-	1
Dryophilinae	5	2	1	-	2	2
Ernobiinae	5	8	-	2	4	1
Anobiinae	14	23	6	7	10	10
Ptilininae	3	1	1	1	2	1
Xyletininae	8	6	3	10	9	4
Tricoryninae	3	4	3	4	4	4
Dorcatominae	9	11	11	19	20	13
Total	**49**	**58**	**25**	**44**	**52**	**37**

3.5. The geographical areas of distribution.

The anobiids are largely spread all over the continents and large archipelagoes with tropical and subtropical climate (table no 1). The anobiids are frequently found in the areas with a temperate climate and also in the North American and Eurasian taiga. There are few such insects in the tundra or none at all. There is much data on the geographical areas of their distribution owing to Fr. Espanõl, V. D. Logvinovskyi, R. E. White [10].

4. Species of *Anobiidae* that damage the cultural heritage objects identified in the research

The *Anobiidae* found in Romania

In Romania 32 species of *Anobiidae*of 6 subfamilies (*Hedobiinae*, *Ernobiinae*, *Anobiinae*, *Ptilininae*, *Xyletininae* amd *Dorcatominae)* were found. They are species found in the natural unprocessed wood and in closed spaces. The species that damage the patrimony goods identified in Moldova are*: Anobium pertinax, Anobium punctatum, Oligomerus brunneus, Oligomerus ptilinoides, Oligomerus retowskii, Ptilinus pectinicornis, Stegobium paniceum, Xestobium rufovillosum.*

4.1. The *Ernobiinae* subfamily

They are 5-9 mm long insects, almost cylindrical with a pro- or hypognathous head, without ventral cavities. The antennae are thread-shaped, being made of 10-11 segments with or without a club. The prothorax is not very curved, with its lateral margin complete or present only on the posterior side. The elytra have a thin surface, without any dots. The aedeagus has certain shapes being symmetric or asymmetric.

The *Xestobium* genus. They are the largest Anobiidae in Europe, with a length of 5-9 mm. Their bodies are covered with long fine hairs, placed horizontally or vertically. The head is hypognathous. The antennae are made of 11 segments. The prothorax is convex, with complete lateral margins. The elytra have fine irregular dots. The pro and mezzo sternum do not have cavities between the coxa. The abdomen has 5 unsealed sternites. The aedeagus is very different from that of other genera belonging to the subfamily.

The species that were found in Romania are: *Xestobium rufovillosum* DeGeer, 1774 ; *Xestobium (Hyperisus) plumbeum* Illiger, 1801.

Xestobium rufovillosum. Morphological data: 5-9 mm in length, the head is covered with golden hairs, grown in spots on the pronotum and the elytra; there are antennae made of 11 segments, the last ones being larger than the anterior ones; the prothorax is wide with rounded angles and the maximum dimension in the posterior third; the elytra have rounded lateral angles and apices; flatened tibia, trilobate symmetrical long aedeagus that narrows in the median part, with strong apically bifurcated paramera.

Geographical distribution: the holarctic region, neotropical region, New Zealand. In Romania it can be found in all the areas, both in buildings and in nature. Sampling areas: Bacău: Bogdana Monastery ; Botoşani: Ipoteşti; Iaşi.

4.2. The *Anobiinae* subfamily

Their body are 2,5-7 mm long, subcylindrical and have a hypognathous head. The thread-shaped antennae are made of 10-11 segments, the last 3 segments being larger than the anterior ones. The prothorax is more or less curved, with prominent areas; the lateral margin is complete. The elytra have dots on the whole width or only on the lateral margins (the *Gastrallus* genus), grown in rows or irregular. The prosternum is a little excavated in order to shelter the head. The aedeagus is variable in shape both at the level of the genera and the species.

This is a subfamily that is important for the society because it causes significant damage to the cultural and economic goods.

The *Stegobium* genus. The body is short, oval and covered with hairs. The antennae are made of 11 articles. The prothorax is a little curved, it has complete lateral margins and the maximum width at the basis. The elytra has rows of regular fine dots. The abdomen has the first two sternites equal and longer than the 3^{rd} and 4^{th} segments. The genus has one well known species only [3].

Stegobium paniceum. Morphological data: a length of 2-4 mm; the body is brick-like-brown in colour; the antennae are thread-shaped with the 9^{th} to 11^{th} segments longer and wider than the 2^{nd} to 8^{th} ones; the prothorax basis is sinuous; the pubescence of the elytra is double with some of the hairs long and thick and some short and thin; the aedeagus is asymmetrical, looking in a specific way.

Geographical distribution: a well spread species, being a common pest in food storage facilities and also in libraries and archives.

The *Oligomerus* genus. The relatively large insects, of 5-7 mm in length have a long reddish-brown cylindrical body with a fine yellowish pubescence. The eyes are complex, large and prominent. The antennae are made of 10-11 articles the last three being a lot larger. The prothorax has complete and well-defined margins. The elytra are as wide as the prothorax and have rows of dots. The anterior and median coxa are cotangent or barely separate. The aedeagus is trilobate with symmetrical paramera that have lateral apendices with hairs. 19 xylophagous species were found in Europe, Asia, North America and Africa [3].

Oligomerus ptilinoides. Morphological data: cylindrical 5-7 mm long body, covered with long thick hairs, horizontal with a granular surface; their eyes have long hairs; the antennae are made of 11 segments, the last segment of the maxillary palp being very large; the prothorax has a maximum width in the posterior margin; the elytra have simple regular dots with spaces between flattened rows.

Geographical distribution: species found in the palearctic area, imported to Japan by means of the processed wood.

Oligomerus brunneus. Morphological data: a species that is very much similar to the *O. ptilinoides* but it also has antennae made of 10 segments and the eyes with very short hairs; the elytra have rows of double dots sometimes irregular, with spaces between rows that are more flattened and with shorter and thinner hairs than in the case of the *O. retowskii*.

Geographical distribution: a species found in the eurasian subregion. In Romania, it was discovered in Dobrogea and Bucovina by Ed. Fleck (1904).

Oligomerus retowskii. Morphological data: a 6-8 mm long, brown, and covered with yellowish hairs; the eyes have short hairs; the antennae are made of 10 segments; the elytra have rows of dots that are not too deep, regular and barely doubled with barely convex spaces between the rows.

Geographical distribution: Crimeea, Caucasus, Greece. In Romania CA Rosetti found it in the Danube Delta.

The *Anobium* genus. They are small insects of 2-5,5 mm in length, and a subcyllindrical chestnut-brown body, covered with short hairs. The antennae are made of 11 segments. The pronotum is curved and narrowed towards the anterior side, having rounded posterior angles. The lateral and posterior margins are thin and complete. The shape of the pronotum differs within the species of the genera this aspect being important in identifying the species. The sternites of the prothorax have a ditch on the median side for withdrawing the antennae and the legs. The aedeagus is trilobate, symmetrical and varies according to the species.

Anobium punctatum. Morphological data: they are 2,5-5 mm in length; the body is brown, covered with short hairs and thick, being visible especially between the rows of dots on the elytra; the antennae are made of 11 segments, the last three being larger and longer than the anterior ones; the prothorax is narrowed on the anterior side, with a triangular prominence in the median posterior half; the elytra are wider than the prothorax with 10 rows of large dots that have a rounded apical part; the last abdominal sternite of the male is a median depression; the aedeagus is symmetrical, having a specific shape.

Geographical distribution: a holarctic species, common to Southern and Central Europe as well as to Romania.

4.3. The *Ptilininae* subfamily

The insects have a thin, elongated cylindrical body, covered with fine hairs. The head is hypognathous at rest, the buccal apparatus being far form the meta sternum. The antennae are made of 11 segments usually serrated in the case of the females, in the case of the males being either pectinate or serrated. The convex prothorax has on the lateral side sharp edges between the anterior and posterior angles. The elytra are as wide as the prothorax and have fine irregular dots. They do not have cavities for withdrawing the antennae or legs. The aedeagus has a shape that is specific to the subfamily.

The *Ptilinus*, *Plumilus* and *Pseudoptilinus* genera were found in the Eastern part of Europe [9].

The *Ptilinus* genus. The insects have a narrow elongated body. The males' antennae are pectinate and those of the females are serrated. The last segment of the maxillary palp is elongated. The complex eyes are small and prominent. The prothorax is as wide as the eytra and has a coarse surface in the case of the male and a finer one in the case of the female. The dots in the elytra are fine and irregular. The anterior coxa touch one another and the median ones are just a little separate. The curved wide meta sternum has in the posterior median half a narrow ditch. The tibia of the legs have a series of bumps in the shape of dents on the length of the external edge. The abdominal segments are free. The aedeagus is arched at the short basic part and has long apically clubed paramera. They have sexual dimorphism.

Ptilinus pectinicornis. Morphological data: they are 3,5-5,5 mm long; have a narrow enlongated body; the colour is brown to black, and only the elytra are lighter to brick-like brown; the males' antennae are pectinate at the females' antennae are serrated; the prothorax is very little narrowed to the anterior side with a small shiny area in the median area, close to the posterior margin; the elytra have fine irregular dots.

Geographical distribution: in the palearctic region, common to Central and Southern Europe. In Romania it was found in Moldova and Transilvania.

4.4. The *Xyletininae* subfamily

They are evolved species with the ability to contract their body so that the buccal pieces can touch the meta sternum. The body is oval and is 2-5 mm long. The antennae are made of 11 serrated or pectinate articles, being placed in cavities of the pro sternum during rest. The convex prothorax has a complete sharp lateral margin. The meta sternum and abdomen do not have transversal depressions. The anterior coxa are small and cotangent. The aedeagus is trilobate, with the median lobe widened and with short and wide paramera that have a lateral lobe with cillia.

The *Lasioderma* genus. The insects have an oval body with parallel lateral margins, being curved, with a fine and more or less short pubescence. At rest the head is strongly bent towards the meta sternum. The antennae are made of 11 segments being serrated or pectinate. The last article of the maxillary palp is elongated. The prothorax does not have any bulges. The meta sternum is strongly bent towards the front and has a semicircular shape. The elytra have fine irregular dots. The anterior and median coxa are adjacent. The abdominal segments are free.

Lasioderma serricorne. Morphological data: 2-3 mm in length; oval chestnut-brick-like brown body, with long golden hairs; the antennae are made of 11 segments; the prothorax is wide, the posterior angles are rounded and the anterior ones almost straight; the elytra are wide with thin/rare hairs; the first segment of the tarsa is twice or three times longer than the 2nd segment; the aedeagus is trilobate, symmetrical in a specific shape.

Geographical distribution: it is a widely spread species, frequently met in our country too, in storage facilities, warehouses and buildings.

5. Biological data on the *Anobiidae* that damage the cultural heritage collections

Sexual maturation. After complete chitinization the adults do not have a developed reproductive system and therefore stay for 3-7 days in the pupae house in order to grow even if they are fully capable of walking.

The attraction of the individuals of opposite sexes takes places by means of chemical signals such as sexual pheromones and communication by means of sounds. The adults that are able to mate can locate and court their sexual partners by hitting the wooden support with their heads, the rhythm and intensity of the beats being specific to this species.

Laying eggs. The eggs are laid in dark areas, sheltered from air currents or natural enemies. The xylophagous species lay eggs in wood cracks, incisions and often in the flying holes or galleries, fixing them to the substrata by means of a secretion. The eggs are laid in groups/series.

Prolificacy. In the case of the Anobiidae it is generally reduced, the number of eggs laid varying according to the species, the nutritional support and the microclimate parameters. *Anobium punctatum* lay approximately 20-30 eggs in two or three series, *A. pertinax* lay approximately 10 eggs, *Xestobium rufovillosum* lay 40-60 eggs in series, in groups of 2-7 eggs and the *Lasioderma serricorne* females lay approximately 40 eggs per female. In the case of the there were variations in the series of eggs according to the temperature and the relative humidity: 58-60 eggs at 24°C and UR= 45%; 21 eggs at 15°C and UR= 80%; 3 eggs at 12°C and UR= 80% and only 1 egg at 10°C and UR= 80%.

Embryogenesis starts immediately after fecundation and the egg-laying and appearance of neonate larva in the growing support take place after 1-4 weeks. The shortest larval stage takes place in 1-2 months (*S. paniceum* şi *L. serricorne*) with an average of 1-2 years in the case of the xylophagous species. The pupation takes place in a cocoon built close to the surface of the support so that the adult can fly out of the object.

Biological cycle. Most of the anobiids that damage the cultural heritage objects (*Anobium* sp., *Oligomerus* sp., *Ptilinus* sp., *Xestobium rufovillosum*) have a 1-2 year old biological cycle except for the *Stegobium paniceum* and *Lasioderma serricorne* which are polivoltin species.

6. Ecological data on the *Anobiidae* that damage the cultural heritage collections

6.1. The influence of the abiotic factors

Temperature and humidity. The optimal values of growth for the Anobiidae are 22-25 °C with a minimum of 11-14°C and maximum of 29-35°C. *Xestobium rufovillosum, Anobium pertinax, Nicobium castaneum* are higrofile, preferring UR of 60-70%. *Stegobium paniceum* develop at 40-70% UR, having a biological threshold of 12,6^{0}C, the thermal constant being 547^{0}C, the prolificacy threshold being 17,4^{0}C, the thermal optimal value of 30,5^{0}C and the superior thermal threshold of 36^{0}C.

Light and colours. The adults have a positive phototropism during the mating season, the negative phototropism being found at the females that lay the series of eggs. The attraction of *Xestobium rufovillosum, Anobium punctatum* and *Stegobium paniceum* adults to the white surfaces and the light shades of colour has been proved, without any preferrence for a certain colour.

The nutritional support. The *Anobiidae* are insects that are mostly xylophagous and living within the dead wood outside (in the treebark, the trunk of the coniferous trees: - *Dryophilus*, *Episernus* and *Ernobius* or in the wood of the broad - leaved trees - *Grynobius*, *Hemicoelus*, *Ptilinus*, *Rhamna*) and inside *(Anobium*, *Xestobium*, *Oligomerus*, *Ptilinus, Calymaderus*). *Lasioderma serricorne* and *Stegobium paniceum* are polyphagous species that develop on various products: tea, food, dry plants, herbariums and insect drawers, etc. Some species such as *Nicobium castaneum*, *Falsogastrallus* sp., *Stegobium paniceum* or *Tricorynus* sp prefer old books that they seriously damage. The dorcatomines are mycetofiles and mycetophagous. Species of *Xyletinus* have been found in the dry excrements of the herbivores. Some species develop within the thallus and the fruit of some plants such as the ivy, the mastic and the mistletoe.

The nutritional support. They are xylophagous insects and some species have become pantophagus (*Stegobium paniceum, Lasioderma serricorne*). The species belonging to the *Anobium*, *Oligomerus*, *Ptilinus*, *Xestobium* genera are mostly xylophagous, attacking either broad-leaved tree or coniferous tree wood materiales that derive from wood (paper or cardboard). They prefer at least 10 year old wood, biodegraded before by bacteria, macro and micromycetes. The sapwood is attacked but the heartwood degraded by the fungi makes the wood accessible to the insects, its mechanic resistence weakening.

6.2. The influence of the biotic factors

Predatorism. The following predators were found: *Liposcelis bostrychophilus* for *Xyletinus peltatus*; *Korynetes caeruleus, Opilo domesticus* and *O. mollis* (*Cleridae*), *Tillus elongatus*, *Paratillus carus* for *Anobium punctatum; K. caeruleus* and *Tilloidea notata* for *Stegobium paniceum; Tillus elongatus* for *Ptilinus pectinicornis*; *Pelecotoma fennica* (*Rhipiphoridae*) for

Ptilinus fuscus; Peregrinator biannulipes (Hemiptera, *Reduviidae*) for *Stegobium paniceum* and *Lasioderma serricorne*

Parasitism. The following predators were found: *Entedon longiventris, Eulophus pilicornis* for *Stegobium paniceum*; *Eusandalum inerme* (*Eupelmidae*) for *Ernobius longicornis*, *Hedobia imperialis*, *Ptilinus pectinicornis; Calosota aestivalis* for the *Anobium* sp., *Xestobium plumbeum* and *Ptinomorphus imperialis; Calosota vernalis* for *H. imperialis*, *P. pectinicornis*; *Cerocephala cornigera* and *Teocolax formiciformis* for *Anobium punctatum*, *A. Pertinax; Theocolax elegans* for *Lasioderma serricorne* and *Stegobium paniceum*; *Anisopteromalus calandrae, Lariophagus distinguendus*, *L. puncticollis*., *Pteromalus anthonomi for L. serricorne* and *S. paniceum*; *Sclerodermus domesticus, S. brevicornis*, *Cephalonomia formiciformis, Cephalonomia gallicola* and *C. rufa* (*Bethylidae*) for *A. punctatum*, *L. serricorne*, *S. paniceum; S. harmandi* pentru *Ernobius mollis*, *Nicobium castaneum*, *Ptilineurus marmoratus*; *Spathius exarator* (Braconidae) for *Anobium punctatum*, *A. pertinax*, *Ptilinus pectinicornis; Doryctes leucogaster, Spathius pedestris for A. punctatum*; *Aspidogonus abietis*, *Coeloides strobilorum*., *Bracon pineti*, *Triaspis aciculatus* for *Ernobius abietis; Heterospilus luridostigmus* for *Hemicoelus gibbicollis*, and *H Heterospilus flavicollis* for *H. Carinatus*; *Demophorus robustus, Hemiteles bicolorinus (Ichneumonidae*) for *Anobium punctatum*; *Hemiteles completes* for *Ptilinus pectinicornis*; *Pyemotes anobii*, *P. beckeri*, *P. Herfsi*, *P. Schwerdtfeger; P. ventricosus* (*Pyemotidae*) for *Anobium punctatum*; *P.tuberculatus* for *O. ptilinoides; Pyemotes tritici* for *L. serricorne*.

6.3. The frequency of the species of Anobiidae in the cultural heritage objects

Samples were taken from 61 objectives of which there are 2 librairies, 2 memorial houses, a museum, 14 monasteries, 42 parish churches as well as private collections. The most frequently found species is *Anobium punctatum (*83,6%) found both in wood objects and in books. *Xestobium rufovillosum* was found in 34,42% of the locations, *Ptilinus pectinicornis* in 14,75% of the locations while *O. ptilinoides and O. brunneus* in 2 locations and *Anobium pertinax, Oligomerus retowskii* and *Lasioderma serricorne* have been identified in only one location. The most frequently found species in the collections of old books was *Stegobium paniceum* (61,9%) (figure 13).

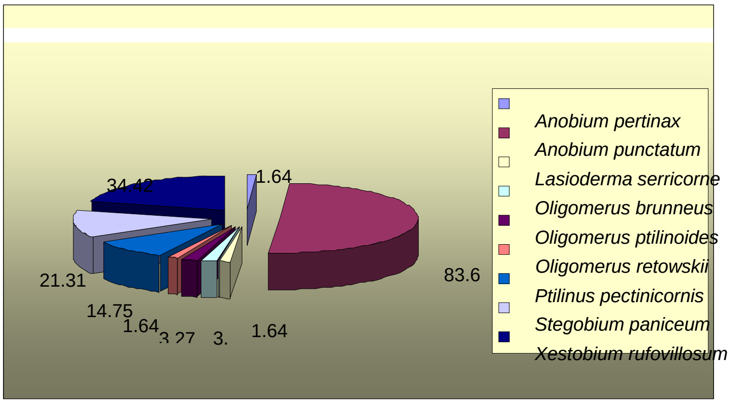


Fig. 13. The frequency of the *Anobiidae* in the studied locations (%)

7. The ethology of the anobiids that damage the cultural heritage collections

After the complete development of the reproductive system, the Anobiidae adults exhibit their availability for mating by spreading sexual pheromones and also by broadcasting sounds by means of a specific communication system.

Locating the partners by means of sounds. The Anobiidae broadcast sounds during the courting ritual by hitting their heads on the wood so that they can find a sexual partner hence the popular nickname, the deathwatch beetle.

The woodworms called deathwatch beetles have been mentioned since 1668 by Wilkins and Fisher (1937, 1938) and Hickin (1963) considered them as mating calls. Birch & Keenlyside (1991) proved that the *Xestobium rufovillosum* adults hit the wooden support with their heads repeatedly: 4-11 times with a frequence of about 11Hz. White P. R. et *al*. (1993) noticed that the females' answer stops at too low (4 Hz) or too high (20 Hz) frequency beats. The number and frequency of the beats are the same for both genders. In most of the cases the males initiate o series of beats that the females immediately answer to, after which the males start the beating again. Goulson et *al*. (1993) thinks that only the virgin females hit the wood and this confirms their availability for mating, their sexual potence. If the males do not get an answer they remain inactive.

In the case of the *Anobium punctatum* and *Ptilinus pectinicornis* hitting the wood is only part of the courting ritual as they locate the females by means of the sexual pheromones.

Locating the partners by means of sexual pheromones. The sexual pheromones stimulate the courting behaviour, the precopula as well as the mating one [6]. The increase in the quantity of sexual pheromones is determined by the sexual development, the presence of the volatile substances emanating from the adequate nutritional support and the substances generated by the eggs - laying progress.

J. Coffelt and W.E. Burkholder (1973) noticed that the *Lasioderma serricorne* females produce pheromones starting with their first day as adults. The quantity constantly increases until they are 4 or 5 days, when they reach their maximum potential. The decline occurs after approximately 7 days of adult life. For the *Stegobium paniceum* the maximum quantity of sexual pheromones broadcast by the females was registered 5 days after chitinization. The production of sexual pheromones continues until their 14th day of adulthood.

Mating behaviour. Mating takes place in the wooden support outside it and in the holes used by the adults for laying eggs. The females take a slightly curved position with their heads forward and their posterior legs extended, after which they take the ovipositor out of their anal segment and the sexual pheromones are eliminated. The reception of the pheromones by the males occurs by means of the antennae elevation for detection of the females' location, the extension of their legs, locomotion and motions of their copulative apparatus.

Goulson et *al*. (1993) noticed that when they have the possibility to choose from more potential partners, the *Xestobium rufovillosum* females have the tendency to mate with the heaviest male. The partners' weight is assessed by attempting the sexual act: if the males are too light the females do not take out their genitals, refusing mating.

Laying eggs behaviour. The *Lasioderma serricorne* females were proved to mark their laying eggs location with *α – serricorone* dispersion pheromones in order to avoid the competition of the new born larvae for the food sources and the means of locomotion.

The chemotactic orientation. In the case of the *Xestobium rufovillosum* females one could notice the chemotactic orientation ability, using the rotten wood to direct themselves by receiving the volatile substances emanating from it. The males reach the wood by following the females. The females were discovered to find the rotten wood in the shortest time: 1—16 days, a time when they usually lay eggs.

Defence mechanisms. The *Anobiidae* adults mimate thanatosis (the name *anobius* means lifeless) in case of danger. The insects lie motionless with their antennae and legs close to their bodies, for a few minutes up to a few days (for example *Nicobium castaneum*).

8. The anobiids' way of attacking and the damage caused to the cultural heritage objects

The importance of the Anobiidae attack is reflected by their high frequency in most of the churches, libraries and museums, on unique objects of cultural, esthetic, historic, documentary and religious value. The damage caused by the insects removes these objects from our daily lives and prevents their valuable use in culture, tourism and economics.

8.1. The anobiids' way of attacking and the damage caused to libraries and archives

The book blocks and wood covers are attacked especially by the *Anobium punctatum* and *Xestobium rufovillosum* and more rarely by the *Ptilinus* (figure 14) The larvae make tunnels of 2-4 mm in diameter that can cross the entire block of pages and the adults punch through the covers and book edges in order to hatch, causing esthetic and functional damage.

The cardboard covers are preferred by the *Stegobium paniceum* and *Lasioderma serricorne* because of the use of the paste in the book binder, the larvae digging tunnels through the first pages of the book block. The holes and tunnels are 1-1,55 mm in diameter but they can be very numerous and can punch through the whole book.

A book is usually attacked by one species of Anobiidae but they can be frequently attacked in turns according to the microclimate conditions present at the time. The books that are kept in a wet environment can be easily attacked by *Xestobium rufovillosum*. Once the books are dry, their attack stops but the books are vulnerable now to the *Stegobiumn paniceum* species. Similarly, the books that are exposed to the attack of the *Anobium punctatum* that usually happens in the iconostases and church furniture, can be subsequently attacked by the *Stegobium paniceum* in the storage facilities.

a. 

b. 

c. 

d. 

e. 

f.  g. 

Fig. 14 - The books that are damaged by the *Ptilinus pectinicornis* (a), *Xestobium rufovillosum* (b-d), *Stegobium paniceum* (f-g), *Anobium punctatum* (e)

8.2. The anobiids' way of attacking and the damage caused to collections, churches, storage facilities and monuments.

The *Anobium punctatum* species cause the most significant damage, both esthetic and functional to the icons and iconostases, being the most frequent pest and attacking the wood for decades until it is destroyed. The *A. punctatum* larvae chew the wood especially along the fibers but when they want to get out, the tunnels become too sinuous. The dimensions of the tunnels are between 0,5-2,2 mm in diameter, they are full of compacted sawdust of a specific long shape. The active attack is identified during the adults' flight period because the sawdust drops out of the holes, making small heaps on horizontal surfaces (figure 15 d-g). The objects exhibit many holes on the surface, with more holes in the unpainted wood than in the painted one. The number of holes can indicate the intensity of the attack.

The *Anobium pertinax* attack was noticed especially on the iconostases, in the wood damaged by fungi (figure 15h), being usually associated with attack of the *Ptilinus pectinicornis* and *Xestobium rufovillosum* species. *Ptilinus pectinicornis* attacks objects made of broad-leaved tree wood (figure 15 a-c) being often found in the objects attacked by the *A. punctatum* or *X. rufovillosum*. They dig irregular tunnels and often avoid the preparation stratum of the painting so the wood can be damaged and the painting will not show it. In the case of the construction wood, the attack does not imperil its structural resistance. The hatching holes are about 1,5 mm in diameter.

The *Xestobium rufovillosum* species attacks the wet or rotten wood, in which case it has access to duramen, the mechanic resistance of the wood being compromised. The larvae dig tunnels of up to 3,5 mm in diameter, full of sawdust and flat excrements (figure 15 i, j).

The insects belonging to the *Oligomerus* genus are more rarely found than other species of *Anobiidae*, the attacks being extremely strong. The insects attack objects made of broad-leaved tree wood (walnut, beech, durmast, etc), the holes made for flying being of 2-3 mm in diameter. The tunnels are irregular in the whole mass of the wood. In the final phases of the attack the wood has only a thin layer on the surface that can cave in under little pressure, underlying the spongy structure of the wood and implicitly deforming the object. The attack can be ignored for long if the wood is covered by polychrome strata. In the construction wood, it does not affect the resistance structure unless it is associated with an attack of the xylophagous fungi.

Fig. 15 - Icons damaged by the *Ptilinus pectinicornis* (a-c), *Anobium punctatum* (d-g), *Anobium pertinax* (h), *Xestobium rufovillosum* (i, j).

9. The control of *Anobiidae* pests and the preservation of the cultural heritage collections

The methodology used for fighting against the insect attack on the patrimony goods has two objectives: eliminating the active insects by the use of curative measures and preventing the new attacks by using preventive methods.

9.1. Identifying the attack of the *Anobiidae* in museums, churches and storage facilities

Identifying the active attack of the Anobiidae in the exhibition and storage spaces of the collections is done by inspecting the objects and the storage modules by the professionals with the help of traps (glue traps, traps with pheromones or kairomones, with white or coloured light, electrical traps), devices with audio sensors [11], by measuring CO_2 [12], X-raying and CT scanning the objects [13].

Identifying the active attack in the book storage facility of Golia Monastery

As a result of the inspection of the volumes in the old book collection I have noticed the presence of live insects (*Stegobium paniceum* adults and larvae) which caused the monitoring of the attack by using glue and pheromone traps. They were captured on all the sticky cardboard sheets with two exceptions leading thus to the ideea of a generalized attack on the whole storage facility (figure 16).

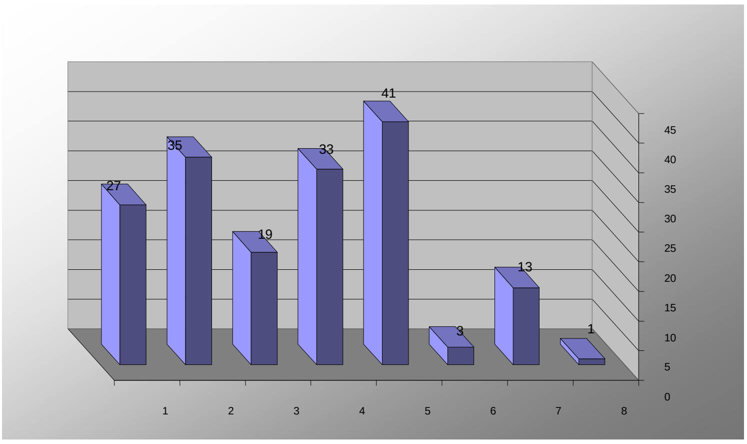


Fig. 16 - The *Stegobium paniceum* captures from the old book storage facility in the Golia Monastery by using pheromone traps

The presence of the predators that are specific to the Anobiidae in the storage spaces is an indicator of an active attack. The *Anobium punctatum* species frequently appears due to the live insects of *Tillus elongatus* and *Korynetes caeruleus*.

The shape of the excrements and sawdust fallen from the wood attacked by the Anobiidae along with other characteristics of the attack as well as the diametre of the flying holes or the essence of the attacked wood help identify the pest (figure 17)

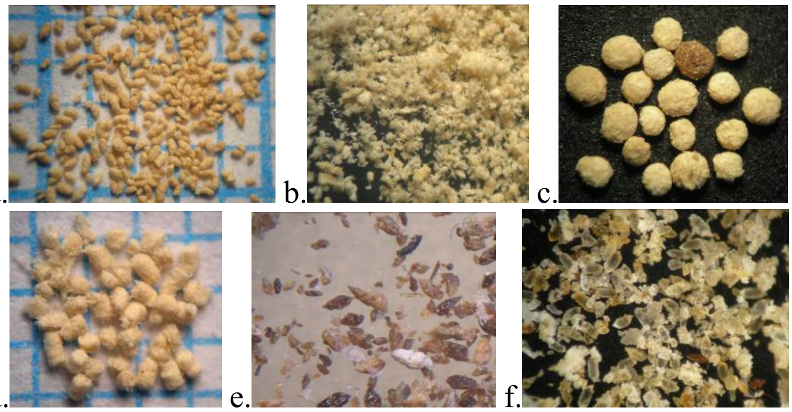


Fig. 17 - The aspect of the sawdust and excrements: *Anobium punctatum* (a), *Ptilinus pectinicornis* (b), *Xestobium rufovillosum* (c), *Oligomerus ptilinoides* (d), *Stegobium paniceum* (e), *Lasioderma serricorne* (f)

9.2. Methods of control against the anobiids' attack

Figthing the Anobiidae that damage the patrimony collection can be done by chemical, physical and mechanical means. The simultaneous or alternative use of these methods has the purpose of reducing the quantity of insecticide used and the decrease of the unwanted side effects on the cultural goods and on the operators.

9.2.1. Physical methods

The numerous cases of resistance to synthetic insecticides, the negative effects on the patrimony goods on the personnel and the environment are solid arguments for avoiding the treatment by means of chemical as opposed to physical means.

The glue traps can be used for reducing the pest effectively when they are not too large. Even though this is not the way to erradicate an insect attack, the fact that it reduces the number of insects and therefore the damage caused by the potential descendants can be an important element in a set of measures to fight the pest.

Exposing the infested objects to lethal temperatures is an alternative of fighting the Anobiidae. The effectiveness of the thermal treatments depends on the species, the type of object that is treated and the way of applying it. High mortality can happen only at sudden changes in temperature from positive to negative so that the insects will not have the possibility to adapt to the new conditions of the environment. In previous studies scientists consider lethal the following temperatures: -16 -17^{0}C in 48 hours for the *Anobium punctatum,* -10^{0}C in 2 hours for the *Stegobium paniceum larvae*, -20^{0}C for 2h for the eggs and pupae [14], -12 and +2 °C for 2,5-14 days for *Lasioderma serricorne*.

In the lab a 100% mortality was reached for the *Stegobium paniceum* and *Xestobium rufovillosum* larvae where the infested books were exposed to -80^{0}C for 2h. The treatment was done by means of the Sanyo MDF-U5386S freezer. The only exception was represented by five *S. paniceum* larvae that did not die even though the book they were infesting was exposed to -80^{0}C for an hour. Being protected by the thickness of the book covers, the larvae were active, with a normal colour of the tegument after 5 days when the objects were checked. The exposure time concept must include the protection of the treated objects against the layer of ice crystals on their surface.

Exposing the insects to high temperatures of 55-60^{0}C ensures the highest mortality of the insects by irreversibly degrading their protein. Previous studies present as lethal the exposure of the objects to 48^{0}C for 32 minutes for the *Anobium punctatum* larvae, to 44°C for 2 h for the *Stegobium paniceum* larvae, to 50^{0}C for 28-35 for *Lasioderma serricorne*. In the lab a maximum mortality percentage was reached in the case of the *Xestobium rufovillosum* larvae in a 8,5 cm thick book. They died after the exposure of the object to 60^{0}C and 60% UR, for 12 h and after being acclimated at 20^{0}C and 60% UR.

In specialised labs for preserving cultural goods there are acclimating rooms (for example *Thermo Lignum*) for treating objects by gradually increasing and decreasing the temperature under the conditions of a controlled UR.They use temperatures gradually increased up to 52°C, being treated for 15-24 hours.

Other methods of disinsectization require the esposure of the infested objects to anoxic atmosphere or to anoxic atmosphere with a high content of carbon dioxide and inert gas, to microwaves or gamma radiation, but with controversial side effects.

9.2.2. Chemical methods

The main categories of insecticide used are anorganic products (compounds of the Fluorum, Phosphorus and Sulphur) and organic products of natural origin or produced by synthesis. These act on the insects by contact, ingestion or inhalation and are applied by spraying, painting, injecting or gasing [15].

The *Anobiidae* can be fought off by using liquid or gas products that can penetrate the infested wood applying biocides on the surface being ineffective because the adults do not eat only the wood but also punch through the surface for laying eggs. Applying liquid substances requires a long time, the impossibility of penetrating the biocide deeply but has the advantage of being affordable for the operators as it does not ask for special devices. The gas treatments are fast, effective but costly being done by specialised firms, with trained personnel that can use the appropriate technology and must guarantee the safety of the personnel and the environment.

Synthesis insecticides and their side effects on the patrimony goods. The most frequent synthesis insecticides in the area of cultural goods preservation are the methyl bromide, the sulphuryl fluoride, the prussic acid, the organic phosphoric products (*Parathion, Dimeton, Diazitol, Tepp, Malation*) and such carbamates as *Propoxur, Carbaryl*. The prussic acid is also used as well as products bases on boron (boracic acid, sodium tetraborate), ethylene oxide, formaldehide, xylamone, organic chloride (*DDT, Lindan, Toxafene, Aldrin, Dieldrin, Endrin, Chlordan*). The most used products in Romania are those based on Pyrethrin.

The side effects of some insecticides based on permethrin on the cultural goods. There are a series of insecticides based on permethrin dilluted with a range of solvents on the market; the producers add a series of components to them without making the right specifications on the package. That is why 4 insecticides were tested in order to notice the negative effects on the treated patrimony goods. The biocides that were used were *Permetar© in petrolio*, *Protettivo per legno antiparassitario*, *Permetar© concentrato* (dilluted with 2% white spirits) and *permethrin in shellsol D70*. 5 types of painted or unpainted wood were treated.

After treating and drying the painted wood samples with permethrin in shellsol D70 one could notice the presence of residues on the surface and in stratigraphies, visible macroscopically, with a stereo magnifying glass and the electronical microscope with SEM deflection. (figure 18).

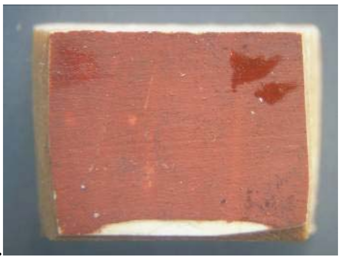
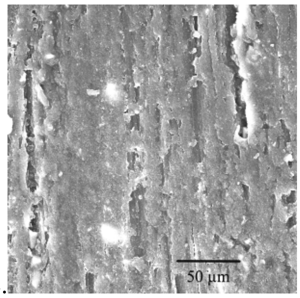
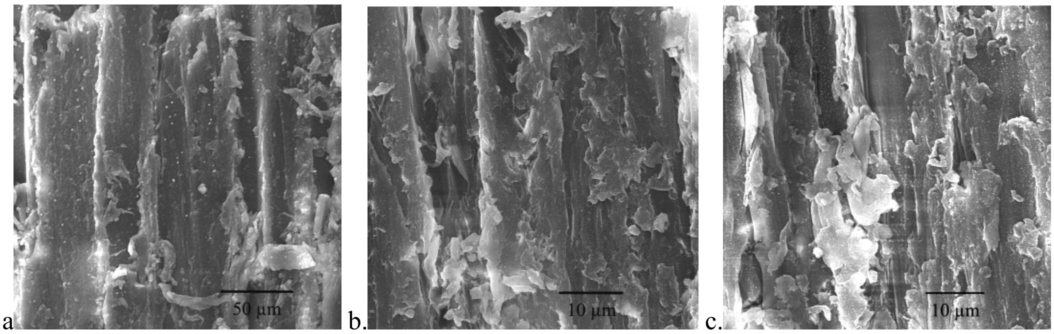
a. 
b. 
c. 

Fig. 18 - Deposits and infiltrations of residual substances on the painted wood after the permethrin treatment in shellsol D70: macroscopically (a), stratigraphy under the stereo magnifying glass (b) and SEM (c)

The samples treated with *Permetar in petrolio, permethrin in white spirits and Protettivo per legno* exhibited desposits of substances visible by means of the stereo magnifying glass but the images shown by SEM prove the saturation of the samples with residual materials (figure 19). These additions of biocides are not beneficial to the paintings because they modify their aspect, no one knows the way they age and the preservation and restauration are hindered.



a b. c.

Fig. 19 - Deposits of residual substances on the wood treated with *Protettivo per legno* (a), *Permetar in petrolio* (b) and permethrin in white spirits (c)

Vegetal origin insecticides. In addition to the requirements for the safe preservation of the patrimony goods, the methods of fighting against such insects must meet ecological and economical criteria. An alternative would be the use of plants with insecticide or repellent effect, based on the relationship between plant and insect.

The use of essential oils from plants. In previous studies scientists reported the biocide effect of the basil essential oil on *Stegobium paniceum* and Ahmed & Eapen (1986) noticed a highly bioacid effect on the same species by using *Gaultheria* (Fam. *Ericaceae*) and *Eucalyptus* (Fam. *Myrtaceae*) oils. The biocide effect of the basil was confirmed in the lab by exposing the object to its vapours and by ingestion. The *Stegobium paniceum* larvae exposed to vapours of *Ocimum basilicum* (produced by Aroma Land) in Petri dishes died within a week (figure 21 a). The vaporisation took place by soaking 1 cm^2 of paper into one drop of oil. 100% mortality was reached also by feeding the *S. paniceum* larvae with a dry mixture of 5g of flour, 1 ml of water and 1 ml of basil essential oil.

The sensitivity of the *S. paniceum* larvae was tested by exposing them to absinth essential oil (*Artemisia absinthium*, fam. *Asteraceae*) obtained in the lab by using the Clevenger device. The larvae reduced their activity to eating old manual paper treated with a solution made of absinth oil in alcohol 1:6 and within 7 days, 33% of the larvae were dead (figure 20 b-c).


a. b. c.

Fig. 20 - The biocide effect of the essential oils from *Ocimum basilicum* (a) and *Artemisia absinthium* (b, c) against *Stegobium paniceum* larvae

The use of the insecticide powders obtained from plants. The effect of capsaicin (the active substance in the *Capsicum* sp. hot pepper) was tested on the *Anobium punctatum.* The capsaicin natural product (produced by Sigma-Aldrich) as a white powder made of 65% capsaicin and 35% dihidrocapsaicin was dilluted with 0,2 % ethanol after which it was brushed 3 times in 2 days on 10 fragments of lime-tree wood and 7-year-old fir-tree wood kept at 19^0C and 55% UR. 24 *A. punctatum* larvae kept on fir-tree wood were used under the room temperature. When they checked the larvae after 7 and then 14 days, the larvae were dead without making visible holes in the wood.

Using plants for disinsectization by fumigation. The exposure of an icon under the active attack of the *Anobium punctatum* to hot pepper and black pepper fumigations brought about a significant decrease in the number of insects but without eradicating them. The exposure took place for about 3 h in 3 consecutive days. High mortality can be reached only by exposing the objects for a long time to such toxic atmosphere.

9.2.3. Biological methods

The biological action taken against the pest in the storage facilities is difficult, the results being quite modest. The predators or parasitoids in the locations actively attacked by the Anobiidae cannot significantly reduce the woodworms, thus confirming the natural balance of the species within the biocoenosis. The additional effectives of predators in the collections of patrimony goods would have side effects on the objects and moreover, an unpleasant esthetic impact on the viewers. The biological method of fighting against the Anobiidae by means of pathogen microorganisms was very little- studied, the previous studies mentioning only some results on the pathogenicity of the *Bacillus cereus* and *B. thuringiensis* bacteria and the *Lasioderma serricorne* species.

9.3. Preventing the attack of the *Anobiidae* on the patrimony collections

The preventive preservation of the patrimony goods focuses on preventing the deterioration of these objects by applying some measures that ensure the protection of the goods towards the external aggressions and to prevent the appearance of processes inherent to the materials within the objects.

Preventing the attack of the *Anobiidae* means creating an adequate space for preserving the patrimony goods but unfavourable to the development of the insects. Therefore it is recommended to keep the collections under temperatures as low as possible for the objects stored or exhibited.

The protection of the collections by filtrating the air from the outside, keeping the objects into boxes, covering the fissures and flying holes in the wood, going through quarantine with the newly acquired pieces or the pieces of furniture, sanitizing the locations properly, checking the pieces of collection or the storage places periodically with the help of specialized personnel, are important elements that prevent an insect attack, the effects of such measures being assessed only after a long time.

Installing ultrasound devices at the windows or keeping the repellent substances close to the access ways can prevent an attack of the anobiids.

Conclusions

In the researched locations I have identified nine species of Anobiidae that damaged the heritage goods (i.e. old books collections, icons, iconostases, pieces of furniture, ethnographic wood, iconostases and monumental components and other objects made of vegetal materials): *Anobium punctatum*, *A. pertinax*, *Lasioderma serricorne*, *Oligomerus ptilinoides*, *O. brunneus*, *O. retowskii*, *Ptilinus pectinicornis, Stegobium paniceum* şi *Xestobium rufovillosum. Ernobius mollis* and *Priobium carpini* have been collected inside these locations without finding objects damaged by them. *Oligomerus retowskii and O. ptilinoides* have been found for the first time damaging Romanian heritage objects. In Moldova *Oligomerus brunneus* was discovered for the first time on location beside the above mentioned species. New aspects of the above mentioned species morphology, biology, ecology and ethology were discovered. Methods of preventing the attacks of the Anobiidae and of fighting against them have been suggested in the context of preserving cultural heritage.

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