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IS THERE SCOPE FOR A MORE INTEGRATED APPROACH TO THE MANAGEMENT OF ANOBIID TIMBER PEST POPULATIONS IN HISTORIC BUILDINGS?

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BY

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Abstract

Concerns regarding the environmental repercussions and general effectiveness of using chemical preservatives to counter wood boring insects are widespread. This paper, whilst highlighting the inevitability of timber degradation in the very long term, sets the current climate of opinion in context by tracing the development of preservation methods from the earliest of times: times when decay mitigation techniques largely comprised acknowledging and exploiting the materials own natural durability characteristics. Exploration regarding the use of artificial substances reveals a recurring pattern of both acceptance and reliance on biocidal compounds. This is seen to begin with the development and introduction of new synthetic materials followed by a prolonged period of widespread application. Later, in some cases very much later, environmental and/or human health ramifications become manifest. These initiate a period of bioassay and evaluation amid rising public and governmental concern. In many cases appraisal leads to restrictions on use or, quite frequently, outright prohibition.

The challenges of deploying synthetic chemical agents to protect timber or remedy decay in service within buildings, are examined. These include a limited range of application methods and the difficulty of ensuring adequate target contact whilst avoiding or minimising non-target effects. The incidental effects of the indiscriminate application of broad spectrum biocides on pre-existing natural control agents, predators, parasites and parasitoids are assessed. The market consolidation of synthetic remedies through formal underwritten guarantees to building owners and lending institutions is examined for its significance in establishing the present treatment climate. The use of man made compounds to control deleterious insects in buildings is governed by UK and, increasingly, EU legislation. Recent trends toward a more proscriptive legal environment will impact on the scope for chemical application generally and particularly within habitable buildings.

For historic buildings, a widely accepted tenet of conservation policy is maximum retention of fabric and minimum intervention. Clearly, the limitations of traditional methods of timber preservation and conservation in historic buildings allow a great deal of scope for supplementation by other, more innovative, techniques. Integrated Pest Management is defined is an encompassing control strategy whereby several mutually complementary techniques are employed simultaneously. The disproportionate increase in effect sometimes experienced with the use of combined techniques is illustrated. In-depth understanding of the biotope is a perquisite and the extent to which this exists is established. A pest resistant medium benefiting from helpful cultural practices and pre-existing natural predators and parasites is at the core of the method. The prospects for further enhancement of biological control by the introduction or augmentation of biocontrol agents are evaluated. The challenges of suppressing cryptic pest populations in timber are considerable and are presently, contrary to expectations, not surmounted. The areas where significant studies are required to fill gaps in extant knowledge are highlighted. Given the exceptionally high proportion of the anobiid lifecycle devoted to wood burrowing a possible technique of egg interception during the crucial free living, mating and ovipositing stage is presented for trials and further evaluation. That broad spectrum biocides can become simply one technique in a range of possible options is lent weight by a survey questionnaire which clearly suggests a high level of openness to ecological approaches in timber treatment.

In summary, the challenges facing timber pest population suppression are explained together with recommended areas for further study.

Introduction

"……….to stave off decay by daily care………"

William Morris. *Society for the Protection of Ancient Buildings: Manifesto* 1877

The Nature of Decay and the Need for Control

Introduction

All matter containing carbon, the fourth most common element after hydrogen, helium and oxygen, conforms to a complex biogeochemical system known as the 'carbon cycle'. The land (geosphere), sea (hydrosphere), air (atmosphere) and living organisms (biosphere) all play a role in the accumulation, storage and release of carbon. In the biosphere, which includes all trees, 1900 gigatonnes (1,900,000,000,000 tonnes) of carbon (wikipedia.org) are stored. Autotrophic organisms, those able to synthesise their own organic compounds, use absorbed carbon dioxide gas and water to manufacture complex carbohydrates in a process powered by sunlight called photosynthesis. The process of synthesis is counterbalanced by that of biodegradation and decay and gives rise to the concept of a cycle. Ultimately the tree, 50% of whose dry weight is carbon, dies and decays and in so doing, it gives up its carbon store.

From the very moment of plant photosynthesis, plant tissue becomes a potential source of nutrient for invasive organisms. In the utilisation of plant tissue, in the form of useable timber, for purposes of building construction, we interrupt, but not permanently suspend, a powerful cyclical process. The healthy living tree resists attack by potentially damaging disease and decay organisms through having a range of defensive capabilities. Decay is inhibited, resisted or arrested by the laying down of chemicals (extractives) noxious to invaders, the mobilisation and deposition of resins and by virtue of high tissue moisture content (Desch, 1969; 239). At the cessation of natural life processes, many of the mechanisms by which a tree defends itself from invasive agents cease to operate. Even in the most durable of timbers, any residual natural durability is impermanent and the irrevocable process of decay will inevitably, except in special circumstances, lead to complete degradation. Fossil records confirm this as a long standing pattern (Brues, 1936).

The effective long-term protection of wooden materials therefore becomes a matter of great importance in ensuring that items built in part or wholly of wood are fit for purpose and endure. In the absence of active plant defences, it also becomes the responsibility of man. If timber materials are to be prevented from being consumed by opportunistic decay organisms then one or more of several preconditions must be avoided. Oxygen must be excluded from the environment, water must likewise be absent or the food source itself must be unavailable. The drying of timber is an important first step in removing water. Only in rare circumstances can oxygen be excluded. Strategies to remove the food source rely on rendering it unpalatable or lethal to invasive organisms.

Prior to the beginning of the twentieth century informed timber selection, choosing the right wood for the right purpose, was accepted unequivocally. Through knowledge accumulated over many generations, each species of timber developed its own well understood and unique profile of characteristics. Those that resisted decay, or were highly combustible, or were able to withstand the shock of impact, or were light in weight, or had superior resonant properties were identified and set aside for purposes that best suited them. In addition, timber soaked in water or air dried slowly, both traditional methods of processing, becomes permanently depleted of starch and less liable to attack by decay organisms. (Britton 1961:18-19)

With the changes in the emphasis of traditional craftsmanship, the shortages of timber wrought by WW1 and increasing mechanisation and commercialisation of the use of timber (Ridout, *pers comm*) suitability for purpose regarding durability, became a less important consideration in the early decades of the twentieth century. After all, components had to perform structurally and had to have the necessary aesthetic appeal so strength and visual appearances remained of vital importance. As a result the characteristic most commonly compromised became that of durability. Furthermore, resistance to decay is something that only becomes apparent in the medium to long term, and is therefore most easily ignored or overlooked in the short term. Consequently, insect and fungal damage in the form of wood boring insects and wood rotting fungi, hitherto only of local, often individual building significance, became increasingly common. Moreover, the increasingly widespread use of inferior woods, particularly softwoods, resulted in both occurrence of decay while in service and attempts at timber treatment and preservation becoming more common place.

Simultaneously, developments in building technology and style contributed to increasingly serious decay. Stylistic innovations such as panelled walls and suspended ceilings served to limit natural ventilation to structural components (Fisher, 1940), creating poorly ventilated areas where, through moisture ingress, decay could commence unobserved. Indoor plumbing, in itself a major sanitary achievement, also brought with it the possibility of leaks and, if uncorrected, attendant decay. Moisture impermeable materials such as cement mortars and paints often lead to a build up of potentially damaging moisture where before the harmless evaporation of water had been possible. Internal or parapet gutters, whilst enabling new trends by making many design innovations possible, presented the inevitable scenario of significant potential water penetration of the structure in the long term as the lead employed inevitably failed.

Given the increasing complexity of buildings and their components, the maintaining of structures of all kinds has become increasingly important. With the potential for decay through component failure having increased over time, so the importance of effective regular and thorough maintenance has also become more apparent. In addition to drawbacks associated with ever more complex building types and the incorporation of systems, including indoor plumbing, and central heating into structures, patterns of usage that impact on decay prevention have altered. Indoor sanitation, laundry and food preparation all lead to the generation of high moisture vapour concentrations in buildings. Further, recent trends in energy conservation, whilst laudable on environmental grounds, have further exacerbated the problem of trapped moisture and increased substantially the risk of surface or interstitial condensation. It is often in the most concealed and least accessible parts of a building that moisture laden air is cooled below dew point and gaseous water vapour reverts to its liquid state – a form suitable for utilisation by wood decay organisms (Desch, 1969; 238). It is by this means that water can be deposited on or in building structures and in so doing precipitate fungal or insect decay or both.

The Dissertation

The aim of this work is to consider what method, or range of methods, of preserving wood are best suited to deployment for the future, and to see how they might be rationalised into a more integrated approach to the management of timber pests. Currently, there exist the combined pressures of the withdrawal of hitherto indispensable stock chemicals, and the rise of widespread environmental concern regarding many of the remainder. The need for the environmentally safe disposal of biocide treated timber has given rise to a new and costly industry. Bioremediation techniques are currently employed to address the growing problem of safe processing of toxic wood waste.

This study investigates the general range of techniques of timber treatment and preservation that have been introduced in the past in order to set the current approach in context, outlines the use of chemical agents to extend timber component life from earlier times to the present to identify a clear trend in the reliance on chemical treatments, and examines the potency, specificity and environmental impact of newly introduced chemicals to assess their prominence in any integrated approach strategy. It then goes on to examine European Union law governing safe standards for chemical use to explain and to justify the need for a more broad based approach. Prospective legislation is anticipated to take account of future trends in control methods. The attitudes amongst the public towards the use of chemical control methods have changed in the last forty years, and these are examined to determine the extent of potential consumer demand for biological control.

The degree to which chemical control methods are able to effectively suppress pest populations is considered, in the light of our understanding of their complex and cryptic life cycles, which might amount to assessment of the true effectiveness of the chemical control method. Doubts over efficacy and environmental impact may eventually lead to a rethink on chemical use. The degree to which respect for and confidence in science, marketing and guarantees between 1942 and 1970 secured a dominant place for chemical methods of post infestation eradication is assessed, and what has been learnt from nearly a hundred years of biological control investigations is used to illustrate the long but interrupted history of research.

The development of pest control techniques in associated fields is outlined in order to identify potentially transferable approaches and techniques which may be worthy of further investigation. In areas such as agriculture and horticulture concerns over environmental degradation through the use of synthetic chemicals have sometimes lead to a more integrated approach to pest management (Mai *et al*; 2003: 486).

A field survey will be undertaken with the intention of lending practical substantiation to this work. Research by questionnaire into the preparedness of the general public to consider and/or accept a broad based approach to timber preservation will assess how far people are open to the idea of the biological control of timber pests.

Literature Review

Information concerning integrated approaches/methodology for controlling timber pests in historic buildings in northern Europe has tended to be peripheral to the mainstream of research in timber conservation. However, broadly associated fields exist which are of considerable relevance. Publications covering the fundamental principles of biological control design can be regarded as applicable to any field endeavouring to employ such techniques, timber preservation included. Jacas *et al*. (2005) concern themselves mainly with the problems of citrus production in Spain. However, their parameters for sound bio-control design are highly transferable to other areas and should have an important influence on timber preservation techniques. Similarly, papers (e.g. Mai 2003) concerning research in biotechnology in the wood industry provide important concepts such as 'enhancing the treatabililty of wood and replacing chemicals with biological control agents'. The wider environmental considerations that must be acknowledged in work in this field render all research into methods of biological control interdependent. In this way, important and universal lessons may be learned whether the subject be the control of termites in buildings in the USA (Kenne 2000, Gould 2004), stain fungi in felled trees (Mai, 2004), screw worm in Mexico (Hendrichs 2001) or deathwatch beetle in the UK (Belmain 1999).

Writing in 1963, Norman E. Hickin considered the biological control of *Anobiidae,* woodworm, in some detail. The challenges facing effective use of the technique, the cryptic nature of the pests and the difficulty of rearing predators, were spelled out and still seem significant. Yet he retained some optimism. This is an interesting stance in view of the prevailing climate of reliance on, and confidence in, the use of chemical pesticides. Realisation of the bioaccumulation of toxic compounds in the natural environment, particularly high up in the food chain, was still some way off and yet, in spite of this, he urged that 'the idea of biological control in some special circumstances should not be lightly thrown aside' (Hickin 1963).

Interestingly, writing some four years later, the same author, albeit in a less specialised volume, makes not even a passing reference to the prospect of biological control (Hickin

1967). Moreover, in a list of sixteen ‘recommendations to the wood preservative industry’ none sound a note of caution with regard to environmental degradation or even mention the need for research into biological methods of control.

It is clear that the prevailing opinion had yet to be influenced by the consequences of profligate insecticide and fungicide use. In addition, the intervening four years had seen a technological innovation of great importance in the pre-treatment of timber – pressure impregnation with organic solvents (Ridout 2000:101)

A consortium of organic solvent compounds, including the now infamous pentachlorophenol (PCP) and tributyl tin oxide (TBTO) took centre stage in the fight against timber decay. These totemic materials were now able to be driven deep into the wood tissue. Not surprisingly, chemical pre-treatment by pressure impregnation and remedial application by spray, gained absolute supremacy over other control methods. The combined forces of highly effective biocides, which overcame efficacy issues, and a method of application that ensured deep penetration and long lasting effect seemed like the ‘golden bullet’ of timber pest eradication. By 1991, however, both materials had been banned from general use by EEC directive. Much of the HMSO publication ‘Remedial Timber Treatment in Buildings – a Guide to Good Practice and the Safe Use of Wood Preservatives’ (1991) is given over to using pesticides with caution, safety and responsibility. There is a growing trend to go beyond mere caution, however. The founding principle in this publication is stated as a question; ‘Is there any need to use wood preservatives to control and stop timber decay?’ Hence, the use of pesticides and fungicides at all is questioned, and the importance of effective and thorough maintenance emphasised.

This theme is further developed by the Society for the Protection of Ancient Buildings (Oxley 1999). In an article entitled ‘Is Timber Treatment Always Necessary? An Introduction for Homeowners’, Richard Oxley’s answer is sensibly put as ‘sometimes’. More significantly, steps one and five of his decision making strategy are concerned with ensuring moisture exclusion by assessing previous maintenance and implementing regular and appropriate future maintenance. The situation has now developed whereby a dual approach to timber preservation is evident. On the one hand, the judicious use of well designed chemical biocides is an option, and on the other, preventive methods are stressed. This is, of course, to be commended but as yet, no mention of biological control of xylophages in buildings or a possible return to the use of naturally durable timbers has occurred.

Much of the data reviewed in the process of researching this work is taken from academic journals. This is significant. Articles have frequently outlined work of a highly specific nature and it is clear that, perhaps in view of *X rufovillosum* being of major economic importance only in the UK (Fisher, 1937), no broad study is currently underway, nor has taken place in the last 25 years. In writing up highly specialised laboratory or field experiments on a piecemeal basis, researchers reveal a subject largely overlooked (Martin *et al* 1991:257).

Contrasting Viewpoints or Perspectives

Biological Control: Definition

Whilst this might seem semantic in nature, mixed ideas concerning exactly what techniques comprise biocontrol are unhelpful and potentially confusing. One interpretation, commonly referred to as ‘classical biocontrol’, encompasses the concept of the ‘self-sustaining and density-dependent regulation of one species by another’ (Garcia *et al*. 1988). This view is supported by an earlier definition of control (Bierne 1962) as ‘a phenomenon brought about by predators, parasites and pathogens’, and restricts the field to living organisms with the capacity to make efficacious response. Here techniques such as sterile insect technique and habitat manipulation are excluded as is the use of enzymes in the biotechnology industry. It is a point of fact, clearly put by Roush (2002), that transgenic releases and sterile male releases are actually *inversely* density-dependent. The term density dependent clearly presents some problems.

Contrasting markedly with this is the inclusive description by Kalmakoff *et al* (1980). This allows ‘the use of predators, parasites, pathogens, pheromones, genetic manipulation and habitat modification’. Here, the definition suggests that any approach not dependent on the use of chemicals may be included. Gabriel *et al* (1990) appear to concur. They state that ‘biological control is seen by many to encompass much more than the use of natural enemies to regulate a pest population’. However environmentally sound this might be, in the author's opinion, a clearer picture is required in order to prevent the essential meaning of 'classical' biological control from becoming lost, distorted or diminished. The USA National Academy of Sciences presents the definition (1987) 'the use of natural or modified organisms, genes, or gene products to reduce the effects of undesirable organisms (pests) and to favour desirable organisms such as crops, trees, animals and beneficial insects and micro-organisms'. Interestingly, the target is the *effect* of the pest rather than the pest itself. In the author's opinion separating the pest from its effect only serves to make an effective and acceptable definition harder to secure. The same might be said of DeBach's definition (1964). Here the target of the control is the population density and maintaining it at a lower average than would otherwise occur. Clarifying the terms of reference for biocontrol is important since, if and when more prominence is gained by the technique, misinterpretations and misnomers, as seen in 'organic' farming or 'renewable' energy, are to be avoided.

To conclude what must be a necessary preamble to biocontrol, Hickin (1963) in his totemic work, whilst not offering a precise definition, suggests strongly only the deployment of predators and parasites. A level of interpretation may be necessary in view of the entomological and genetic developments of the last 43 years.

Host Specificity

The importance of specificity, the degree to which an organism exclusively affects the target organism, is disputed. Proponents of autocidal control through sterile insect technique, point to complete specificity as a significant advantage. Indeed, as the capacity for reproduction between organisms lies at the heart of species definition, sterile insect technique can be termed specific in an absolute sense or, by definition, intraspecific. This characteristic is implicit in the mechanism.

Van Driesche and Bellows (1996) claim, with regard to 'classical' biological control, 'polyphagy or hyperparasitism (in control agents) should not always be considered negative'. To substantiate this, it is pointed out that substantial diet breadth can lead to the protection of endangered non-target species. For example, if a predator is polyphagous, it is better for the diet range to be wider rather than narrower. Following this theme they go on to say that only 'extremely polyphagous' agents should be ruled out. McEvoy (1996), however, notes that a limited host range is one of the two founding principles of biological control, and elsewhere in the paper he states that the highly selective nature of the technology is one of its chief attractions. Harris (1988) adds substance to this and confirms close host affiliation as a key requirement by promoting advance specificity tests prior to the control release. Interestingly, he goes further in advocating a high degree of monophagy by cautioning against the unforeseen and entirely counter-productive effect on extant control agents already functioning in the field, some of which may be deliberate introductions. For example, 1877 saw the introduction of the mongoose to several Caribbean islands to control the Norway rat. The target pest numbers were reduced, but those of the tree rat rose for two reasons. Firstly, mongooses cannot climb trees but they do kill and eat native snakes, snakes that play a major role in controlling tree rat numbers (Lawson:http://cast.csufresno.edu/faculty/lawson). Referring to vertebrates as possible biological control agents, Smith and Remmington (1996) warn against their use on the grounds of 'a broad diet and opportunistic feeding habits'. Overall, the balance of writing seems to favour good host specificity, although the author would contend that advanced understanding of specificity and of the dependent inter-relationships present, is of more use in determinant design and selection than the degree of specificity itself. This is because introductions can affect non-target populations in indirect and subtle ways such as via intermediate species. (McEvoy 1996, Stiling 2003)

Pre and Post Release Evaluations

The stakes are often very high in commercial biological control. For example, control of the New World screw-worm fly (*Cochliomyia hominivorax)*, a major cause of livestock morbidity and mortality in the USA, by sterile insect technique has cost $40billion over 25 years, but is calculated to have saved that amount of money *each year*. (Hendrichs, 1999). Notwithstanding this example, several papers lament the lack of post release evaluation and even pre-release studies have sometimes been limited. In the author's view, this is especially worrying as increasingly invasive exotic pests are targeted with exotic biological control agents. (Jacas *et al*. 2005). DeBach (1964) goes further in emphasising the importance of pre-release measures in saying that 'no amount of planning and preliminary research can replace actual and empirical research for natural enemies in the field'.

Similarly diligent post-release follow up is advocated by Hoelmer *et al*. (2005) who urge the use of genetic fingerprints as a means of evaluating distribution in the field.

Given the widespread acceptance of the importance of predictive and post-release evaluation, it is surprising that Thomas and Willis (1998) report that funding for in this work is difficult to secure. Elsewhere, Hoffman *et al*. (2006) admit that 'the importance of natural enemies has not been adequately studied'. Tantalising findings should spur research into broadening areas of biocontrol application. For example monitoring the rise in the number of silk–encased deathwatch beetles X*estobium rufovillosum* and predatory clerid beetles *Korynetes caerulus* during the emergence season is clear evidence of a natural control mechanism at work – unplanned and unaided (Ridout 2000;178). Well designed and carefully considered input in this situation could lead to further pest suppression.

With the increasing body of legislation accompanying the release of biological control agents it is to be hoped that a statutory duty will be placed upon proponents of biocontrol to predict and monitor events actively in the field, rather than simply judge success by the effects on the balance sheet.

Co-evolutionary Advantage

Missing from the body of literature reviewed is clear reference to or acceptance of the evolutionary dynamic nature of biological control. Kenne *et al*. (1999) and Ordish (1972: 104) hint at it in the context of 100 million years of co-evolution of predator, parasite and prey relationships. However, it is clearly viewed as an adaptive progression only in the longer term. Also, Hoelmer *et al*. (2005) recognise 'long periods of co-evolution' of pest and predator, but only in the context of taking control agents from the evolutionary centre of origin, itself often a doubtful concept. The observation that on successfully introducing a control agent it requires no additional input (Hoffmann, 2006) is an understatement. Organisms continually adapt through random mutation and the consequent processes of natural selection. Hence, there exists a phylogenetic dynamic. This contrasts markedly with the deployment of broad spectrum biocides in that, upon first use, survivor organisms become the seed of a new resistant community. Pests routinely evade the damaging effects of chemical biocides, and the attempts of biological control agents. However, they are likely to be less successful in the latter case. The difference lies in the ability of the control agent to overcome evasion by its own, parallel evolution. For example, in the notional case of a pest developing a thicker cuticle to resist the egg of a parasite, the latter develops a sharper ovipositor. No such phenomenon exists with the non-dynamic areas of biological control, habitat manipulation for example, or with the ‘blunt instrument’ of broad spectrum chemical biocides.

That this important evolutionary potential exists is borne out by the development of insecticide resistant pests. Here the often short life cycle of pest organisms, giving greater scope for adaptation, is an obvious drawback. The tendency of a control agent to adapt in response to pest adaptation is a great merit of the biocontrol system, but itself gives rise to a serious challenge. Accurately anticipating the effects of the release of organisms is difficult enough: having to anticipate possible future evolutionary changes yet more so. Predictions rely on the likely effect on the target and non-target organisms and require a thorough understanding of interspecies interactions. This knowledge is not always present as witnessed by Belmain *et al*. (1999) who say ‘the behaviour of deathwatch beetle in buildings is poorly understood’. Anticipating the ramifications of release becomes a great deal harder when there is the complicating factor of an unknown degree of adaptation and evolution.

The history of biological control

Natural insecticides are known to have been used to protect valuable perishable commodities in storage as long age as the Bronze Age. On the Greek island of Santorini, exclusion methods involving airtight vessels were employed alongside natural animal and plant substances to mitigate pest damage. (Panagiotakopulu *et al.* 1995). The first known instance of biological control can be dated to China in 300AD. Here predatory ants (*Oecophylla smaragdina*) were introduced into citrus orchards to control caterpillar and beetle pests (http://www.safe2use.com/ca-ipm/01-04-27.htm). Much later, in 1763, Linnaeus suggested the se of mechanical and biological control methods to protect crops. The years 1848-1878 saw the introduction of an aphid, (*Daktulosphaira* (=*Viteus*) *vitifoliae)* from the eastern seaboard of North America that nearly put an end to the French wine industry (Ordish, 1972). Luckily, the release of a natural enemy, the mite *Tyroglyphus phylloxerae,* from North America in 1873, and the grafting of vines onto American stocks in France provided adequate levels of control. Similarly, *Phyloxera vastatrix* in vines was countered by grafting resistant strains from the pest's geoevolutionary location (Ordish, 1972).

The earliest successful, recorded trial of a biological control method took place as long ago as the early 1880s. Although it was in the field of agriculture, it lay the basis and set the context by establishing important principles for any future attempts to protect timber in buildings. By 1882 the Californian citrus industry was being devastated by 'cottony-cushion scale' (Hoffmann 2006). More by serendipity than clear design, the introduction of two agents from Australia by Koebele lead to complete control within the space of a few years. These were the predacious beetle *Rodolia cardinalis* and the parasitiod fly *Cryptochetum iceryae.*

In carrying out this work Koebele demonstrated for the first time several important principles of enduring relevance and pertaining to any field of biological control, be it agriculture, bulk storage or timber preservation. Firstly, although each agent exerted a degree of control independently, when acting together their effect was magnified many times. In just two years the target organism was controlled. (Van Driesche, 1996). Secondly, Koebele prospected for suitable natural enemies in the pest's area of origin, in this case, Australia. There, the prey and predator could reasonably be thought to have co-evolved in a mutually dependent relationship. Finally, there was an element of forethought and design behind the work. Gradually, the field of biological control began to change from being an art, based on empirical evidence at best and guess work at worst, to one where a carefully designed programme yielded the best results.

The Spanish experience of biological control illustrates the typical pattern upto the middle of the twentieth century (Jacas 2005). Between 1908, the first introduction of an exotic invertebrate control agent and 1942, fifteen natural enemies were released. During the next twenty seven years there was, remarkably, only one. Socio-political affairs were influential in the form of the Spanish Civil War, but there were other significant developments. What happened around 1942? At that time, the discovery of the insecticidal properties of benezene hexachloride and dichloro-diphenyl-trichloroethane (DDT) gave rise to a new era of insect control in agriculture, horticulture, stored products, timber preservation and public health (see Appendix I). Finally, so it seemed, a new age of pest eradication had arrived. Control was now complete and cheap. Moreover, control by the application of chemicals was individualistic in nature and no widespread and concerted effort was required, as with biological control, and farmers could spray and, literally, reap the benefits themselves (Ordish 1976:179). In addition, research and development were chiefly commercially led with little central government investment. (Ordish 1976:192) Alarmingly, however, the first resistance to DDT was noted as early as 1946, and during the 1950s and 1960s, an increasing number of pests were observed to be resistant to this and other pesticides. In a process whereby an evolving organism counters a static threat, 504 insect species were known to be resistant to at least one insecticide by 1993 and 17 resistant to all of them (Stiling 2003). Public opinion also began to be galvanised against a perceived over reliance on chemical control. Rachel Carson's seminal book 'Silent Spring' (1962), in spite of being derided as 'emotional and unscientific' (Ordish 1976:4) was instrumental in raising public awareness of the environmental effect of the indiscriminate use of chemicals and their residues and introduced for the first time the term 'biocide'. Recognising the food chain bio-accumulation of DDT, 1970 saw its widespread ban. (see Appendix I). Gradually, the theory relating to 'integrated pest management' rose in prominence with Germany, India, Malaysia, Indonesia and the Philippines adopting it as official policy by 1986, and Denmark and Sweden following suit a year later.

In all major arenas, except one, where insect control is a desirable or necessary outcome, the blanket reliance on chemical formulations has been downgraded and balanced with complimentary approaches so as to constitute a genuinely integrated approach to control. Only in the field of timber treatment and preservation does chemical use overwhelmingly hold sway. The reasons for this and possible future directions are considered below.

Some of the advantages and pitfalls of biological control have now become clear and may be listed as follows;

Advantages;

1. Potentially high level of control
2. Low individual cost. Cost benefit ratios range from 1:3 to 1:>100 (Hendrichs 1996)
3. Combination of control agents can increase beneficial effect disproportionately (Van Driesche, 1996).

4. Self perpetuating at little cost after initial effort. Complete lifecycle required and attainable.
5. Few, if any harmful effects to man and natural environment
6. Some natural enemies reproduce rapidly
7. Some are able to seek out cryptic prey
8. Some natural enemies survive at low host densities
9. No evidence of hosts developing resistance to technique
10. Analysis indicates that 16% of deployments give rise to complete control, 42% to partial control whilst the remaining 42% showed no effect (Hall, 1980).

Disadvantages:

1. Pest population may not be reduced sufficiently. Damage to timber may still occur if activity remains above a quiescent threshold. In other words suppression is occurring but not enough to bring about the desired result.
2. There may be a delay in controlling numbers which leads to excessive damage. After all, the predators 'aim' is to utilise the pest for its own purposes, of a food source or egg laying medium *inter alia*, rather than affording protection that benefits mankind.
3. Unforeseen side effects may be experienced. For example the Caribbean mongoose. Generalist determinants can have significant effects on non-target native communities (Stiling 2003; 151)
4. Use of one biological control method necessitates an integrated approach (a range of complimentary techniques) throughout the pest complex.
5. Rigorous research is of fundamental importance yet carries no guarantee of success.
6. Control agents may themselves be pests in other environments. For example the moth *Cactoblastis cactorum*, introduced successfully in Australia to control the Prickly Pear Cactus, caused damage to indigenous cacti when illegally introduced to Florida (http://cast.csufresno.edu/faculty/lawson).
7. In practice, unsuccessful introductions rarely survive. However, there is always the possibility of unforeseen negative environmental repercussions.
8. 'Recall' is impossible and further releases may need to be made in order to redress the situation.

9. Bio control successes have been rare in the following fields; the control of plant pathogens and insect vectors of disease.
10. Instigating biological control is less straightforward than the use of chemicals
11. Biocontrol has the aim of bringing the pest population down to an acceptable level rather than 100% eradication. In timber preservation at least, this may not be so appealing to consumers.

It is against this background that the author of this work attempts to assess the merits of an approach to timber conservation in buildings that integrates a wider range of techniques. These may fall into one of the following categories;

1 Applied Biological Control, i.e. the manipulation of natural enemies by man to control pests

2. Conservation Biological Control, i.e. the enhancing of conditions for natural enemy survival and reproduction through habitat manipulation.

3. Augmentation Biological Control, i.e. the rearing and release of natural enemies as a supplement

4. Natural Biological Control, i.e. that which occurs without man's intervention

The context of previous research clearly illustrates the development of biological control in parallel fields. From the beginning, when introductions were on a trial and error basis, were under-researched and were mostly observation based, we have traced how the design process has matured to an ever greater degree of sophistication. It remains for this work to evaluate the possibility of applying such parameters to the field of the conservation of building timbers.

Specific Questions or Problems Arising out of the Context.

Scientific research, going back more than a century, serves to illustrate and clarify a framework within which biological control decisions must be made. It is clear that there is an established methodology for design. In assessing timber conservation, with regard to insect pests, as a potential field for the deployment of biological control, the following questions must be answered:

1. Is there in depth understanding of the pest organisms involved?
2. Are the existing controls adequate, acceptable and sustainable?
3. Do existing controls meet the control objectives?
4. Are pre-existing 'natural biological controls' already present in the biota?
5. Are there already 'conservation biological controls' operating?
6. Is there scope for 'augmentation biological control' by supplemental release?
7. Is there scope for further intervention by 'applied biological control'?
8. What will be the effects on conventional controls (pesticide use) of implementing/enhancing biological ones?
9. Is the efficacy of future biological control methods compromised by the application of previous non-biological controls?
10. Is the wider control environment conducive to using biological control?
11. Is there sufficient demand for other approaches in order to overcome any inertia?
12. Do changes in national and EU law favour research into biological control?

These specific questions, arising out of the wider context of the subject, will form the key points of the main text.

Methodology

Introduction

This section contains an account of data collection and analysis, why they were collected in the way they were and details of any limitations of the method which came to light.

Survey Aims

It is apparent that there are inconsistencies in public attitudes to pests of different kinds. Public awareness and concern regarding the reliance on chemicals for pest control is demonstrated by well publicized themes such as organic gardening and the growing interest in biocontrol in gardening (Helyer 2004). Yet, in spite of this awareness of the potential for environmental harm, there is little evidence that house holders, house sellers and buyers, lenders, surveyors and remediation specialists consider alternatives to chemical treatment.

67 completed forms were returned, again by e-mail, and the results printed and correlated. The percentage of ‘Yes’, ‘No’, or ’don’t know’ answers for each question was calculated.

It was hoped that significant trends might appear. These might in themselves enable assumptions to be formulated regarding public interest in biocontrol in buildings. Some failings in design were noted for improvement in future work. They were as follows:

1. Implicit in the research design was that the sample was restricted to those with access to e-mail. A sample obtained in this way cannot be representative, merely indicative.
2. The ‘starter’ sample comprised contacts known to the author. Thus the sample began, and may well have been restricted to, a particular socio-economic class. There were no questions aimed at ascertaining the respondent profile.
3. The author lacks training or experience in formulating survey questions. Notwithstanding useful external input, there is the possibility that respondents were inadvertently ‘lead’ to an answer.

No precautions were taken to prevent an overlarge response. Given the unpredictable nature of forwarded e-mails this would have been wise. In future work this would be incorporated as a matter of course, possibly as a ‘suicide attachment’

The purpose of the survey was to evaluate the acceptance in principle of biocontrol of timber pests in buildings. It was felt that demonstrating a significant level of acceptance would drive further dedicated research and development in this field.

Sample Selection

The survey questionnaire was sent via e-mail to a number of recipients. In order to obtain the largest sample possible these recipients/respondents were asked to forward the form to other potential respondents according to explained parameters. Ideally respondents would be owner occupiers, i.e. those most likely to take the greatest interest in the wellbeing of their housing. By this method it was hoped that information would be secured from a large and representative sample of the population.

Simple, clear questions were composed with a choice of answers including a ‘don’t know’ option. Use of possibly loaded terms such as ‘predator’ ‘prey’ were avoided in favour of more neutral ones such as ‘harmless wasp’,’ eat’ or ‘be eaten’. Questions designed to determine whether existing biocontrol methods were already employed elsewhere by the respondent, such as in the garden, were included. It was felt that a leaning towards biocontrol in one area would probably predispose towards utilization elsewhere and this comprised a test. The draft questionnaire was reviewed by a representative of Durham University Department of Anthropology and their suggested improvements incorporated.

Results, Data Summary and Analysis

Appraisal of Conventional Chemical Preservation and Treatment Methods

It is clear that preserving and conserving timber by the addition of chemical biocides, being materials applied to remove or reduce the effect of pests (Ordish 1976:35), relies chiefly on the strength and potency of the biocide and the effectiveness of application. However, to be of practical use and acceptable today, many other properties must be present. Not least of these, in the context of preserving historic buildings, is that minimum damage is caused to cultural property. Frequently, traditional approaches to eradicating xylophages have conflicted with the objectives of building conservation which have the overriding aims of minimal intervention and damage to historic fabric (Wood 1999:1).

Applying Chemicals; Methods and Challenges

Chemical timber preservative application frequently takes the form of pretreatment, and this certainly has its place in conserving historic timber buildings, but in considering decay mitigation, we are chiefly concerned with wood *in situ*. Here, sophisticated methods capable of driving preservative material deep into wood tissue are restricted. No method of pressure impregnation, for example, has been devised to treat timber components *in situ*. Similarly, dipping, steeping, incising, sap replacement, and osmosis are not feasible options. Large scale heat treatment, whilst available in mainland Europe, is not widely practised in the UK, and in addition requires structures to be reduced to their skeletal form. Moreover, unaffected wood boring beetles have been discovered in the heart of large section fire damaged timbers, casting doubt on the method (Belmain *et al*. 2000) and cryptic insects are known to be relatively immune to temperature fluctuations (Buckland 1975).

The role of chemicals is justifiable as part of an eradication strategy, where known areas of activity are to be carefully targeted. The localised injection/percolation and paste application of insecticides should be considered viable as part of an integrated approach to wood preservation where the attendant risks of possible surface staining and fire have been evaluated and overcome (Wood 2000). Low temperature sterilisation through freezing is an effective method for smaller items but is obviously restricted for use in buildings. Only the methods of brushing and spraying are universally suited to conditions in the field.

The surface penetration of preservatives applied *in situ*, in a roof space for example, is therefore a critical issue. Even assuming adequate access to all sides and both ends of a piece of timber, the methods available to operatives cannot ensure the deep and even penetration of the wood fibres on which preservation relies. Anatomical features often conspire to inhibit penetration. In softwoods, tracheid cells have closed ends so liquids travel via intermediate valves or ’pits’ in the cell walls. If these pits close during drying, as they often do, then preservative transmittance is inhibited. Spruce, Larch, Hemlock and Fir show this tendency. Pits that remain open may nevertheless be blocked by translocated extractives (Ridout 2000). This is common in Douglas fir. Treatment by soaking or bio-remediation by inoculation with permeability enhancing micro-organisms (Mai 2003: 478) can open the pits but is not viable for timbers in service.

Hardwoods generally present less of a transmittance problem due to the open nature of the vessels. In oak heartwood, however, the vessels are frequently blocked with extractives significantly lessening adsorption. Crucially, both oak and to a lesser extent Douglas fir, both hard to treat species, feature prominently in historic timber buildings. Even in a relatively ‘preservation porous’ timber, European redwood for example, treated by the process of full immersion, penetration is limited to 2mm for spirit based materials and 1mm for water based (Ridout 2000). Given that timber treatment may be to counter wood boring organisms, which diligently avoid the timber’s surface, spray and brush application with their lower penetration levels must lead, inevitably, to significantly less efficacy.

Insecticide Accessibility to Pests

In practice, in historic buildings, components are fixed in place. They are jointed to other pieces and abut other building materials. Frequently, only a limited surface area for treatment is exposed. Even the rafters of roofs, whilst having largely exposed surfaces, pass over purlins and wall plates and support roofing battens. They might also disappear behind a sloped plastered ceiling thus preventing adequate access to the brush or lance. The diffusion of paste insecticides, intended to penetrate deeply, goes some way to promote pest contact but due to their cost are best limited to localised, concentrated application. Similarly, introducing preservatives into bored holes is not viable for entire timber structures and raises cosmetic, conservation and structural issues. Moreover, in both of these techniques, adequate accessibility to the timber surface is a limiting factor. Low accessibility is a key issue in preserving timbers *in situ* as fungal decay is most likely to occur in the very zones where treatment is hardest to achieve (Wood 1999). Decay of all kinds, flourishes in contact with damp materials such as masonry and in inaccessible places where air circulation is at its lowest.

Chemicals; Ensuring Target Contact

Surface deposited biocides do indeed have an opportunity to counter wood borers at certain points of their life cycle. On emergence, the adult beetles must chew their way out of their puparium and at this point their mouthparts must come into contact with poisoned wood fibres. Whether they digest the chemical and die as a result has not been demonstrated. Given that adult beetles are known, by the dissected gut showing no food content (Fisher, 1937, 1938), not to feed (Ridout 2000), this seems unlikely. Indeed, only contact insecticides have any control potential for non-phagous organisms. Later in the insect's lifecycle, surface deposited treatment materials may come into contact with target organisms during egg laying. There is no evidence that surface lying biocides affect egg laying female beetles or the eggs. It *is* known that females lay their eggs on rough surfaces or in fissures in the wood surface (Hickin 1964: 47, Fisher 1938), and avoid the indiscriminate laying of eggs on smooth surfaces. It is most likely that this adaptive behaviour is intended to conceal and protect the eggs from natural egg predators and the effects of drying but, incidental to this, it also serves to limit contact with potential ovicides. As previously noted with the limitations of *in situ* treatment, these are the areas that preservatives are least likely to have penetrated.

On hatching the larvae burrow immediately into the adjacent timber (Hickin 1963: 49) and the confines of a crevice are thought to afford 'purchase' for this act (Belmain 1999: 24). Indeed, newly hatched larvae are oriented towards the timber. In this way they successfully avoid contact with any surface deposited larvicides. It might be thought that adult beetles must succumb to surface lying cuticle degrading protease on re-entering treated timber. This is not necessarily the case, however, as it is now known that, at least in deathwatch beetle *Xestobium rufovillosum* de Geer*,* insects make use of old exit holes and natural fissures to regain admittance to timbers. (Ridout 2000: 189).

Under what conditions can broad spectrum biocides be most effectively utilised? Firstly, contact with free living organisms may be best achieved by application during the April to June emergence season. At this time beetles have left the protective environment of tunnels and chambers and seek a mate. As females lay up to 80 eggs in total (Hickin 1967), mortality of adults at this stage might significantly reduce next generation numbers. Notwithstanding this fact, there is no evidence that it is routinely accepted in the wood preservation industry that there exists a preferred 'season' for the remedial treatment of wood *in situ*. On the contrary, it is assumed, most likely in deference to commercial pressures, that timber treatment is equally effective, regardless of the time of year. The timing of application of chemicals is only an issue in relation to the conservation of bats. Here, there exists a statutory duty on behalf of building owners to seek advice in advance of any treatment work proving that allowances for good timing are possible to enforce given the right circumstances and sufficient will.

Chemical Treatment Guarantees

Historic building owners are disadvantaged in assessing the effectiveness of timber decay mitigation measures through chemical application. Indeed, owners are often unaware that historic, inactive infestations leave highly misleading permanent traces (Oxley 1999: 13). Exit holes, for example, can be misinterpreted as indicating active infestation many years, even centuries, later. Unlike other contracted works such as decorating, reroofing or repairing fittings, which manifest themselves as freshly painted walls, new slates or functional windows, timber treatment has little or nothing to show. Even the closest inspection of, say, a roof void, will not confirm the effectiveness of the work. Population monitoring techniques do exist such as the use of sticky traps and the surface bonding of ‘tell-tale’ papers to reveal fresh emergence holes but, although simple in operation, they may require considerable experience to interpret. To help overcome the problem of consumer confidence, a system of ‘guarantees’ operates throughout the damp proofing and timber preservation industry.

The guarantee protection scheme operated by the Property Care Association (www.property-care.org) on behalf of the British Wood Preserving and Damp Proofing Association in fact underwrites the treatment *work* and does not constitute a guarantee that the timber has been rid of pests. Thus, the guarantee ensures that if ineffective treatment has been carried out, further, possibly pointless, treatment will be repeated. It could be argued that in the absence of any clearly visible benefit to timber treatment, a certificate of insurance is the next best thing in affording an element of peace of mind. In time, these were to become yet more attractive to building owners by virtue being, in themselves, guaranteed through the underwriting of a central organisation. In the context of a well organised timber remediation treatment industry, it is not difficult to account for a lack of research into integrated pest management.

‘Institutionalised’ Chemical Treatment

Even in the circumstances where a building owner receives reassuring advice on timber condition and treatment options and perhaps an assurance that wooden elements are no longer at serious risk, treatment may still be carried out. The practice of ‘institutionalised treatment’ accounts for much timber preservation work carried out today and arises from the standard requirements of financial institutions involved in the property market. (Belmain *et al.* 2000: 235) Banks, building societies and other mortgage providers view certificated timber preservation as an important means of protecting their financial interests. In spite of current practice and attitudes, European Law governing the use of insecticides and fungicides precludes their use as a precaution (Ridout, pers comm). Only in cases where their deployment can be justified by a known and quantifiable risk is their use sanctioned. It is to be hoped that practical application in the field responds rapidly to this sensible legislation.

Chemical Pesticides and Public Concern

During the 1960s and 1970s confidence in the ability of science to safely, effectively and cheaply manipulate the natural environment to our own aims was at its zenith. To a large extent the hurdle of public dissatisfaction with unpredictable old remedies that existed prior to 1939 was overcome by the joint efforts of better operator training, more advanced biocidal materials and guarantees (Hickin 1967:109).

On its own, the spectre of environmental degradation might not have been enough to swing public opinion against chemical use. At this time, however, Carson's 'Silent Spring' prompted concerns over technological fallibility. Also, taken with high profile occurrences of major human impact such as the prenatal exposure to the anti-nausea drug 'thalidomide' (1962), the Three Mile Island and Chernobyl nuclear accidents (1979 & 1986), the Bhopal chemical accident (1984), and the Exxon Valdez disaster (1989), public opinion began to be more moderated in its view of science, and as a result, more mistrustful of synthetic insecticides. The accepted phenomenon of global climate change further erodes a mindset that had previously welcomed, unquestioningly, timber preservatives such as inorganic arsenicals, coal tar creosote and pentachlorophenol. The background to shifts in public attitude to new technologies points to the strong possibility of a broad acceptance of a biological method of timber treatment or preservation that is based on environmental concern and in depth understanding of ecosystems.

Chemical Preservatives; Effects on Predators

Having considered the effects of chemical timber treatment *in situ* on timber pests, consideration must be given to other consequential effects of their use. The application of insecticides in buildings results in the development of a toxic surface deposit. Free living and surface dwelling organisms in the building biota will be affected by any treatment undertaken. Moreover, given the cryptic nature of timber pests, it is likely that the greatest control effect will be on non-target organisms. This is undesirable for at least two reasons:

1. The current conservation climate dictates that unnecessary and randomly targeted loss of fauna is not acceptable, and
2. More importantly for the biocontrol researcher, the reduction in the potential natural predator population caused by the profligate use of biocides.

Consider the house spider *Tegenaria domestica.* This arachnid is known to take crawling insects, such as beetles, earwigs, and cockroaches, and many flying insects. A significant numbers of deathwatch beetle carcasses may be found in its webs (Ridout 2000:178). Such is their polyphagy, that these eurytopic organisms have even been observed feeding on earthworms. It is, however, a ready victim of untargeted treatment (Wood 1999: 4).

To take another example, the common wasp, *Vespula vulgaris,* a great feeding opportunist, is often found nesting in buildings, primarily roof voids. As a generalist predator, it is known to take virtually any soft bodied insect whether it is at rest, in flight, stationary or even trapped in a spider's web (Edwards 1980: 141). It seems likely, therefore, that the common wasp would include in its diet, or that of its larvae for which it gathers flesh, anobiid beetles. Roof space wasp colonies are routinely regarded as undesirable by occupants and owners and removed by direct insecticide application, insecticidal baiting, trapping, or electric grid devices (Edwards 1980: 245). Until such a time as the moderating effect of *V. vulgaris* colonies on the population of anobiids can be accurately determined, this practice must be questioned.

Bat conservation precautions are enshrined in law. It is worth noting the reason for this policy. Studies have shown that bat populations suffer even when there is no direct contact with chemical preservatives and they are absent when application takes place. Mortality can occur simply through contact with surfaces treated with older style compounds such as lindane (Scottish National Heritage http://www.snh.org.uk/publications/on-line/wildlife/batsandpeople/buildings.asp). Regarding anobiids, the controlling role of bats is unclear. On the one hand they are insectivorous, but on the other they have been noted to co-exist with deathwatch in substantial numbers. (Hickin 1953)

Predacious species might suffer the effects of chemical compounds in several ways. Firstly, they may suffer the deleterious effect of direct contact with toxic substances during the process of application. Affected organisms are, on the whole free-living and are likely to come into direct contact from the brush or spray equipment with consequent mortality. Secondly, the invertebrate prey diets of these organisms will be contaminated adding further scope for their reduction in numbers. Finally, their nesting habitat and web building sites will be 'polluted', further inhibiting survival. We face, with a heavy reliance on chemical remediation, the very real prospect of a control method of limited efficacy and highly counterproductive side effects.

Chemical Insecticides and the Legislative Framework

The most recent legislation regulating the use of preservatives in the UK is the Control of Pesticides Regulations 1986 (as amended 1997). This places a statutory duty on manufacturers to apply for approval to the Health and Safety Executive, submitting information on the toxicity, any environmental effects and efficacy. Applications are then considered by the independent Advisory Committee on Pesticides. Approvals are subject to review as and when concerns arise and in any case at regular intervals. Importantly, a new European approval system is being introduced under the Biocidal Products Regulations 2001 (as amended 2003) but it will be several years before this fully replaces the Control of Pesticides Regulations.

Recent experience of changes in legislation, such as the tightening up on the use of permitted materials, indicates a legislative environment less accepting of and more challenging to chemical control. Paul King, director of campaigns for WWF-UK has said "Because of decades of inadequate legislation even healthy diets are exposing us all to potentially harmful chemicals………" and Elizabeth Salter-Green, head of WWF-UK toxics programme said; "Our food is contaminated, our air is contaminated and our bodies are contaminated. Something is desperately wrong here and we need to solve the problem". (Times Newspapers 21.9.06) Both called on the EU to introduce strict controls on the use of chemicals and new laws soon. In such a climate of public opinion, the use of chemicals is likely to become less acceptable and more marginalized.

Further contra-indications for chemical use arise from waste wood disposal. That conventional chemical wood preservatives are toxic and are able to cause environmental problems is widely accepted. In recent years, however, the ramifications of disposal have become more apparent as the first ‘generation’ of chemically treated wood comes up for waste processing. Timber is, in many cases, no longer as easily diverted to other uses as it would have been in the past. This is due to it being impregnated with toxic materials that are highly resistant to biodegradation. Dumping in landfill sites raises fears of the leaching out of toxic compounds into rivers and aquifers. Incineration is technically feasible but prohibitively costly. Re-processing into most wood based products is not possible with a toxic pulp. Interestingly, and perhaps ironically, we may become reliant on living organisms themselves to overcome the problem. Woods treated with creosotes and pentachlorophenols (PCP) are the subject for pioneering research into remediation using microbial agents. (Mai *et al*. 2003).

Mainly because studies have found that pesticide contamination above regulatory levels in the natural environment has not diminished over a ten year period, the EU is planning to introduce a Thematic Strategy for Pesticides (July 2006). Interestingly for the prospects of biological control in historic buildings, member states would have to create the necessary conditions for implementing Integrated Pest Management (IPM), which would become mandatory as of 2014. Also, the use of ‘biopesticides’ is actively promoted. These are pesticides and entomogenous fungi and bacteria that are biological in origin (i.e., viruses, bacteria, pheromones, *Laboulbeniaceae, Bacillus thuringiensis,* natural plant compounds) in contrast to synthetic chemicals. Even where these are not genuine biocontrol agents, it is likely they will exert a much less disruptive influence on Integrated Pest Management.

Applying Biological Control to Xylophages

The research findings of the development of biological pest control techniques in associated fields clearly show them to be not only wide-ranging and effective (Appendix IV), but the chief means of control in a substantial number of cases (eg; control of 'cottony cushion scale' *Icerya purchasi* Maskell and 'European corn borer' *Ostrinia nubilalis* Hübner). Industries where biological control has become established have taken advantage of the agents' population self perpetuation, the density dependent relationship between host and control agent and good cost effectiveness. Underlying each sphere of biocontrol activity, the observance of the same core principles may be seen operating, beginning with a thorough understanding of the various organisms concerned (Ordish 1976: 40) and, most importantly, the relationships between them.

Boldness in implementing control measures has been boosted by the general acceptance that failed strategies, on the whole, do so safely. This may be due a range of factors including climatological (e.g. poor overwintering), chronological (e.g. lack of synchronicity in lifecycle) and ecological (e.g. agents become easily targeted hosts) Whilst there have been instances of serious ecological harm due to releases and invasions, well illustrated by current concern in the UK over the harlequin lady bird, *Harmonia axyridis* (Pallas)(Coleoptera: Coccinellidae) (Majerus *et al* 2006), these are in the minority and failures typically result in a falling agent population to the point where it is statistically insignificant or undetectable. Also contributing to the perceived fail safe nature of biocontrol, most researchers favour a high degree of host specificity. Specificity helps to ensure that failed practical initiatives do so benignly because agents cannot easily switch to an alternative and unexpected food source to ensure their survival. In the circumstances where supposedly host specific agents *do* unexpectedly switch host, however, the potential for consequential environmental harm may be considerable. When this happens, host specificity becomes a highly undesirable characteristic as the newly targeted food source may be an endangered species or another biocontrol agent. In short, a high level of host specificity is desirable but carries risks too. Interestingly, a 'fail safe' tendency in released organisms has not lead to a casual, ill considered approach to project design and implementation, even in times when statutory control was lacking or absent (Jacas 2005). The mass rearing of biocontrol agents is sometimes complex and difficult (Hickin 1963: 74) and requires a considerable investment on the part of the commissioning organisation.

It is likely, therefore, that financial considerations alone guard against profligate, unplanned releases. More recently, a thorough review of biological control programmes has revealed a greater incidence of generalist agents attacking more than one genus of host (48% of sample) and a low incidence of absolute specificity (22.5% of sample), prompting the need for more caution (Stiling 2003).

Research for this paper has shown pre-release evaluations to be deficient in two important areas. Firstly, consideration must be given to the pre-existing environmental situation. Have other agents been released and what will be the effect on them of further releases? It is possible, if not likely, that as biological control gains in acceptance and increases in use the potential for the disruption of earlier biocontrol programmes will rise. A new initiative, implemented without knowledge or regard for earlier work, might lead to a lowering of pre-existing beneficial predator or parasite numbers by intra-agent action. This could be in a direct way, through a pre-existing control agent becoming a host or prey of a subsequent determinant or indirectly through effects on the original agent's food or nest habitat for example.

The second widely overlooked area of pre-release study is that of anticipating the effect of ongoing evolution. Invertebrate biological control agents frequently have short lifecycles, are multivoltine and produce very large numbers of offspring (Hickin 1967: 65). These characteristics, each facilitating random mutation, enable a high degree of evolutionary potential over even a short time. We have already seen for example how DDT resistance in insects was observed in as little as two years. This matter adds a considerable layer of complexity to the already complicated process of pre-release evaluation.

Disrupting Beetle Life Cycles to Moderate their Populations

The best starting point for identifying a method of controlling anobiid populations by the use of biological control is an examination of the organism's lifecycle or the successive stages through which the organism passes from a fertilized egg to a fertilized egg of the next generation. Each separate phase of the life cycle will, it is expected, present opportunities and challenges for control through biological means. *Anobium punctatum* de Geer (furniture beetle) and *Xestobium rufovillosum* de Geer (deathwatch beetle) are closely related biologically and exhibit many of the same features and potential control determinants (Fry, 1987). The life history of both will be considered together with special consideration of the subtle differences between them as it is felt that it is the finer points of the life cycle may hold the clues that enable an effective strategy to be formulated.

The point on the cycle for beginning this exploration has been taken as the emergence of adult beetles from infested wood. *X rufovillosum* emerges during the period mid April to mid June with most activity occurring during the month of May. (Ridout 2000: 44) In England, the earliest ever recorded emergence is mid-March and the latest is 1st August (Hickin 1963: 109). Emergence may take several forms. 'Classical' emergence occurs when an adult beetle chews through the puparium wall making the 3-4mm diameter hole often used in diagnosis. The mouthparts must come into at least some contact with any applied preservative even if the wood fibres do not enter the insects' digestive tract. In view of the fact that adult beetles do not feed (Belmain 2000, Fisher 1937, 1938), the ingestion of chemicals seems unlikely. Research is required to assess insect mortality arising from the activity and justify the surface application of insecticides. A study (Ridout 2000) has shown that upto 27% of emerging deathwatch beetles do so through existing holes or fissures overcoming the risk of ingesting toxicants. Also, emergence is known to take place into inner cavities in the wood (Fisher 1938). In this case, even where the active compound is of the contact type, no benefit will accrue.

Opportunities for biological control increase once the beetles have emerged from the relatively safe confines of tunnels or puparia. The adult deathwatch beetle's life lasts from 4 to 10 weeks for females (Wood 1999: 3) and upto 9 weeks for males after copulation (Hickin 1963: 114). Control agents therefore have considerable opportunity to act during this long period, and it is likely that fertilized females, through longevity, are most vulnerable to attack. This is because, whilst males and females emerge simultaneously, males die first (Belmain 1999: 25). Moreover, of the females, unfertilised ones die before fertile ones. (Ridout 2000: 45) Fertilized females are, therefore, available for predation the longest.

In *X rufovillosum,* the characteristic tapping sound made by both males and females (Birch *et al*. 1991, Fisher 1937)) is a behaviour intended to bring the sexes together for mating. The frons of the head is struck against a substrate 4-11 times at a frequency of 11Hz. Males initiate tapping and females react most strongly to a series including at least 6 blows (White 2005: 549). In *A punctatum*, the unsaturated fatty acid pheromone, stegobinone (Birch and White 1988), is produced, often by both sexes, to communicate with and locate a potential mate (Crowson 1984: 334). Little is known about how pheromones operate in anobiids at present, especially with regard to *X rufovillosum*. However, there exists the clear possibility of increasing the efficacy of sex pheromone traps by incorporating a sound generating device imitating the pitch, volume and rhythmic quality of the insect's own sound as, in the laboratory, insects respond readily to the sound from an artificial tapper of suitable call rate and constancy (Berg 2005: 59). This could supplement the chemically attractive qualities with an audible one leading to the capture of males and females alike. A light source emitting at the right frequency could further enhance attractive properties. It is known from experiment in the field, through trapping being more effective near windows, that insects are attracted to daylight (Wood 1999: 3, Simmonds 2001: 49). Also, photoresponsive behaviour is strongest in females during the critical time of mating and egg laying (Belmain 1999: 15). Importantly, the very nature of this device would most likely lead to removing fertile but unmated insects i.e. prior to egg laying. Chemical insecticides need not be present. A trap of the 'sticky' type would hold the pests indefinitely and cause a complete arresting of the lifecycle of the individuals involved. For each fertilised female captured, population development may be prevented by a factor equivalent to the number of eggs laid. In this case the factor would be eighty.

In addition, beetles have been shown to have a colour preference. In laboratory and field experiments, more beetles were trapped on white sticky surfaces than yellow or darker colours (Simmonds 2001: 49). Useful for the purposes of preventing ovipositing, a high proportion of them were females. Hence, incorporating white surface into the multifaceted trap could render it 'irresistible', and improve its effectiveness still further. These devices could be removed at the end of the 'flight' season (August) or remain in place to be replenished the following April. Devices exist which utilise the attractant properties of ultraviolet light and the destructive property of electricity (Edwards 1980). In terms of maintaining a balanced and healthy building biota these appliances must be considered too indiscriminate. They are as likely to destroy neutral overwintering and beneficial organisms as pests and are therefore unacceptable on environmental protection grounds.

Tegenaria domestica, the common house spider, builds webs inside buildings and in roof voids. These consist of a flat area of web with a funnel shaped retreat at the perimeter. Webs are particularly common in unused spaces that are well lit and examination of these structures frequently shows considerable beetle debris (Ridout 2000). Clearly, the likelihood of becoming entrapped and devoured exists but it is also possible that webs contribute to sound muffling of the acoustic neighborhood thus decreasing tapping communication (Berg 2005: 59). Also, webs reduce air circulation leading to an inhibiting of the dispersal of communicant pheromones. Here habitat manipulation, through the provision of increased light levels, could serve to encourage the naturally occurring predator at the expense of the pest. Whether building owners and occupiers would accept more spider activity is explored in the field survey.

Another arachnid, *Pholcus phalangioides*, or 'Cellar Spider', is 6 to 8mm in length and builds a web of a different kind. This comprises loose random strands that the spider shakes to further tangle a prey organism, such as another spider or insect, which is then bound up as a stored food source. Encouraging this arachnid might also enhance timber preservation as part of an integrated pest management scheme by taking free living wood boring insects.

During the time following emergence, there exists the possibility of disrupting the life cycle of *X rufovillosum* through sterile insect techniques (SIT). Here, the aim is to obfuscate the females attempt to become fertile by limiting their exposure to fertile males. If sufficient transgenic males, with partial or complete infertility, or even light weight males which are known to be less attractive to females (Goulson, 1993), are released in inundative fashion then rates of reproduction will be low and females will lay unfertilised eggs. Such a method has proved invaluable elsewhere, as has already been shown, but depends on more than overcoming the technical challenges that arise from ensuring male sterility. SIT works most effectively where females mate only once as in *Cochliomyia hominivorax* (New World Screw-worm Fly), and research indicates this is not the case with anobiids (Hickin 1963: 46). In addition, sufficient organisms must be artificially bred for release. Autocidal control is acceptable on environmental grounds as it does not rely on the introduction of an exotic species and is, by definition, specific. Moreover, due to their sterility introduced sterile insects cannot become established in the environment. (Hendrichs *et al.* 1999). Conversely, no cost effective self perpetuation advantage exists.

Female death watch beetles lay upto 80 eggs (Hickin 1963) and viability is high at 95% (Fisher 1938). Clearly, the efficacy of biological control measures will be greatly increased by disrupting the animals' lifecycle before ovipositing occurs. The substrate for egg laying might provide vital information for defining a biological control strategy. Studies of ovipositing preference indicate that wood from the 13th – 19th centuries is favoured over new wood from the 20th century (Belmain 2004). In addition to a preference for old timber Fisher 1940), *X rufovillosum* demonstrates anemotactic orientation when exposed to odour (Belmain 2002). The odour plume of volatiles generated by wood decaying fungi *Coriolus versicolor* and *Dokioporia expansa* causes significant anemotaxsis (Belmain, *et. al.* 2002). In an experiment to confirm beetle behaviour, females preferred to oviposit on cellulose paper impregnated with extracts from the various fungi. Fungal 'broth' preparations and frass odours, both consistently repellent to females might be utilised in conjunction with attraction traps.

That xylodetriticolous beetles are not attracted to sound timber is logical as these organisms play a role in the breaking down of matter and do not ordinarily encounter undecayed heartwood in their natural environment (Ridout 2000: 41). With the female having successfully mated, fertilised her eggs and on the point of laying them a technique of 'habitat substitution' may be employed (see Appendix II). By this method a sacrificial timber piece may be introduced into an infested environment that closely duplicates the conditions most conducive to successful egglaying. A block of historic oak heartwood, for example, containing a culture of *Donkioporia expansa*, *Coriolus versicolor*, *Coniophora puteana* and *Fistulina hepatica,* individually or in combination, would be most effective (Belmain 1998) . This could be textured in order to provide crevices, cracks, joints, shakes, roughened surfaces and holes into which eggs could be laid, aiding concealment from predators and helping to avoid desiccation through moving air currents. Also, some wood boring beetles are attracted to burnt and charred timber by chemical attractants in the smoke (Crowson 1981: 580). Fires reduce healthy living trees into habitats for decay fungi and insects, though whether anobiids conform to this pattern is unknown. Nevertheless, there is at least the possibility of enhancing sacrificial block attractiveness by charring. Laboratory experimentation could confirm this and identify the most appropriate combination of physical features. The timing of block placement would be important. Installing such a device would be best before the emergence season begins, say early April. The block could be left *in situ* until the following spring as the minimum length for the larval stage is 1 year (Mean larval stage 4-6 years duration. Maximum 13 years). It could then be removed and destroyed or reused after sterilizing. This could be accomplished by freezing the block.

Such a method, neutral to non-target organisms, could help to suppress a pest population in the long term by preventing the uninterrupted life cycle from replenishing pest stocks via eggs and larvae. By no means would it be an in instant solution and acceptance of the fact that control would come about gradually would be necessary. Further, it might be a method best suited to cultural property of great historic value where those responsible for maintenance are familiar with the complexity of the processes involved and conscientious in remedial practice.

The deathwatch beetle egg is 0.6-0.7mm long, pearly white, 'lemon' shaped, and sticky tending to adhere to each other (http://www.entomology.ucr.edu/ebeling/ebel5-2.html#death watch beetles). Incubation is temperature dependant lasting from 36 days at 14°C to 26 days at 18°C (Hickin 1963: 115). Humidity is important, with moist conditions being better than dry ones. Survival externally is 95%. Beetle eggs, just like any eggs, are a potentially important food source for oviphagous organisms. It is likely that any browsing carnivorous organism will take eggs, though no reports of the occurrence have been reported. A further threat exists from ambient conditions. Eggs are known to be damaged through desiccation in warm and dry conditions. The possibility of wood boring beetle populations being suppressed by the effects of climate change on egg survival rates exists. Recent trends towards hotter summers, shorter, milder winters and warmer springs might increase or decrease the environmental stress factors on beetles in buildings.

In the field, eggs are laid purposefully concealed and fixed in place (Hickin 1967: 109). During the process of egg laying, there is a transmission of symbiotic yeast organisms from the females' reproductive organs to the outer egg surface. The presence of this yeast in the larval gut is essential in enabling the synthesis of nutrients that would other wise be lacking in the organisms diet. These are 'B' group vitamins and steroids (Crowson 1984: 525). The last part of the egg to be laid, the alveolus, is rough and pitted in texture readily accepting the yeast deposit. Inside the egg, the developing larva's head faces this zone and on hatching it breeches this very part of the chorion, consuming the egg shell and the yeast cells in the process. In so doing, it takes the yeast into its gut (Hickin 1963: 49).

Intervention at this point might prove an effective limitation on larval survival. A mechanism that prevents the transfer of yeasts would render the larva incapable of growth and development and result in its death. A vector intended to browse on the egg's yeast deposits might prove an innovative means of biological control. Research in this area should aim, in the first instance, to identify a naturally occurring agent for this purpose in order to be the subject for innundative release. On hatching the larvae begin to tunnel immediately into the adjacent wood. For this reason ingress holes are difficult to find. Conversely, in the laboratory larvae crawl over the surface looking for a place to commence burrowing.

Predators and parasites on beetle larvae are quite numerous. *Korynetes caerulus* ('steely blue beetle') is an oligophagous clerid beetle (<www.bugscep.com>) that is particularly associated with *X rufovillosum*, although it is also known to prey on *A punctatum,* as well as dermestids and scolytids in the wild. Whilst the adult is 4mm long and dark, shining blue, it is the ectoparasitic larvae that have the ability to pursue anodiid larvae deep within wood tissue and kill them. In this way the organism is able to achieve something chemicals fail to do: kill wood boring larvae deep within wood: a significant advantage in the biological control of xylophages (Micales, 1997). Importantly, neither the larvae of *Korynetes* nor the beetle damage timber. Their potential role in biocontrol is undermined however by their fiercely carnivorous nature. Both larvae and adults attack insects of the same species necessitating rearing them in isolation. Consequently, rearing enough for a supplemental release would be difficult and expensive.

Opilo mollis is another clerid beetle but quite rare. It is known that the larvae of this beetle search out xylophagous larvae and eat them. Indeed, to aid their search they are able to excavate tunnels in wood. As with *K caerulus* problems of rearing individuals are present when considering a commercial scale operation so it is most likely that domestic clerid beetles have a contributory rather than a dominant role to play in biocontrol. After all, they are not numerous and their populations risk being overwhelmed by the rapid rise in xylophage numbers during the emergence season. In Germany, a related insect is considered the most important enemy of *A punctatum* (Hickin 1967: 72). O*pilo domesticus* is not found in the UK but may be effective if introduced as an 'exotic', subject to the necessary pre-release evaluations, of course.

Anobiid parasites can help to suppress beetle populations by making environmental conditions less favourable for growth and development. The mite *Pyemotes ventricosus* parasitises many insect larvae by thrusting their chelicerae into a suitable host and sucking out nutrient contents. It is common for larvae to be host to many parasitic individuals. Given that female mites produce up to 300 offspring, rearing them as nymphs within the protected environment of her own body, further research into the mass rearing and inoculative release of this organism, would be very worthwhile.

Anobiids in thin wooden stock can be effectively parasitised by the hymenopteran *Spathius exarator*. The limiting factor here is the length of the wasp's ovipositor (5-7mm), which the female uses to deposit an egg on the larvae. Hatching within two or three days, the host's skin is pierced and the juicy contents are sucked out. Three to eight days later the *Spathius* larvae is fully grown and spins its cocoon of silk next to the withered body of its host (Hickin 1963).

Common on beetle infested timber is the chalcid fly, *Theocolax formiciformis.* Ranging 2.8 – 3.1mm in length, the female seeks out anobiid larvae and lays her 0.5mm diameter eggs next to them. (Hickin 1967: 70) There can be up to nine eggs and anobiid larvae have been known to launch a counter attack, squashing and eating the threatening eggs. More usually, however, the *Theocolax* eggs hatch and the larvae fasten on to the host and commence sucking. After 12 – 14 days the anobiid larvae is dry and shriveled and the parasite larvae pupates. *Theocolax formiciformis* is thought to be the most common hymenopterous parasite of *Anobium punctatum* in the UK.

In Germany, recent trials with another wasp parasite, the ectoparasitoid *Lariophagus distinguendus,* have been carried out. This insect has great potential as a biological control agent as the females are able to regulate the male/female proportion of offspring (Papadopoulou 2004). The main, or 'Cranach', altar in Erfurt Cathedral, constructed of lime wood and bearing no less than eleven rare medieval paintings of the highest conservation value, was observed to be suffering from severe *A punctatum* infestation. Conventional methods of countering the decay involving chemical treatments were ruled out on the grounds that they would risk damaging the delicate surface finishes. In conjunction with The Federal Institute for Material Research, timber scientist Erhard Heinemann devised and executed a procedure for biological control. After first ensuring that ambient conditions were most propitious regarding temperature (15° – 25°C) and humidity (15%), 3000 2.5mm long live female *L distinguendus* wasps were released into a polythene enclosure. These insects are small enough to navigate the bored holes with ease, locate prey using their sense of smell and have a four metre radius of action (Steidle 2002). Conditions were sustained for five weeks during which time up to an estimated 18,000 eggs would have been laid inside the bodies of *A punctatum* larvae. The result of the trial was judged by the effect of the wasps on woodworm infected logs and seeds placed in the enclosure as a control. These controls were known to contain 49 *A punctatum* larvae. At the end of the trial all but one had died in the larval or pupal stage – an impressive success rate of 98%.

Initial findings suggested that the treatment had worked, but doubts were raised over the accuracy of the control mechanisms – particularly the seeds. In seeds, the close bio-association between *L distinguendus* and the granary weevil, *Sitophilus granarius,* is well researched and documented (Papadopoulou *et al* 2004). Consequently incorporating seeds into any control mechanism could be deemed scientifically unsafe. Nevertheless, the treatment was claimed to work and to represent a considerable cost saving over the use of nitrogen gas.

Considerable obstacles had to be overcome in order for the technique to have the possibility of working. As the predator is native to the Mediterranean (Papadopoulou *et al* 2004), temperature and humidity had to be maintained at artificially high levels and physical containment was necessary to prevent the biological control agent from randomly dispersing. In the field of historic building conservation such measures would be difficult or impossible to achieve.

The predacious biocontrol of xylophages within timber has serious limitations. Larval predation implies an acceptable degree of damage to wooden building elements. Moreover, field evidence suggests a considerable lagging behind of predator populations (Simmonds 2001), and therefore occasions when, with control organisms unable to cope, pests will predominate. If this uncontrolled phase of the pest's life cycle includes the time of egg laying then predator effect might never be more than a background suppressant.

Conditions for the larval development of anobiids are not ideal in buildings and this is reflected in this stage of the life cycle taking as long as 13 years as opposed to as little as one year in the wild (Hickin 1963) or 10 months under optimum conditions (Fisher, 1941). A swift resolution of any infestation problem would benefit from a shortening of the life-cycle by artificial means, if this could be achieved. As has already been noted, female beetles show preference for laying eggs on timber partially decayed by the action of fungi, and this reflects the conditions likely to be encountered in forests and woodlands. It is known that fungal attack aids *X rufovillosum* attack by physically softening the wood tissue. (Ridout 2000: 44). Anomalies do exist, however, and death watch beetle infestations can occur without fungoid influence. For example, Bishopstone Church, Wiltshire is said to be one of the most seriously *X rufovillosum* infested buildings in Britain, yet displays very little evidence of fungal decay (Simmonds 2001)

In the absence of preferred timber, any will do but a clear preference exists. The reason for this is that sound timber cannot ordinarily be digested by the larvae and fungal activity supplies essential proteins and vitamins (Fisher 1941). Such is the correlation between insect activity and fungal decay that it is possible to accurately plot the extent of the latter by the presence of the former (Hickin 1967: 117). This in its turn indicates timbers or parts of timber with a high moisture content (above 20%) such as wall plates or timbers built in to masonry (Fisher 1940). The fungal decay of timber is inevitable at moisture levels in excess of 20% with microscopic spores being present everywhere in the air. Moreover, the slow drying of timber and the processing of diseased trees can lead to fungal growth in quiescent form in timber incorporated into buildings. Fungal growth in buildings, therefore, is only to be precluded by avoiding damp conditions. For this reason preventing insect attack in historic buildings by removing fungal growth alone is not feasible. Rather, it is preventing high moisture levels that can effectively prevent insect infestation through lessening the chances of fungal attack. This relies on sound maintenance procedures and practice. The question for those exploring the application of biological control methods to anobiids is essentially whether the relationship between the beetle and the fungus can be disrupted.

Historic timber buildings must, in the overwhelming majority of cases, contain areas of the structure where decay has been initiated at some time. Through, neglect, damage or disaster moisture levels will, inevitably, at some time in the past, have been high enough for fungal attack to commence. A low level beetle infestation will be present in these circumstances as is indeed the case with many historic buildings throughout the UK. Beetle attack is regarded as extremely hard to completely eradicate and measures usually involve containment and ongoing population suppression. A pest organism that can extend its larval stage to thirteen years obviously requires a long term strategy for remediation. At the conclusion of an extended larval stage, pupation occurs and an adult emerges to restart the lengthy process again. With this pattern it is easy to see how remediation may need to extend over several decades.

Survey Results (see Appendix II)

Within the limited scope of the survey questionnaire several interesting phenomena arose. Question 1 was intended to discover the extent of biocontrol awareness in the respondent The proportion of respondents who indicated no personal experience in the established field of biological control in gardening was 78%. Questions 2 & 3 evaluated the respondents' openness to the prospect of using biocontrol to protect buildings and indicated a high degree of acceptance (mean 83%). This contrasts markedly with the results of question 1 and suggests little experience but considerable openness to biocontrol. Questions 4 & 5 were intended to measured commitment beyond just the theoretical and gauge willingness to act and invest in pest suppression measures. Here a measure of ongoing awareness and action were presented for consideration. Again, positive responses were well in the majority (mean 78%, 68%) and suggest that commitment extends beyond the theoretical into taking positive practical action. Question 6 failed to assess the extent of willingness to alter roof space biota through habitat manipulation when unforeseen complications came into play. Many respondents questioned permanently illuminating roof voids on the grounds of wasting electrical energy and one respondent raised concerns regarding the risk of fire. Notwithstanding these considerations, 59% of respondents were prepared to consider the proposal. Question 7 aimed to arrive at the extent of the householders' knowledge of historic treatment of their homes. This served not only to illustrate the general level of concern and attentiveness in this area but also, and more importantly, to indicate the likely future success of any biocontrol programme. The forms of treatment applied in the past will inform and influence design decisions involved in the planning and execution of pest suppression strategies. 41% of respondents had no knowledge of the timber treatment history of their dwellings raising questions of how control strategies are to be formulated in the absence of thorough and complete knowledge of the toxicity of existing micro conditions. Question 8 offered respondents a summary of this paper's findings. This was more than a courtesy gesture. The fact that fully 65% of respondents answered in the positive suggests a genuine interest in pro-actively tackling timber pests in buildings in a way that impacts less detrimentally on the built and wider environment.

Conclusion

Assuming that the effective suppression of fungal decay through moisture mitigation measures is in place, the primary obstacle to countering Anobiidae in historic timber buildings results from their cryptic lifestyle: a lifestyle that has almost certainly evolved to provide maximum protection for the organism for as much of its life as possible.

For an individual *X rufovillosum* in unfavourable conditions (cool and dry) the 'free living' phase of its life i.e. that of an emerged female adult beetle, could amount to as little as 0.64% of its existence.[1] For a male beetle, living but 10 days (Belmain *et al.* 1999) the figure is a staggeringly small 0.2%. Hence, the 'window of opportunity' for adult remediation by the means of either biocide application or mass biocontrol action is severely restricted where conditions unfavourable to the larvae exist. Conditions conducive to larval growth and development (warm and moist) expose the organism to control methods for 9%[2] of its life. Xylophage remediation in buildings through adult interception appears most effective under conditions most suitable for their proliferation. Furthermore, synchronous beetle emergence risks overwhelming natural predators. Large numbers of prey appearing in a short space of time can result in a significant numerical disparity between competing species. Predator populations may, indeed, rise in response to the abundance of food but there is likely to be a time delay. During this time of imbalance, pest propagation is readily

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[1] Calculation (Unfavourable Conditions); $\frac{\text{emerged adult time}}{\text{Total life time}} \times 100$ or $\frac{\text{1 month}}{\text{156 months}} \times 100$

[2] Calculation; (Favourable Conditions); $\frac{\text{emerged adult time}}{\text{Total life time}} \times 100$ or $\frac{\text{1 month}}{\text{11 months}} \times 100$

achieved by largely unimpeded mating and egg laying. Also, fecundity is inevitably greater in prey than in predators. This is certainly the case with anobiids and their natural predators, adding a further challenge to population suppression by biological means.

Interspecific asynchronicity contributes further to undermining control objectives as during the time when population imbalance occurs the primary goal of decay prevention is negated. In other words, fertile eggs are laid, larvae hatch and wood tissue damage is sustained.

A surface application of insecticide with minimal penetration of toxic substance must be of little effect in countering an organism that spends upto 99.8% of its life as an egg, a larva tunnelling beneath the surface of wood and in the pupal stage.

Also, in a timber section 250mm x 200mm, a size not uncommon in historic buildings, an application of insecticide that penetrates even 2mm deep renders only 3.6%[3] of the wood volume hazardous to wood borers. A picture, therefore, emerges of an organism that spends 99.8% of its time in conditions 96.4% safe.

Whilst the outer zone of the timber member where the toxic agents lie is the area *least* likely to be occupied by xylophages hoping to avoid predators, parasites and desiccation, it is the zone *most* likely to be occupied by free roaming, browsing predators. There exists the strong likelihood, therefore, of highly counterproductive effects of non-specific chemical insecticide on beneficial organisms. The precise nature of any impact would merit close study. In short, major challenges persist in ensuring adequate chemical contact with the target.

The range of available chemicals with which to counter wood boring organisms has declined in recent decades due to concerns over environmental and human health, and this trend can be expected to continue. A well established pattern has emerged whereby manifest environmental degradation due to the bioaccumulation of compounds, formerly regarded as benign, is recognised and controlling or restricting legislation is introduced. There is no reason to expect this trend to not continue as environmental sampling methods

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[3] Calculation; $\frac{\text{affected cross sectional area}}{\text{total cross sectional area}} \times 100$ or $\frac{(250\times2\times2)+(196\times2\times2)}{250\times200} \times 100$

become more effective, regulations more stringent and public and political opinion less tolerant of environmentally damaging side effects. Furthermore, even beyond the rigorous testing and introduction of new control materials, EU law in this area stipulates ongoing monitoring and evaluation aimed at the early interception of harmful materials.

Pre-existing biological control agents do play a role in pest population suppression and must be factored into any integrated control strategy. However, their suitability for supplementation or augmentation by controlled release is limited by the difficulty of rearing them in sufficient numbers. Many are not just carnivorous but are as likely to attack each other as they are the target pests.

Notwithstanding the difficulty of predator rearing and ensuring sufficient opportunity for contact, the introduction of exotic control agents is a possibility. However, the fundamental prerequisite of a thorough understanding of the target's biology is lacking. Much more needs to be known of anobiid biology before possible biological control agents can be identified and this is a most worthwhile area for further detailed study. A more advanced understanding of anobiid biology, particularly concerning the dependency of *X rufovillosum* on the presence of fungal decay, might in itself prompt effective control mechanisms.

The prospects for effective biological control of anobiids using predacious agents are further complicated by the legacy of nearly one hundred years of treatment with chemical preservative. If the answers of respondents are to be taken as typical, upto 75% of roof voids contain wood with a surface layer of toxic compounds. Whether, effective biocontrol with predators, parasites or parasitoids can take place in such an altered environment requires careful investigation. There exists the clear possibility that artificially induced environmental conditions are not conducive to an integrated pest management scheme utilising living organisms: organisms that are, of course, potentially susceptible to biocides.

Habitat manipulation may successfully help to inhibit pest populations. Encouraging environmental conditions that favour naturally occurring predators will impact on pest numbers and reduce consequential damage. Further, pests can be directly targeted by means of traps. These can be of two types. 'Sticky' traps will arrest the life cycle of anobiids but, being non specific, affect beneficial insects too. Sacrificial lures (see

Appendix II for design specification) *are* specific to the target organism by virtue of the pheromone attractant, fungoid odour and other attractant mechanisms and can be deemed environmentally neutral in operation

Moreover, they have the advantage of disrupting the pest life cycle at the most critical point (mated females prior to ovipositing) thus preventing damage to historic timbers. Such timely intervention reduces the environmental load on the building biota to a minimum. Research to ascertain the effective range and general efficacy of such devices is necessary. Also, their use would require an understanding of the principles at work and diligence in carrying out the proscribed procedure. Counterintuitavely, success of the method is not indicated by the presence of flight holes in the device. In fact the opposite is true: flight holes indicate that the opportunity of removing the target has been lost as mature adults have emerged to reproduce.

The results of the survey questionnaire indicate that, whilst there is little personal experience of ‘hands on’ biological control, there is considerable openness and interest in the subject. Also, willingness, extending beyond the theoretical, is suggested as there is a readiness to consider implementing biocontrol measures and to meet the financial costs of them. This should be seen as validating further investigations into the field of biocontrol of xylophages in buildings.

General observations;

1. In historic buildings, and in the light of current understanding, control and suppression of insect decay is the realistic approach rather than outright eradication.
2. Control programmes, if not seen as ongoing, should be expected to run in the long term.
3. The concealed nature of the larval stage of the anobiid lifecycle presents serious challenges for control by *any* means.
4. Insufficient data exist concerning anobiid biology.
5. Except in a small minority of cases, control by insecticide application is likely to be found largely ineffective and possibly counterproductive.

6. The range of available chemical agents has reduced markedly and is likely to continue to do so. The most potent examples have been withdrawn in the process.
7. There are good indications that the experience of biological control, already well established in agriculture, might easily extend to timber conservation.
8. Treatment methods need to make allowance for pre-existing natural predators and parasites.
9. The legacy of past applications of toxic compounds might reduce the effectiveness of future innovative control methods.
10. Life cycle acceleration (reducing the lifecycle to a single year) by habitat manipulation (creating warm and moist conditions) may condense a control programme *providing* there is an efficient and reliable elimination method such as the sacrificial lure trap and incidental damage, through fungal damage for example, is insignificant or acceptably low.

Recommended areas of further study;

1. Most importantly, investigations should be undertaken to ascertain the circumstances that allow extensive *X rufovillosum* infestation in the absence of widespread fungal decay in Bishopstone Church, Wiltshire. What special characteristics of the timber, the insect or combination of factors must be identified. The findings may well point to improved biocontrol strategies.
2. A thorough reappraisal of the efficacy of controlling timber pests with insecticides must be undertaken to clarify and quantify efficacy.
3. Anobiid biology must be studied to fill in the gaps in understanding particularly with regard to interspecific communication and fungoid interrelationships.
4. Research is required into the effect of surface deposited biocides on building biota in general and pre-existing beneficial organisms in particular.
5. Research into the range and efficacy of sacrificial lures is necessary. Combined investigations into the effect on lignicolous anobiids of light, sound, odour and surface texture will aid in refining the trap profile.
6. Life cycle compression is feasible in theory but the practicalities need to be experimentally assessed in order to bring infestation remediation to the swiftest conclusion.

7. Fully evaluating the extent of natural predation by pre-existing determinants in historic buildings is a prerequisite for biological control by augmentation. The effects of V*espula vulgaris, Tegenaria domestica* and *Scutigera coleoptrata* as well as other potential control agents should be assessed.
8. Studies aimed at clarifying the bat/anobiid relationship should be carried out to avoid potential conflicts of approach and harmonise strategies.
9. The prospects for deploying the exotic O*pilo domesticus* as a determinant of *a punctatum* should be investigated fully.
10. The prospects of deploying the parasites *Pyemotes ventricosus* and *Theocolax formiciformis* as debilitating agents against *A punctatum* should be investigated fully.

Summary

Finally, a picture has emerged in which facultative synanthropic xylophages continue to prevail. Curtailed mostly by a reliance on natural population regression in the very long term, and in the absence of any visible impulse to restore suitability for purpose and durability criteria in material selection, the destruction of historic fabric by insect decay agents continues largely unimpeded. Indeed, it can be seen that in some instances the application of control methods favours pest propagation by suppressing natural pest predators. Only in innovative techniques borne of detailed understanding of insect behaviour and biology is there hope of achieving effective, environmentally acceptable and long term control and protection of valuable timber-built cultural property. Strong indications exist that there is scope for a more integrated approach to the management of anobiid timber pest populations in historic buildings and the challenge for the future is to promote the advancement of a thorough understanding of decay processes and the furthering of innovative and informed control programmes.

> "…..for even trees are liable to attack of disease,
> since what created object
> is exempt from these evils"
>
> Gaius Plinius Secundus (Pliny the Elder) AD23-79

References

Belmain, S.R. *et al* 1999 *Deathwatch Beetle, Xestobium rufovillosum, in Historical Buildings: Monitoring the Pest and its Predators* Entomologia Experimentalis et Applicata Volume 93 pp. 97 – 104

Belmain, S.R. *et al* 2000 *The Deathwatch Beetle – Accommodated in All the Best Places* Pesticide Outlook. Volume 11, Number 6, pp. 233-237

Belmain, S.R., Blaney, W.M., Simmonds, M.S.J. 1998 *Host Selection Behavior of Deathwatch Beetle Xestobium rufovillosum: Oviposition preference choice assays testing old vs new oak timber, Quercus sp*. Entomologia Experimentalis et Applicata Volume 89, Number 2, November pp. 193-199

Belmain, S.R., Simmonds, M.S.J., Blaney, W.M. 2002 *Influence of Odour form Wood Decaying Fungi on Host Selection Behavior of Deathwatch Beetle, Xestobium rufovillosum* Journal of Chemical Ecology Volume 28 Number 4 pp.741-754

Belmain, S.R. *et al*. 2000 *Behavioral Responses of Adult Deathwatch Beetles, Xestobium rufovillosum de Geer (Coleoptera: Anobiidae) to Light and Dark* Journal of Insect behaviour Volume 13 Number 1 pp 15-26

Berg, A., Greenfield, M.D. 2005 *Sexual Selection in Insect Choruses: Influences of Call Power and Relative Timing* Journal of Insect Behavior Volume 18 Number 1 pp. 59-75

Bierne,B. 1962 *Trends in Applied Biological Control of Insects* Annual Review of Entomology Volume 7 pp 387 - 400

Birch, M.C., Keenlyside J.J. 1991 *Tapping behavior is a rhythmic communication in the death-watch beetle, Xestobium rufovillosum* Journal of Insect Behavior, Volume 4 Number 2

Birch, M.C. and White, P.R. 1988 *Responses of Flying Male Anobium punctatum(Coleoptera: Anobiidae) to Female Sex Pheromone in a Wind Tunnel* Journal of Insect Behaviour Volume 1 Number 1 pp111 - 115

Britton, E.B. 1961 *Domestic Wood Boring Beetles* British Museum (Natural History) Economic Series Number 11A

Brues, C.T. 1936 *Evidences of Insect Activity Preserved in Fossil Wood* Journal of Paleontology Volume 10, Number 7, pp. 637-643

Buckland, P.C. 1975 *Synanthropy and the Death-Watch; a discussion* The Naturalist April/June

Crowson R.A. 1981 *The Biology of the Coleoptera* Academic Press (London) Ltd, London

Culliney, T.W., Grace, J.K. 2000 *Prospects for the Biological Control of Subterranean Termites (Isoptera: Rhinotermitidae), with Special Reference to Coptoternes formosanus* Bulletin of Entomological research Volume 90 Number 1 pp 9 – 21

DeBach, P. 1964 *Biological control of insect pests and weeds*. London Chapman & Hall,

Desch, H.E. 1969 *Timber Structure, Properties, Conversion and Use* London Macmillan Press

Edwards, R. 1980 *Social Wasps: their biology and control* Rentokil Limited, East Grinstead, Sussex

Fisher, R.C. 1937 *Studies of the Biology of the Death Watch Beetle* Annals of Applied Biology Volume 24 pp 600 - 613

Fisher, R.C. 1938 *Studies of the Biology of the Death Watch Beetle* Annals of Applied Biology Volume 25 pp 155 – 180

Fisher, R.C. 1940 *Studies of the Biology of the Death Watch Beetle* Annals of Applied Biology Volume 28 pp 545 – 557

Fisher, R.C. 1941 *Studies of the Biology of the Death Watch Beetle* Annals of Applied Biology Volume 28 pp 224 - 260

Fry, J.M. *Natural Enemy Databank 1987* CAB International Institute of Biological Control Oxford

Gabriel,C. *et al* 1990 *Biological Control- the Need for a New Scientific Framework* BioScience Volume 40 Number 3

Garcia, L.E. *et al* 1990 *Biological Control: The Need for a New Scientific Framework* BioScience Volume 40 Number 3

Gould, F. Schliekelman, P. 2004 *Population Genetics of Autocidal Control and Strain Replacement* Annual Review of Entomology Volume 49 pp 193-217

Goulson, D. e*t al* 1993 *Paternal Investment in Relation to Size in the Deathwatch Beetle, Xestobium rufovillosum (Coleoptera: Anobiidae), and Evidence for Female Selection for Large Mates* Journal of Insect Behaviour Volume 6, Number 5

Hall, R.W. 1980 *Rate of success in classical biological control of arthropods* Bulletin of the Entomological Society of America

Hanks, L.M. *et al* 2001 *Patterns of Host Utilisation by Two Parasitoids (Hymenoptera: Bracondiae) of the Eucalyptus Longhorned Borer (Coleoptera: Cerambycidae)* Biological Control Volume 21 pp. 152 – 159

Harris, P. 1988 *Environmental Impacts of Weed Control Insects* Bioscience Volume 38 pp 542-548.

Helyer, N. 2004 *Biological Control in Plant Protection* London Manson Publishing

Hendrichs, J. 1995 *Sterile Insect Technique* Journal of Applied Entomology Volume 119 Number 5 pp. 371-377

Hickin, N.E. 1967 *The Conservation of Timber Buildings* London Hutchinson & CO. (*Publishers*) LTD.

Hickin N.E. 1963 *The Insect Factor in Wood Decay* London Hutchinson & CO. (*Publishers*) LTD.

Hickin, N.H. 1953 *Bats and the Deathwatch Beetle* The Practical Builder

Hoelmer, K.A. Kirk, A.A 2005 *Selecting Arthropod Biological Control Agents Against Arthropod Pests: Can the science be improved to decrease the risk of releasing ineffective agents?* Biological Control Volume 34 pp. 255 – 264

Hoffmann, M.P., Frodsham, A.C. 2006 *Natural Enemies of Vegetable Insect Pests* Cornell University New York USA

Jacas, J-A. *et al* 2005 *History and Future of Introduction of Exotic Arthropod Biological Control Agents in Spain: A Dilemma?* BioControl Volume 51 pp. 1-30

Kalmakoff, J. *et al* 1980 *Defining Biological Control* BioScience Volume 30 Number 10 p. 646

Kenne, M. *et al* 2000 *Hunting Strategy of a Generalist Ant Species as a Biological Control Agent against Termites* Entomologia Experimentalis et Applicata Volume 94 Number 1

Mai, C. *et al* 2004 *Biotechnology in the Wood Industry* Applied Microbiology and Biotechnology Volume 63 pp 477 – 494

Majerus*, et al* 2006 *The potential impacts of the arrival of the harlequin lady bird, Harmonia axyridis (Pallas)(Coleoptera: Coccinellidae) in Britain* Ecological Entomology Volume 31 pp 207-215

McEvoy, P.B. 1996 *Host Specificity and Biological Pest Control* BioScience Volume 46 Number 6 pp. 401 – 405

Martin, C. *et al* 1991 *Tapping Behaviour Is a Rhythmic Communication in the Death Watch Beetle, Xestobium rufovillosum (Coleoptera: Anobiidae)* Journal of Insect Behaviour Volume 4 Number 2 pp. 257 – 263

Micales,J.A. 1997 *Mechanisms of Wood Decay and Biological Control – an Introduction* International Biodeterioration and Biodegradation Volume 39 Number 2-3 pp 99 – 100

Ordish, G. (1972 *The Great Wine Blight* London J.M.Dent and Sons Ltd.

Ordish, G. 1976) *The Constant Pest: A Short History of Pests and their Control* London Peter Davies

Oxley, R. 1999 *Is timber treatment always necessary? An introduction for homeowners* SPAB News Volume 20 Number 4 pp. 13 – 16

Panagiotakopulu, E., Buckland, P. C., Day, P. M., Sarpaki, A. & Doumas, C. 1995 *Natural insecticides and insect repellents in Antiquity*. Journal of Archaeological Science Volume 22 pp. 705-710

Papadopoulou, S.C., Athanassiou, C.G. 2004 *Lariophagus distinguendus (F.) (Hyme., Chalcidoidea, Pteromalidae), an ectopsarasitiod of Lasioderma serricorne (F.) (Col.,Anobiidae), found for the first time in tobacco stores in Greece* Journal of Pest Science Volume 77, Number 3 / July, pp.183-184

Remedial Timber Treatment in Buildings; A guide to good practice and safe use of wood preservatives Health and Safety Executive/HMSO London ISBN 0 11 885987 0

Ridout, B. 2000 *Timber Decay in Buildings: the conservation approach to treatment* London E & FN Spon

Roush, R. *Defining Biological Control* BioScience Volume 30 Number 10 p. 646

Simmonds, M.J. *et al* 2001 *Integrated Pest management of the Control of Deathwatch Beetles: Trapping* English Heritage Research transactions, Volume 4, pp.40-50

Smith, L. 2006 *Man-made Toxins are Found Even in the Best Diets* The Times September 21st 2006

Smith, H.R., Remington, C.L. 1996 *Food Specificity in Interspecies Competition* Bioscience Volume 46 pp 436 – 447

Steidle, J. L. M.; Schöller, M. 2002 *Fecundity and ability of the parasitoid Lariophagus distinguendus (Hymenoptera: Pteromalidae) to find larvae of the granary weevil Sitophilus granarius (Coleoptera: Curculionidae) in bulk grain* Journal of Stored Products Research Volume 38 Number 1 pp 43-53.

Stiling, P. 2004 *Biological control not on target* Biological Invasions Volume 6, Number 2 pp151-159

Thomas, M.B. Willis, A.J. 1998 *Biocontrol- risky but necessary?* Trends in Ecology & Evolution London Imperial University

Van Driesche, R.G. *et al* 1996 *Biological Control: Guide to Its Application* New York Springer

White, P.R., *et al* 1993 *Intraspecific variability in the tapping behaviour of deathwatch beetle, Xestobium rufovillosum (Coleoptera: Anobiidae)* Journal of insect Behaviour Volume 6, Number 5, September pp. 549-562

Wood, C. 1999 *Deathwatch beetle and its Treatment* Structural Survey Volume 17 Issue 3 pp. 131 – 137

Online Sources

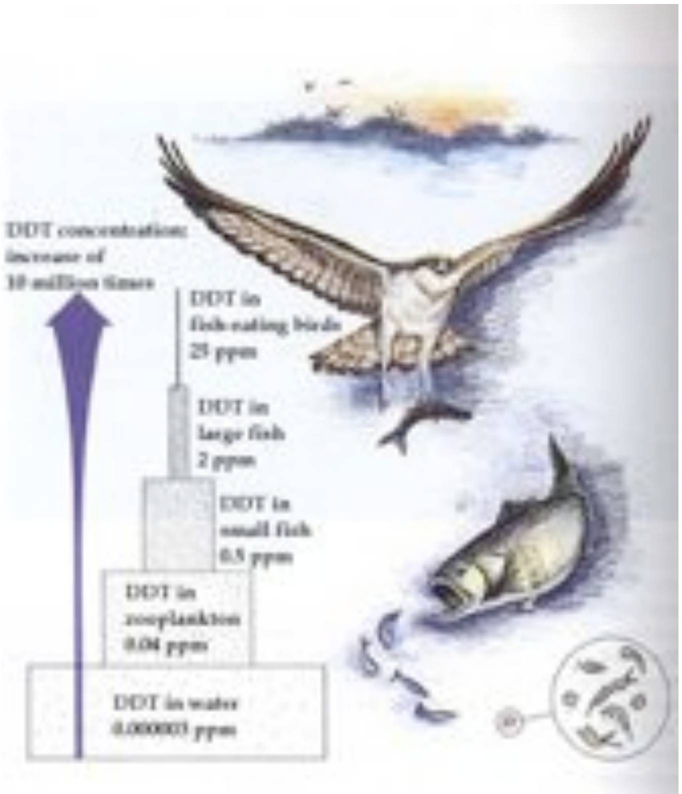
http://www.pesticides.gov.uk/home.asp
http://www.entomology.ucr.edu/ebeling/
http://helios.bto.ed.ac.uk/bto/microbes/bt.htm
http://en.wikipedia.org/wiki/Category:Biological_pest_control_agents
http://www.alanwood.net/pesticides/class_insecticides.html
http://en.wikipedia.org/wiki/Insecticide#_note-0
http://nbn.nhm.ac.uk/nhm/
http://www.just-green.com/
http://www.bugs2000.org/index.html
http://www.ingentaconnect.com
http://www.csuchico.edu/biol/Sociobiology/volume/sociobiologyv41n22003.html
http://www.goodbugs.org.au/natenemieslist.htm
http://www.jstor.org/
http://www.wcrl.ars.usda.gov/cec/h.htm
http://64.233.183.104/search?q=cache:NdTTP9mkZ9UJ:www.umass.edu/ent/newletter/newsletter3.html+autocidal+define&hl=en&gl=uk&ct=clnk&cd=2
http://www.springer.com/west/home/computer/lncs?SGWID=4-164-22-1441197-0
http://www.sss.uq.edu.au/linkto/phdwriting/fr_phfaq.html
http://www.westernexterminator.com/deathwatch_beetle.html
http://www.udoerasmus.com/firstscreen.htm
http://www.safe2use.com/ca-ipm/01-04-27.htm
http://cast.csufresno.edu/faculty/lawson/classes/plth107/Plth107%20fl05%20lect2%20History.ppt#290,2,Slide 2
http://www.biconet.com/reference/InsectvsInsect.html
http://www.tolweb.org/Stephanidae
http://translate.google.com/translate?hl=en&sl=de&u=http://www.bistum-erfurt.de/seiten/1052.htm&sa=X&oi=translate&resnum=5&ct=result&prev=/search%3Fq%3DAndreas%2BGold%2BErfurt%26hl%3Den%26lr%3D%26sa%3DG
http://cast.csufresno.edu/faculty/lawson/
http://www.spc.int/rahs/Manual/Multiple_Species/SWFE.HTM
http://www.pan-uk.org/default.htm
http://www.ridoutassociates.co.uk/article01a.htm
http://www.grovelands.com/acatalog/Biological_Pest_Control_Syngenta_Bioline_Control.html
http://www.crocus.co.uk/toolsandstuff/refine/?ParentCategoryId=70
http://www.etymonline.com/index.php?search=-phagous&searchmode=phrase

Appendix I

DDT...FOR CONTROL OF HOUSEHOLD PESTS

1947……….

……………1972



Appendix II

Sacrificial Lure Trap: Proposed Specification

Aim: to serve as a repository substrate for the laying of anobiid eggs and their subsequent end of emergence season removal. Low temperature sterilisation for 48 hours before reuse.

Material: Timber; softwood for *A punctatum* and aged oak heartwood (shown) or willow for *X rufovillosum*

Weight: 1510g

Configuration: 397x96x64mm section to suit domestic freezer. Centre handle. Transverse through slots to 0.75 of depth to increase area of available end grain from 9% to 54%

Additives: 2,3-dihydro-2,3,5-trimethyl-6-(1-methyl-2-oxobutyl)-4H-pyran-4-one (Stegobinone)(White and Birch, 1987) as sex pheromone attractant.
Volatile distillates of known attractant fungi.

Electronic Device (not shown): sound emitting device producing 11Hz at 11 beats/second

Colour (not shown): to incorporate white reflective surfaces as visual attractant and/or charring.

Proposed Sacrificial Lure Trap for Anobiid eggs

Appendix III

Survey Questionnaire

Here are the Questions…………

Q1. 'Biological Pest Control' is the use of natural organisms to control pest populations. Do you use any biological control methods in your garden? (eg lady birds for greenfly, nematodes for leatherjackets etc)

Yes No Don't Know

Q2. Would you consider releasing a harmless natural predator in your loft to prevent or eradicate furniture beetle (woodworm)?

Yes No Don't Know

Q3. Would you consider releasing a harmless natural predator in your loft to prevent or eradicate
death watch beetle?

Yes No Don't Know

Q4. If so, would you be prepared to do this regularly? Say, each Spring?

Yes No Don't Know

Q5.Would you consider installing a simple, inexpensive and silent electronic device in your loft to deter pests?

Yes No Don't Know

Q6. If artificial light encourages natural predators (eg spiders) and they, in turn, control pests would you leave
an energy efficient light switched on in your loft?

Yes No Don't Know

Q7. Has your loft space been treated with chemicals at any time in the past?

Yes No Don't Know

Q8. Would you like a summary of my findings?

Yes, please No, thanks

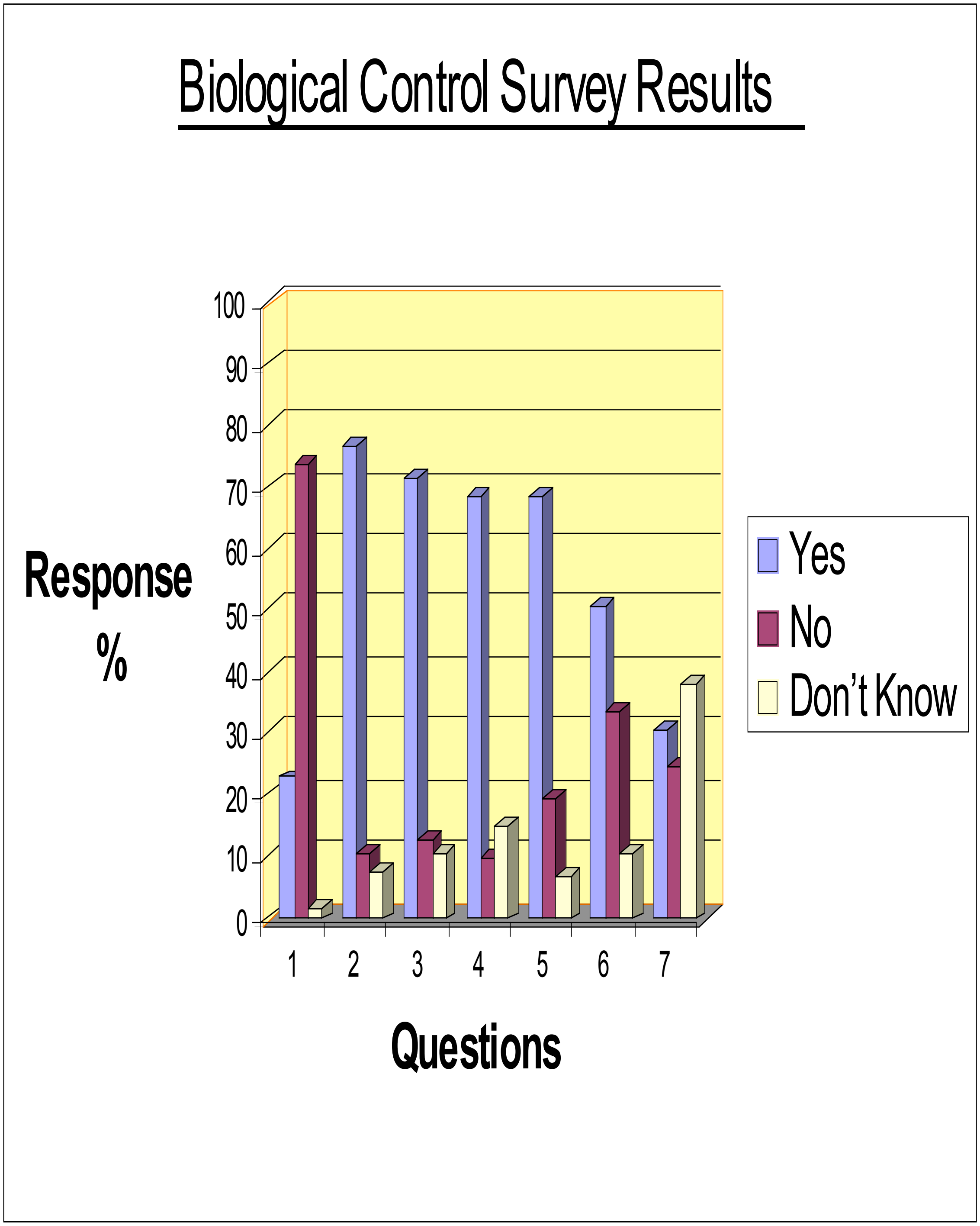
PLEASE FEEL FREE TO CONTINUE WITH ANY NOTES OR COMMENTS ON THE SHEET BELOW

Many Thanks for Your Help

Richard Fox 24th October 2006

Notes and comments

Results from Survey Questionnaire



Details of Questionnaire Responses

	Yes	**No**	**Don't Know**
Q1	**14 no. 23%**	**45 no. 74%**	**1 no. 2%**
Q2	**47no. 77%**	**7 no. 11%**	**5 no. 8%**
Q3	**44 no. 72%**	**8 no. 13%**	**7 no. 11%**
Q4	**42 no. 69%**	**6 no. 10%**	**9 no. 15%**
Q5	**42 no. 69%**	**12 no. 20%**	**4 no. 7%**
Q6	**31 no. 51%**	**21 no. 34%**	**7 no. 11%**
Q7	**19 no. 31%**	**15 no. 25%**	**23 no. 38%**
Q8	**Yes, please** **42 no. 69%**	**No, thanks** **19 no. 31%**	**n/a**

Appendix IV

Biological Control Product Summary – Agriculture/Horticulture

Number	**Pest**	**Control Agent**	**Notes**	**Comments**
1	Slugs	Nematode Worm – *Phasmarhabditis hermaphrodita*	Control activity takes place underground, mainly by day Can control snails if in contact	Seeks out concealed pests. These aggressive nematodes actively seek out and attack slugs. They invade the slug via the dorsal pore, which is a small hole at the back of mantle (the raised area on the slugs back). Once inside, the nematodes release bacteria that stop the slugs feeding within 3 days. The mantle swells as the nematodes reproduce and the slug eventually dies underground after 7-10 days. The nematodes continue to reproduce as the body is broken down and further generations move off into the soil to locate further victims.
2	Vine Weevil Larvae	Nematodes - *Heterorhabditis* or the *Steinernema* species *Steinernema kraussei* Previously - *Heterorhabditis megidis*	Larvae die in 2-3 weeks	Larvae similar in appearance to wood boring beetle larvae
3	Spider mite	Predatory mite - *Phytoseiulus persimilis*	Eats eggs, young and adults. Requires 16-20C Ideal in glasshouses	Spider mites are commonly attacked by predator mites. Five species are commercially available in the U.S.: *Phytoseiulus persimilis*, *Mesoseiulus longipes*, *Neoseiulus californicus*, *Galendromus occidentalis* and *Amblyseius fallicus*. Predatory mites can be distinguished from spider mites because of
4	Spider mite	Predatory mite - A*mblyseius californicus*	Ditto. Less temperature sensitive. Better outdoors	

				their longer legs. The front pair of legs is often extended forward. They are more active and move about at a fast pace. They are often red or orange in color. *P. persimilis* is the most common predator and preys on all stages of mites (Osborne 1999). It can consume 20 eggs or five adults daily.
5	Fungus Flies	*Hypoaspis* mites	Soil dwelling mite that attacks the larvae	
6	Fungus Flies	Nematodes	Nematodes (*Steinernema feltiae*) will search out the larvae in the soil media, kill them and use their bodies to reproduce in.	
7	Thrips 'Thunderbugs'	predatory mite; *Amblyseius cucumeris* and *Orius laevigatus*.	Feeds on larvae or young. Min 15C	
8	Thrips	*Orius lavigatus.*	Larvae and adult thrips and aphids	
9	Chafer Grub	Nematode - *Heterorhabditis megidis*	Primary damage – tunneling, secondary damage by foxes, badgers and birds seeking to feed on grubs	Secondary damage is of main concern to gardeners
10	Leatherjackets	Nematode - *Steinernema feltiae*	Death of pests within 2-3 weeks	
11	Ants	Nematodes	Not killed but driven away by nematode presence	
12	Aphids (50/day), thrips, red spider mite and moth eggs	Lacewing - *Chrysoperla carnea*	Effective predator in larval stage. Adults not predatory. Min. 12C	
13	Aphid	Parasitic wasp - *Aphidius colemani*	They are very efficient at finding individual or new colonies of aphids	
14	Greenfly and aphids	the midge; *Aphidloletes aphidimyza*		
15	Aphids	Hoverfly - *Episyrphus balteatus* Lady Bird *Adalia bipunctata*	Larvae is the predator, adults feed on pollen and nectar. I larvae consumes 300-500 in its lifetime (2 weeks)	Hoverflies can be encouraged by growing attractant flowers such as the poached egg plant *(Limnanthes douglasii)*, marigolds or P*hacelia*

				throughout the growing season.
16	Caterpliiars	Nematode *Trichogramma brassicae* wasps	Replaces the natural bacteria, *Bacillus thuringiensis* – withdrawn from sale	*Trichogramma brassicae* seeks out caterpillar eggs to lay their own eggs in. When the eggs hatch, the larvae consume the caterpillar egg contents and then pupate. It should be released as early as possible in the growing season to give best control. *Trichogramma* species are the most widely used biological agents in the world. (Sygenta Biological Pest Control)
17	Greenfly/Aphids	Ladybird larvae - *Adalia bipunctata*	Larvae consume more aphids/greenfly than adult beetles. Min 10C	
18	HardScale	Predatory beetle - *Chilocorus nigritus*	20 – 40 scale insects/day. Adults and larvae predate. Must average 22C	
19	Leafminer	Parasitoid wasp *Diglyphus isaea*	Prey are stung	
20	Mealy bug	The predatory beetle *Crytptolaemus montrouzieri,*	The use of predators for mealy bug control can be dated back to beginning of the twentieth century, using the predatory beetle *Crytptolaemus montrouzieri,* which is a ladybird like beetle originating from Australia. Also the compost dwelling predatory mite, *Hypoaspis spp.* Both the larvae and the adults of this beetle feed on mealy bug. The young *Cryptolaemus* larvae can reach 13mm in length, and resemble the mealy bug in appearance as they are white with mealy like points sticking from	Interesting bit of biological control history *Cryptoleaemus* adults and larvae are predators of mealybugs (*Pseudococcus sp*), important pests of indoor plants, which may also appear in ICM and organic salad crop production. It is a *Coccinellid* predator which is used in southern Europe where it is naturally endemic, for the control of mealybug pests on citrus and other tree crops. In northern Europe it has been used commonly for release onto indoor ornamental plants as a population regulator for mealybugs. The large white cottony larve of *Cryptolaemus* should not be confused with its host, which also has hairs and a creamy white colour.

			them. The adults and young larvae feed on mealybug eggs and nymphs and the older larvae feed on the whole lifecycle of the mealybug. Min 16C	
21	Softscale	A tiny parasitic wasp called *Metaphycus helvolus* can be used to control soft scale.	*Metaphycus helvolus* is a parasitoid of soft scale insects, injecting its eggs into the scale insect. Each female lays 400 eggs and can lay up to five a day. The adults live up to 3 months. The scale goes a darker colour as the wasp develops inside the scale insect killing it. Eventually it cuts a small hole to emerge from the scale. This product is only suitable for indoor use in a greenhouse or conservatory, where there are higher temperatures. Temp. 22C Parasitic wasp - *Encarsia formosa* Indoors at 17C	
22	Whitefly			
23	Whitefly	Mixture of two parasitic wasps; *Encarsia formosa* and *Eretmocerus eremicus.* The new wasp; *Eretmocerus* is a more efficient parasite of tobacco whitefly and works better than *Encarsia Formosa.*	More tolerant of higher temperatures	