Eradicating woodworm and other pests from musical instruments

Musical instruments made of wood and other natural organic materials can suffer from infestation by woodworm, carpet beetle, moth larvae and other insects that use them as a food source directly or indirectly. The type of pest and degree of infestation varies with geography, climate and local environment, but the result is the same: functional, structural, cosmetic or acoustic degradation or general compromise of the instrument. Restorers, conservators and collection curators sometimes need to eradicate small or large scale infestations and this article briefly reviews strategies and remedies. 'Woodworm' is used as a general term here as there are countless wood-boring insect species worldwide. Other insect pests likely to be found in old instruments are implied as they will normally respond to the same control treatments outlined.

Some aspects of pests, their biology, their control and the materials and techniques involved in eradication and management can be extremely technical and require scientific understanding to fully appreciate. Pest control in museums large and small is a vital part of collections care and management. The monitoring and control strategies are an important branch of museology and are a specialist study in themselves. Most readers of this journal are not museum owners or extensively trained in sciences, so this article has been written from a practical viewpoint for those seeking to resolve a small-scale problem or to understand the basic concepts involved, so that appropriate decisions can be made or further guidance sought. The reference bibliography directs readers who require more technical or detailed understanding.

In the UK the general term 'woodworm' refers to the larvae of a range of common beetles (Rentokil, 2015) that bore and tunnel through, while consuming, the internal corpus of wooden objects causing structural weakness and subsequent deterioration. Sapwood is the main target, but heartwood attacks are known. The larvae eventually pupate, transform into the adult form and emerge from the wood to fly or crawl. The adult stage of those beetle's lives is not a problem in itself as it is short and they do not feed, however they do leave a 'flight-hole' or 'exit-hole' in the external wood surface as they emerge (typically 1-2mm diameter) and they will re-infect the same wood or nearby wood by laying eggs into the exposed wood surface crevices or into exit-holes. Varnished surfaces are less vulnerable, but most musical instruments have exposed wood, especially internally. The life-cycle of some beetles can be as long as ten years and typically for the common furniture beetle (*anobium punctatum*) the wood-eating larval stage is around 3-5 years dependant on local temperature, humidity and the wood type. Woodworm tend to like fairly moist conditions, so wooden objects stored long-term in damp cellars or attics or against cool walls tend to be candidates for infection, especially if there is an existing infection source in the vicinity and the wood is sufficiently appealing to the egg-laying female. Insect and beetle life-cycles are sensitive to temperature levels and the lifespans of larval stages may become extended in such conditions. Fungi, moulds and the micro-organisms that feed on them can also be quite active in cool environments and some of the material components of instruments can be permanently damaged by such organisms.

Musical instruments that are used, handled and moved about regularly and stored in normal ambient environments tend to be safe from attack. However, if they are consigned to storage for long periods in the circumstances mentioned, then pest infestation is a risk.

Once woodworm attack is underway it can be several years before any external signs become evident. Other pests such as moth larvae may become evident soon after infestation as they eat holes in fabric, paper or leather materials. In museums there are established ongoing control measures known as 'integrated pest management' (IPM) that monitor insect activity across a collection, but for restorers in private practice, usually individual case-by-case infestations may need to be addressed.

It can be difficult to ascertain if a woodworm infestation is still active. The presence of exit-holes is not a guarantee of current activity as they only indicate that pests have emerged. If the object has been relocated from the area of its original infection all the live creatures may already have departed. Placing the object undisturbed in a clean space on a surface where 'frass' deposition can be observed over some time may give a positive indication. Frass is the waste material that larvae expel during wood consumption and it tends to be pushed out through existing flight-holes as the creatures bore through the wood corpus. Small piles of frass may be observed around the object if it is left for some time in the circumstances mentioned. Flight-holes with a new, lighter colour than old holes may indicate recent emergence of adult forms. April–August in the UK is typical activity period when adults emerge, mate and lay eggs. If there is no current activity then there is no need for eradication treatments. Carpet beetles, moth larvae and moth eggs can be observed with the naked eye or low-power magnification and holes in fabric, felt or cardboard may indicate infestation. Other insect life can be monitored or observed by using insect pheromone traps or 'blunder traps' in the storage environment. These are small inexpensive cardboard 'tents' that attract and capture wandering insects on discrete, sticky surfaces. They are safe to place almost anywhere in home or other building where pest-monitoring is needed. They are not an eradication method, but give an indication of the variety of insect life present in any environment. Inspection with an x10 or x12 magnifier will enable identification of the species present.

Chemical eradication

Historically, the eradication method for infested organic materials, furniture or architectural woodwork has usually involved applying or impregnating the object with some kind of biocide chemical that leaves a persistent residue toxic to the target organism. The chemical residue usually remains active for some time, killing any live larvae and preventing successful egg-laying by adult beetles. The chemicals used vary and some older chemicals were extremely toxic. DDT and some organo-phosphates are just two which are no longer in lawful use because of human toxicity. Some modern formulated chemicals are safer for humans and the environment, but may still leave persistent residues and some may require periodic re-application as the original chemical degrades or becomes inactive.

Pyrethroid compounds, commonly available and widely used, are effective pest-control chemicals originally derived from plant sources, but now synthesised and modified or co-formulated to increase effectiveness. They are fast-acting, biodegradable and relatively human-safe. However, the products must come into direct contact with the organism that will consume or absorb the substance. Pyrethroids are used in fly-sprays, flea-treatment sprays, ant-eradicator, and cockroach-spray and as a household-plant insecticide. Pyrethroids derived from plant sources have been used successfully for thousands of years, the earliest use is thought to be in powdered-leaf form in ancient China. Pyrethroids act as neuro-toxins on a range of insects causing paralysis. Pyrethroids are reasonably safe to humans, but animals, fish and aquatic organisms can be affected.

'Permethrin' in aqueous emulsion/solution or hydrocarbon-solvent micro-emulsion (Wykamol Group Ltd, 2015) is a fairly human-safe pyrethroid compound currently commercially available, but deep impregnation into the wood to get at the tunnelling larvae may be problematic, requiring drilling of deep access-holes for the liquid injection. Injection into flight-holes is not a guarantee of full impregnation. If the wood section is thin, for example as with a soundboard or guitar back, then penetration via surface application may be deep enough to do the job. Applying a gentle partial vacuum around the object while introducing liquid treatment may be possible, so that the fluid is sucked into evacuated spaces in the wood.

If using any liquid application one should remember that some surface finishes or decorative elements may be vulnerable to water or solvent exposure. Aqueous emulsions/solutions may also be detrimental to wood itself, causing swelling of the wood and the deterioration of protein-glued joints. Fabrics or leather-based materials may shrink, stretch or change colour or alter in composition. Hydrocarbon solvent-based formulations do minimise grain-swelling, but surface coatings and unknown historical primers or other ancient treatments may be vulnerable to such solvents. Some other biocides (e.g. Boron compounds) with longer-term persistence in the object may have undesirable effects in the future and any potential human or environmental hazards or ethical considerations for the treated object need to be considered and understood before any such treatments are applied.

Another class of insecticides are 'insect growth regulators' (IGR's) some of which interfere with hormonal aspects of insect development to prevent adult maturation and egg viability. One example is methoprene (Cornell, 2015), but there are others with more-or-less human and environmental impacts. One class of IRG's includes 'chitin synthesis inhibitors' (e.g. Flurox™, flufenoxuron), which target an insect's ability to generate an exo-skeleton. The creatures dehydrate and die.

Pyrethroid insecticides were predicted to be replaced by Flurox™ , but the chemical has been banned as a general-purpose insecticide in the EU since 2011. Although it is relatively safe to humans it is very toxic to fish, aquatic organisms, birds, bees and wild insects of many types and it has a potential for bio-accumulation and persistence in the environment. It is currently still approved and used in the USA. and it can be used safely under controlled conditions.

As a general rule this instrument restorer/conservator does not recommend any chemical, insecticide or application of any substance with a persistent residue. The long-term risks to the instrument and to humans who handle the object in future may be difficult to predict or to justify. Museums rarely use chemical treatments for pests except in very specific controlled circumstances, pyrethroids included. Gaseous impregnation (fumigation) with chemical agents such as methyl bromide, phosphene or ethylene oxide was once a common strategy, but is seldom used now because of the extreme toxicity and hazardous nature of the chemicals (Leary, 2015). As with all conservation treatments one must balance the potential damage or loss of an untreated object against the risks of using the treatment.

Heat

Most creatures and insects can be killed by application of sufficient heat and this method is used in some museums for some artefacts. It has been reported (anecdotally) that (long ago) the Natural History Museum sometimes discovered their stored trays of mounted insect-specimens were being devoured by live pest insects and beetles. One quick effective treatment at the time was to place the specimen tray in a heated gas oven, Gas mark $1/8^{th}$ for a while to 'cook' the live pests. Obviously, it was a risky procedure putting rare mounted specimens in jeopardy, thankfully this method is no longer used (!)

Heat, applied to musical instruments and wooden objects presents other difficulties and risks. Wood (as most organic materials) has a certain water content that fluctuates to equilibrate with the external relative humidity*. If the temperature is raised in an enclosed environment then relative humidity falls, causing water to be given up from wooden objects into the air. The wood 'dries out' causing shrinkage, distortion and changes to surface coatings such as varnishes as well as risks to glued joints. Heat treatment requires strict control and monitoring of relative humidity and also the temperature difference between the object and the heated environment (usually no more than 10^{o} C)

A modern commercial system of controlled-heat woodworm and pest treatment for organic materials of all kinds, furniture and wooden objects is currently known as the **Thermo-Lignum** process (Thermo Lignum International, 2015). Usually a large container, similar to a shipping container or even a furniture-van, is sealed with the objects being treated and the internal temperature is slowly increased. As the temperature rises, moisture-vapour is introduced to stabilise the relative humidity at a constant monitored level, reducing the risk of drying-out and the associated problems. At a critical temperature, deemed appropriate for pest elimination (55^{o}C for the object's core), the process is held for some time, usually 1-2 hours, then reversed with relative humidity control maintained until return to normal ambient temperature. The process is effective for many types of organic objects and pests and can be applied on a large scale even within an entire building. No chemicals are used and the process takes just some hours or a few days to complete depending on the objects and quantity being treated. The process can be set up on-site in museum grounds and also small-scale users can buy a space in a group-treatment chamber to mitigate expense.

Although this process seems appealing as regards safety and effectiveness, there are still potential risks to objects and these need to be assessed, especially for musical instruments. For example this restorer/conservator doubts it be appropriate for a Stradivari violin or a rare type of lute to be exposed to heat at that level. Whereas an oak stool or a mahogany sideboard might not be noticeably affected, we need to remember that musical instruments are not simply static objects, but functional acoustic structures, often with eclectic decorative elements and a range of combined materials with carefully engineered relationships. Complex and fragile structural features may be compromised or undergo changes that are undesirable, even though the individual materials themselves may remain safe and intact during and after heat treatments.

Cold

Freezing to sub-zero temperature is a popular strategy for pest-eradication in some organic objects. The freezing process is human-safe and can be controlled very well with modern freezers. With foodstuffs, bacteriological activity is slowed to very low levels and living insect pests cannot survive long at very low temperatures. However, it is known that some insect pests can respond to 'thermal-shock' by entering a reversible hibernation state, so they can recover as temperature is normalised. The temperature required for guaranteed pest-eradication is -20 °C for 48 hours twice. Two cycles of freezing and thawing were originally recommended, but a single-freeze method at -20 to -30 °C for 72 hours is now thought to be enough (Florian, 1997).Very large objects are recommended to be frozen at -30 °C for 72 hours. Shorter periods and higher temperatures do not guarantee eradication although variations in the cycle regime have been effective (Unger, 2001).

If an object is to be frozen it should be wrapped airtight in plastic film and the excess air removed by a vacuum cleaner if necessary, to minimise condensation during freezing. Humidity control measures such as silica-gel packs may be appropriate. Apart from potential risks of handling frozen objects research suggests that wood, fabrics and paints and varnishes are not adversely affected by freezing, despite the differences in expansion coefficients, water content and structural constraints (Strohschneider, 1998). However, this conservator suggests that there are still theoretical risks to fragile instruments and that freezing needs to be used with caution.

Radiation

Gamma radiation

Gamma radiation is used commercially to sterilise perishable foodstuffs in Europe and USA and this type of ionising radiation will effectively kill most pests, pathogens and micro-organisms. It has been tried with library and mixed-materials archives collections. However, the type of equipment and licensed facilities required to use this method are probably beyond the reach of most people. Additionally, the radiation causes irreversible cleavage of cellulose and polysaccharide molecules that make up woody material. The effect has been observed in paper/book irradiation where the paper itself loses significant mechanical strength (around 30%) as well as undergoing visually detectable colour change (Silverman, et al., 2007). So, although the method may be effective, the damage caused to an object may not be justifiable except perhaps in an emergency situation where potential catastrophic loss of an artefact is weighed against the likely damage caused by irradiation.

Ultra-violet (UV) radiation

UV radiation can be used to bacteriologically sterilise air and surfaces (Kowalski, 2009), but it will not penetrate beyond surfaces and therefore is ineffective against wood-boring pests, additionally UV radiation is damaging to almost all organic materials and especially pigmented items, fabrics paintings, varnishes etc. Museums take great pains to regulate the exposure of any object to UV radiation from sunlight or electric light sources.

X-Radiation

X-rays are routinely used to image the internal structures of organic materials. The amount and levels of X-rays are carefully controlled to minimise exposure to objects and humans because molecular changes take place in irradiated items. Virtually all types of materials can be adversely affected by the high-dose radiation needed to eradicate pests. The US mail system has been using X-ray sterilisation process for some years to eliminate anthrax spores and other bio-hazards in or on transported items and there have been many reports of irreversible of damage to paper, film, plastics and other materials exposed. High temperatures can be generated (up to 130ºC) and X-radiation can also potentiate or catalyse chemical reactions within objects that may not become evident until long after exposure. Musical instruments sent as cargo to the US may be at risk of being irradiated. However, irradiation is only currently used on mail to the White House and some US Government offices (US Environmental Protection Agency, 2015).

Anoxia

'Anoxia' means that no atmospheric oxygen is available to living organisms and this can be the safest and most effective treatment method available for all kinds of woodworm and other pests. All insect life-forms require oxygen for survival. They do not have lungs, but absorb oxygen via spiracles that also regulate moisture uptake from the environment. Treatments can be carried out in large or small-scale enclosures and objects as large as a library can be treated or as small as a sealed plastic food box. Larger museums have special anoxic chambers that are designed for big items or groups of smaller objects. The chamber is filled with inert gas such as nitrogen or argon or a mixture of other inert gases and sealed. Humidity is controlled within normal parameters. The gas environment is periodically replenished as some leakage and osmosis occurs. Oxygen can be gradually eliminated from smaller units by using oxygen-scavenging chemical packs that trap oxygen molecules, leaving the unit anoxic. Larger chambers rely on flushing out oxygen with an appropriate inert gas selection and periodic replenishment of the atmosphere. Indicator discs or other gas-monitoring equipment show when anoxia has been achieved and the chamber is then kept sealed for a prescribed period depending on the object, type and degree of infestation etc.; Treatment must typically continue for 3-4 weeks after anoxia is achieved. Shorter periods have been used, but effectiveness is not guaranteed. Although this method has hitherto only been available to professionals and museums it has recently become available to small-scale users who can obtain single-use treatment enclosures and oxygen scavenging packs from the IMC Group. Their subsidiary Hanwell Instruments (sales dept. ;) offer treatment packs and accessories for small-scale use known as the 'ZerO_2 system'. At the time of writing a treatment kit for 1 cubic metre space would cost around £100. Obviously the treatment enclosure needs to remain undisturbed for a long period and the temperature should be normal room temperature or slightly higher. A cold shed or workspace would reduce effectiveness and take much longer. Some more elaborate proprietary units and systems use elevated temperature to improve the efficiency of the gaseous mix. Anoxia is the safest pest treatment currently in use.

'Alternative' treatments

Alternative treatments have been proposed: turning up central-heating, using high-voltage electricity, wrapping in cling-film, home remedies and various DIY concoctions etc.; that have no proven eradication efficacy and in some cases can be dangerous. Practitioners use them at their own risk.

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Disclaimer
The mention of any specific method, product, company or treatment provider does not imply endorsement or guarantee. They are mentioned for purposes of education and illustration only. Alternatives are available and users should seek the most appropriate for their needs.

References

Rentokil. (2015, April 29). *woodworm species*. Retrieved from Rentokil.co.uk: http://www.rentokil.co.uk/woodworm/species/

Cornell, M. S. (2015, May 2). *EXTOXNET*. Retrieved from Extension Toxicology Network: http://pmep.cce.cornell.edu/profiles/extoxnet/haloxyfop-methylparathion/methoprene-ext.html

Florian, M. L. (1997). *Heritage Eaters: Insects and Fungi in Heritage Collections*. London: James and James.

Kowalski, W. J. (2009). *Ultraviolet Germicidal Irradiation Handbook:UVGI for Air and Surface Disinfection*. Heidleberg: Springer-Verlag.

Leary, P. (2015, April 30). *Eradication of Insect Pests in Buildngs*. Retrieved from Cathedral Communications Ltd: http://www.buildingconservation.com/articles/eradication/eradication.htm

Silverman, R., Bliss, M., Erikson, H. M., Fidopiastis, N., Frankl, J., & et, a. (2007). Comparing Mass Drying and Sterilization Protocols. *The Book and Paper Group Annual 26 (American Institute of Conservation)*, 92.

Strohschneider, M. (1998). Diploma thesis. *Holz Technologische Untersuchungen zur Gefriertechnik als Möglichkeit der Schädlingsbekämpfung unter besonderer Berücksichtigung gefaster Bildwerke*. Hildesheim, Hildesheim, Germany: diploma thesis, Hochschule fur Angewandtewissenschaft und Kunst.

Thermo Lignum International. (2015, April 29). *General information*. Retrieved from Thermo-Lignum: http://www.thermolignum.com/thermolignumwarmair/

Unger, A. S. (2001). *Conservation of Wood Artifacts, a Handbook*. London: Springer.

US Environmental Protection Agency. (2015, May 1). *Radiation Protection*. Retrieved from USEPA: http://www.epa.gov/radiation/sources/mail_irrad.html#after_irradiation

Wykamol Group Ltd. (2015, April 30). *microtech woodworm treatment*. Retrieved from Wykamol specialist products: http://www.wykamol.com/microtech-woodworm

*Relative Humidity may be defined as the ratio of the actual measured water vapour density to the saturation water vapour density of air, expressed as a percent:
Relative humidity (RH) = actual vapour density÷saturated vapour density x 100%

Useful resources

Kremer Pigmente GmbH & Co. KG conservation products and art materials
http://www.conservation-resources.co.uk/ conservation and restorers supplies
http://cool.conservation-us.org/ free online conservation research papers, publications and other resources. Searchable database of conservation topics.
http://www.getty.edu/conservation/ free online published research projects, papers and books. Well-funded world class resource.