THE DEATHWATCH BEETLE, *XESTOBIUM RUFOVILLOSUM*, ACCOMODATED IN ALL THE BEST PLACES

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Abstract - Trapping and monitoring experiments were conducted in the roof spaces of four buildings infested with deathwatch beetle, *Xestobium rufovillosum* de Geer (Coleoptera: Anobiidae). Data from sticky traps and an ultra-violet insectocutor showed that adult deathwatch beetles were trapped during the months of May, June and July. The beetles were attracted to natural light and UV light, and more beetles were caught on white coloured traps than yellow, blue or red coloured traps. During the monitoring periods, the proportion of deathwatch beetles out of all arthropods caught was between 30-40% among the four buildings. Weekly trap catch of all arthropods, including deathwatch beetle, was positively correlated with ambient temperature. Adult beetles flew in buildings at ambient temperatures greater than 17 °C. Habitat diversity in the buildings was assessed through the number of resident, over-wintering or non-resident arthropods caught. Spiders comprised 13% of arthropods caught, and evidence of deathwatch beetle predation by spiders was assessed. The predatory beetle, *Korynetes caeruleus*, was found in all four buildings; however, there was no evidence of other deathwatch beetle predators or parasitoids.

Key words - Anobiidae, timber pest, historical building, biological control, pest

INTRODUCTION

Despite the damage caused to timber and wooden artefacts in buildings of historical importance across Europe by the deathwatch beetle, *Xestobium rufovillosum* de Geer (Coleoptera: Anobiidae) (Fisher, 1938), the behaviour of deathwatch beetles in buildings is poorly understood. For example, the literature suggests that the adult beetle does not fly in buildings because the beetle has never been reported to fly (Maxwell-Lefroy, 1924; Kimmins, 1933; Fisher, 1938; Hickin, 1963; Harris, 1964), although the beetle will fly short distances in laboratory experiments (Baker, 1964). We could find no literature on the dispersal of deathwatch beetles in forests, although it has been stated that the 'beetle can walk long distances when inclined to do so' (Fisher, 1938; Hickin, 1963). Perhaps because of reference to the non-flight behaviour of the deathwatch beetle, previous literature has argued that infestation of buildings by the deathwatch beetle occurred when infested timber was brought into a building during construction or repair, the beetles then dispersing in the building by walking away from the original infestation (Maxwell-Lefroy, 1924; Fisher, 1938). Therefore, evidence of beetle flight in a building could help clarify potential dispersal and infestation mechanisms.

Trapping methods designed to monitor for the presence of the deathwatch beetle as well as their potential dispersal behaviours could also lead to a means of effective pest control. Sticky traps are extensively used to trap pest insects, often using an attractive colour, for example, blue for thrips (Coli *et al*., 1992; Vernon and Gillespie, 1995), or a chemical such as Blattellastonoside for cockroaches (Sakuma and Fukami, 1993) to increase efficacy and thereby reduce pest density. Although sticky traps without colour or chemical attraction are sometimes used in buildings to monitor timber pests they have not been used to monitor deathwatch beetles. In this study, traps designed to catch walking and flying insects were used to sample arthropod diversity in buildings infested with deathwatch beetles. Knowledge about arthropod diversity could help establish potential infestation risks associated with a building's degree of exposure to the outside environment as well as monitor for the presence of potential biocontrol organisms that may be using the deathwatch beetle as a food resource. Although their impact on deathwatch beetle populations has never been measured, predators of the deathwatch beetle are known to exist (Hickin, 1963), mainly involving spiders and the Clerid beetle, *Korynetes caeruleus*.

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Wm H. Robinson, F. Rettich and G.W. Rambo (editors). 1999.

MATERIALS AND METHODS

Coloured sticky cards and sticky strip traps

Three buildings with known infestations of deathwatch beetles were chosen as the experimental sites: Salisbury Cathedral, Winchester Cathedral and Kew Palace. Numbered sticky cards and strips were placed in infested areas of the roof in the buildings to monitor overall insect populations, determine the presence of biological control organisms, and monitor the emergence of adult deathwatch beetles. Red, yellow, blue and white paper cards 10 cm by 15 cm were covered in Tangle Trap®. Sticky strips 5 cm wide and approximately 3 m long were cut from rolls of wall paper and covered in Tangle Trap®. The Tangle Trap® had been heated in a water bath to 100°C to reduce viscosity and applied as thinly as possible to one side of the cards or strips with a 10 cm wide paint brush. The sticky cards were placed on horizontal surfaces in groups consisting of one card of each colour. The distance between the cards in a group varied due to the structure of the roof, but distances between cards in a group were never greater than 50 cm. The ordering of the coloured cards within a group was randomised; however, the distance among groups was determined by the roof structure. In Winchester Cathedral, 136 cards were positioned predominantly along the wall plates on either side of the nave roof, roughly in alternate bays. The traps were placed out on 19 April 1995 and brought back to the laboratory on 12 July 1995. In the roof level of Kew Palace, 120 sticky cards were positioned along the floor, either near a wall or away from a wall, as well as in window sills and along timber beams running at head height. The traps were placed out on 1 May 1995 and brought back to the laboratory on 12 July 1995. In Salisbury Cathedral, 124 traps were positioned mainly along the wall plates of the nave. The traps were placed out on 25 April 1995 and brought back to the laboratory on 24 July 1995. Thirty sticky strips were hung in each of the building sites on the same dates. The sticky strips were hung in series, roughly determined by the building features of the roof with almost equal distances between strips in a series. Strips at Winchester Cathedral and Salisbury Cathedral were hung along both sides of the nave roof, whereas at Kew Palace strips were hung usually one or two per room. Sticky cards and strip traps at all sites were checked weekly.

Flight-specific trapping using ultra-violet light attraction and electrocution

Bishopstone Church in Wiltshire, UK was chosen for the positioning of an ultra-violet insect electrocutor (NPW 80 Insectocutor, Pest West® Electronics Ltd.) because the building had a severe infestation of deathwatch beetles and was small enough to provide optimal coverage by the equipment (maximum coverage of 300 m^2). The insectocutor was placed in the windowless nave roof of the church during the first week of April 1996 and remained there until July 1997. Arthropods were collected from the insectocutor on a weekly basis during the deathwatch beetle adult emergence seasons, April to June, in 1996 and 1997.

Biocontrol potential of spiders and predatory beetles in a deathwatch beetle infested building

During 1996 and 1997 Bishopstone Church was searched weekly for living adult deathwatch beetles and predators (Pholcid spiders and *Korynetes caeruleus*). Searching commenced at the start of the emergence period in April and finished the end of June, and was done in the same places on each visit. For example, 1.5 to 2 h were spent collecting beetles and predators in cracks, crevices, under tables and hassocks. The relative density of spiders in Bishopstone Church was not readily assessed because traps could not be placed in public areas. However, deathwatch beetles found encased in spider silk were gathered on a weekly basis as a means of quantifying the impact of some spider species (of the family Pholcidae) on the deathwatch beetle population.

Temperature

Ridout Associates (Stourbridge, West Midlands, U.K.) provided data on the ambient air temperatures of each building obtained from temperature sensors located in the roofs.

RESULTS

Coloured sticky cards and sticky strip traps

Deathwatch beetle adults were trapped on the sticky cards, mostly in May at Kew Palace and Winchester Cathedral, but in June at Salisbury Cathedral (Figure 1).

Arthropods caught on the traps were divided into three categories: 1) non-resident, such as many Hymenoptera and Thysanoptera, that are usually herbivorous and entered the building through windows and became trapped inside, 2) over-wintering, such as many Lepidoptera and Neuroptera and 3) detritus and timber eating residents, such as *X. rufovillosum*, Thysanura, Isopoda, *Anthrenus* spp. and their predators. The arthropods caught in the three buildings between April and July 1995 were combined and expressed as percentages from different arthropod Orders (Table 1a). Resident arthropods represent 74% and 45% of the arthropods caught on the coloured cards and sticky strips, respectively (Table 1a). The proportion of deathwatch beetles on the sticky strip traps at the three sites was similar to that on the coloured cards, although only flying insects were caught on the strips (Table 1a). Similar proportions of deathwatch beetles were caught on the sticky cards (33% to 40%) and sticky strips (32% to 38%) in each of the three buildings (Table 1b). Spiders comprised 13% of the arthropods caught on coloured cards, whereas none were trapped on the sticky strips (Table 1a). The predator, *Korynetes caeruleus*, was caught on cards and strips at the three sites in small numbers (< 1% of total catch). Other beetles that are mainly detritus feeders but sometimes exhibit predatory behaviour, such as *Anthrenus* spp. (< 2% of total catch), were also caught. Dipteran and hymenopteran parasitoids were rarely caught (< 0.5% of total catch), and were found to be non-resident as those species identified do not feed upon any building resident or over-wintering insects. The majority of the other resident arthropods caught were detritus and wood feeders, such as Thysanura, Psocoptera, Isopoda and other wood-eating coleopterans.

Table 1. Comparison of total arthropods caught (%) on coloured cards and sticky strip traps between April to July 1995 broken down by, (a) resident, over-wintering and non-resident and (b) by Kew Palace, Winchester Cathedral and Salisbury Cathedral, (b) including UV insectocutor data from Bishopstone Church.

a) combined total caught among three buildings

arthropod type	resident	over-wintering	non-resident	resident	over-wintering	non-resident
X. rufovillosum	35%			33%		
other Coleoptera	11%			11%		
Diptera		1%	1%			11%
Hymenoptera			1%			11%
Lepidoptera		13%			8%	
Arachnidae	13%					
Isopoda	4%					
Thysanura	9%			1%		
Thysanoptera			6%			15%
Neuroptera		2%			4%	
Trichoptera			1%			
Psocoptera	2%					
Homoptera			1%			6%

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Wm H. Robinson, F. Rettich and G.W. Rambo (editors). 1999.

b) total caught among four buildings

arthropod type	Kew Palace	Winchester Cathedral	Salisbury Cathedral	Kew Palace	Winchester Cathedral	Salisbury Cathedral	Bishopstone Church
X. rufovillosum	35%	40%	33%	34%	38%	32%	31%
other Coleoptera	10%	14%	7%	13%	11%	7%	22%
Diptera	2%	1%	3%	13%	11%	8%	31%
Hymenoptera	2%	1%	1%	18%	7%	7%	1%
Lepidoptera	11%	9%	18%	3%	2%	23%	7%
Arachnidae	17%	12%	12%				
Isopoda	6%		6%				
Thysanura	5%	11%	11%		1%	1%	
Thysanoptera	6%	6%	7%	12%	20%	10%	
Neuroptera	3%	2%			5%	7%	8%
Trichoptera		1%					
Psocoptera	2%	3%	1%				
Homoptera	1%		1%	7%	5%	5%	

The number of arthropods caught on the coloured cards from April to June was positively related to maximum ambient air temperatures (Kew Palace, Spearman Coefficient (Rs) = 0.869, n = 11, P < 0.01; Winchester Cathedral, Rs = 0.797, n = 13, P < 0.01; Salisbury Cathedral, Rs = 0.902, n = 13, P < 0.01). The effects of maximum ambient temperature on trap catch were also observed with the sticky strips (Kew, Rs = 0.803, n = 11, P < 0.01; Winchester, Rs = 0.856, n = 13, P < 0.01; Salisbury, Rs = 0.955, n = 13, P < 0.01). Although ambient temperatures continued to rise and remained high during the rest of June and July 1995, no further deathwatch beetles were caught on the sticky cards or strips.

The distribution of deathwatch beetles among the different coloured cards was analysed to determine if a particular colour was more attractive to *X. rufovillosum*. Chi-square analysis on the null hypothesis that all traps would catch the same number, demonstrated that white traps caught more beetles than yellow, red or blue traps ($c^2 > 11.2$, df = 3, $P < 0.001$) (Figure 2). White cards were not only found to be more likely to have beetles on them, but also to have a greater number of beetles on them than cards of any other colour (Kruskal-Wallis, $c^2 = 56.771$, df = 29, $P < 0.001$).

The attraction of the beetles to light was assessed by comparing the numbers of deathwatch beetles caught on traps placed in or near windows with those in relative darkness (data not available for Salisbury Cathedral as windows were not an experimental feature). More deathwatch beetles were caught on traps in the light ($c^2 > 15.5$, df = 15, $P < 0.01$) (Figure 3).

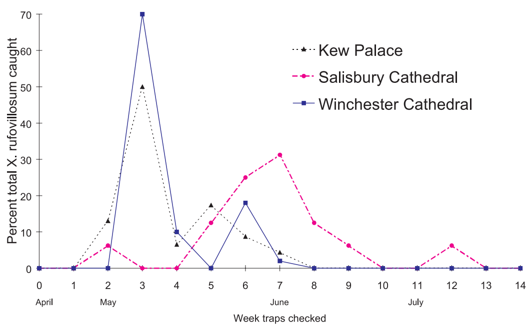

Figure 1. Percentage *X. rufovillosum* trapped weekly at Kew Palace (37 insects caught, 3 May – 7 June), Winchester Cathedral (74 insects caught, 10 May – 7 June) and Salisbury Cathedral (58 insects caught, 3 May to 12 July) over the monitoring period, 19 April to 25 July 1995

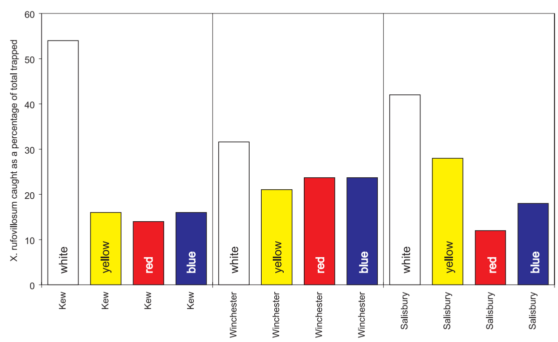

Figure 2. Percentage of *X. rufovillosum* caught by trap colour at Kew Palace, Winchester Cathedral and Salisbury Cathedral

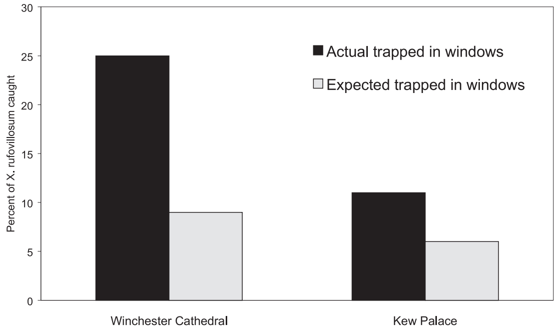

Figure 3. Attractiveness of light to *X. rufovillosum* as determined from sticky trap data from Kew Palace and Winchester Cathedral. The expected values were determined by assuming the null hypothesis that trapped beetles were distributed evenly across all traps in the building. The expected ratios of beetles on traps in the light were then compared to the actual ratios of beetles found on traps in the light.

Flight-specific trapping using ultra-violet light attraction and electrocution

In both emergence seasons there was an increase in the number of beetles caught with increasing maximum roof temperature (1996, $Rs = 0.89$, $n = 6$, $P < 0.001$; 1997, $Rs = 0.78$, $n = 6$, $P < 0.001$; *Figure* 4). Deathwatch beetles were not caught in the insectocutor during either emergence season until the weekly maximum temperature in the roof had exceeded 17°C. The number caught remained relatively low until ambient temperatures were in the range of 24°C to 27°C. The proportion of different arthropods caught in the insectocutor varied from week to week, and the effect of temperature on the total catch of insects was similar to that for deathwatch beetles (1996, $Rs = 0.86$, $n = 9$, $P < 0.01$; 1997, $Rs = 0.95$, $n = 11$, $P < 0.01$). Combined data from the two collection periods showed that deathwatch beetles comprised 31% of all arthropods caught by the insectocutor (Table 1b). Most of the other arthropods caught were potentially detrimental to buildings, as they feed upon wood and decaying material. However, a few predatory beetles, *K. caeruleus*, were caught (< 1% of total catch). Parasitoids were not collected, and all dipteran, lepidopteran and hymenopteran species found were classed as non-residents.

Biocontrol potential of spiders and predatory beetles in a deathwatch beetle infested building

In both 1996 and 1997 the proportion of silk-encased deathwatch beetles found in Bishopstone increased during the deathwatch beetle emergence season (Table 2). The number of predatory Clerid beetles also increased from May to June in both years (Table 2).

Table 2. The presence of Pholcid spiders and Clerid beetles at Bishopstone Church in relation to the number of living deathwatch beetles collected over the emergence period (a) during 1996 and (b) during 1997.

a)

collection week	*X. rufovillosum* caught live	*X. rufovillosum* found in silk	% catch by spiders	*K. caeruleus* caught
23.04.96	45	3	6.25	0
30.04.96	132	5	3.65	0
07.05.96	99	7	6.60	0
13.05.96	106	8	7.02	0
21.05.96	99	10	9.17	2
28.05.96	118	20	14.49	5
11.06.96	144	32	18.18	6
19.06.96	68	21	23.60	10
25.06.96	45	12	21.05	4
Total	856	118		27
% of *X. rufovillosum* caught live		13.7%		3.2%

b)

collection week	*X. rufovillosum* caught live	*X. rufovillosum* found in silk	% catch by spiders	*K. caeruleus* caught
02.04.97	90	0	0.00	0
09.04.97	73	2	2.67	0
16.04.97	85	4	4.49	0
23.04.97	64	2	3.03	0
30.04.97	197	6	2.96	0
07.05.97	201	7	3.37	6
14.05.97	205	9	4.21	7
21.05.97	160	11	6.43	20
28.05.97	88	12	12.00	4
04.06.97	49	8	14.04	9
18.06.97	27	5	15.63	5
Total	1239	66		51
% of *X. rufovillosum* caught live		5.3%		4.1%

Figure 4a Figure 4b

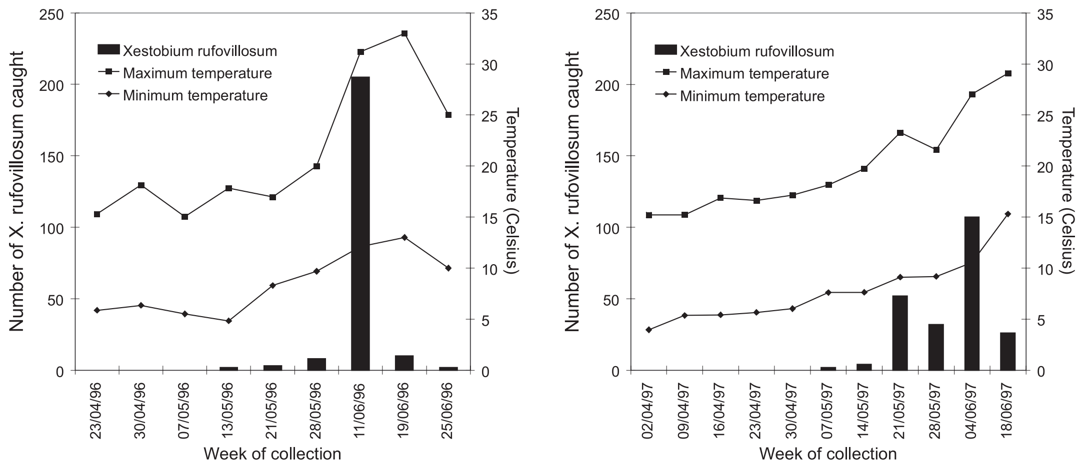

Figure 4. Relationship between temperature in the roof of Bishopstone Church and the number of *X. rufovillosum* caught in the insectocutor, (a) during the 1996 emergence period, (b) during the 1997 emergence period

DISCUSSION

Trap data suggest that the roof structures of the buildings studied demonstrate a variable degree of exposure to the external environment because arthropods were able to enter [and theoretically to exit] the building from outside. Differences in building porosity were represented through the different proportions of non-resident insects caught among the buildings and between card and strip traps. As the sticky strips hung in the buildings caught only flying insects, the strips caught a higher proportion of non-resident insects through trapping a higher percentage of dipterans and hymenopterans than the coloured sticky cards. The flight behaviour of deathwatch beetles, coupled with evidence that the roof structures allowed insects to enter from outside the building, would suggest that infestation of a building is possible centuries after construction.

The number of insects caught relative to temperature follows general knowledge about insect flight metabolism as ectothermic insects require a threshold temperature to fly and are increasingly active with increasing temperature (Blackmer and Byrne, 1993; Ward *et al*., 1996; Holyoak *et al*., 1997). The absence of reports of deathwatch beetle flight in nature is likely to be related to the insect's ectothermic flight behaviour in buildings as flight will only occur when the ambient temperature is high enough to induce flight. However, coloured card data do not distinguish whether the effect of increased tempera-

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Wm H. Robinson, F. Rettich and G.W. Rambo (editors). 1999.

tures is to cause more beetles to emerge or to cause increased beetle activity. It is likely that both factors contributed to the number of deathwatch beetles caught on cards, although the numbers were ultimately linked to the emergence period as further increases in temperature during June and July did not result in further deathwatch beetles being caught through walking or flying.

Evidence of biological control agents was limited to the predatory spiders and Clerid beetles that are known to be natural enemies of the deathwatch beetle (Hickin, 1963). The absence of other biocontrol agents from the survey methods used could be because: 1) There are no other biological control arthropods of the deathwatch beetle; 2) Other biological control agents occur in forests or in other building habitats not investigated or 3) Other biological control agents were present but were not discovered by the methods implemented. Investigation into forest habitats where the deathwatch beetle can be found may prove more fruitful in identifying other biological control organisms.

Spiders comprised a large percentage of the arthropods caught on cards in all buildings and have been observed to feed upon deathwatch beetle adults. In Bishopstone Church, the increasing percentage over time of deathwatch beetles caught by spiders relative to the total number of deathwatch beetles collected is arguably due to a combination of increasing temperature, increasing numbers of spiders resident in the building, and a decreasing deathwatch beetle population. The mean percent of deathwatch beetles caught by Pholcid spiders over the monitoring periods would argue that they could be an effective control organism. Capture efficiencies have been determined for some species of spider (Sunderland *et al*., 1986; Uetz, 1992), and the polyphagous nature of spiders has been argued to make them less than ideal as candidates for control agents (Dent, 1991). However, the cyclical nature of the emergence of deathwatch beetle adults would cause problems for the establishment of classical biological control where predator and prey reach a stable equilibrium, and therefore, biocontrol of adult deathwatch beetles would require an augmentative approach that could cope with the explosive nature of the emergence period where spiders may be of use. The number of predatory *Korynetes caeruleus* caught was low, and its impact upon the deathwatch beetle remains obscure. Maxwell-Lefroy (1924) first suggested that larvae of *Korynetes caeruleus* feed upon deathwatch beetle larvae. Further work (Hickin, 1963) on the predatory behaviour of *K. caeruleus* suggested that the larvae followed pre-existing bore tunnels searching for deathwatch beetle larvae inside the timber. Their predatory efficiency is unknown, but as the beetle has apparently established some level of natural biological control in buildings, augmentation and introduction of *K. caeruleus* into deathwatch beetle-infested buildings could lead to a possible biocontrol solution that attacks larvae deep within timber.

It is possible that the insects have evolved an attraction to white coloured objects (the cards in this case) because white is a common fungal body colour, supporting the proposed hypothesis that insects seek out fungally decaying timber (Belmain *et al*., 1998). However, the white cards may have been more attractive because they presented a stronger contrast to the surrounding timber (Conlon & Bell, 1991; Hughes, 1992), or appeared brighter than the other coloured cards (Kostal, 1991). The fact that the white cards do trap more deathwatch beetles than other coloured cards would suggest that at least some direct attraction is taking place. Further sticky trap research should ideally be aimed at determining trap efficacy (Hagstrum *et al*., 1990; Wileyto *et al*., 1994). The trapping results showed more insects were trapped in the light. However, this could be due to the relative apparency of these traps as traps in darker areas may not be as visible to the insect. The uneven distribution of trapped insects in the light and dark could also result from other environmental effects such as differences in infestation levels. Evidence of deathwatch beetle attraction to light was additionally shown through their attraction to the UV light of the insectocutor. Further research in the laboratory has confirmed deathwatch beetle photo-response behaviour (Belmain *et al*., in press).

The number of species caught in the buildings using the different trapping methods suggests that Bishopstone Church had the most diverse roof ecology and Kew Palace had the least diverse habitat. However, we do not know enough about the specificity of the trapping methods used in this study to evaluate their efficiency in sampling the diversity of arthropods in roof areas (VelaCoiffier *et al*., 1997). In fact, if traps are to be used to monitor or control deathwatch beetles then we need to increase the proportion of deathwatch beetles caught. We are currently investigating whether the efficiency of the traps can be increased by incorporating reflective colours and volatile baits.

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