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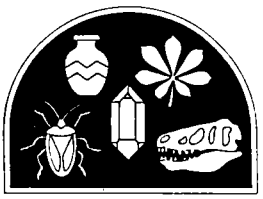

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A REVIEW OF PUBLISHED TEMPERATURES FOR THE CONTROL OF PEST INSECTS IN MUSEUMS

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Abstract.—Reported temperatures for the extermination and control of 46 museum insect pests are tabulated and graphed. Temperature and time of exposure found in publications recommending thermal control methods for museum use are tabulated for comparison to the mortality data from entomological literature. Miscellaneous control temperatures are also tabulated, providing information on chill-coma, feeding and developmental limits. A lethal boundary model is proposed as a provisional guide to thermal extermination of insect pests.

The use of thermal insect control techniques in museums and archives has been fostered by increased restrictions on, and costs of, fumigant and pesticide use. Thermal control methods are used when there is reticence to expose cultural property or museum personnel to proven or potentially deleterious chemical agents.

Adoption of thermal control techniques to replace pesticides is hampered by concerns that thermal techniques will fail to control insects. These concerns are due to the lack of available data on insect susceptibility to heat and cold, an awareness of some insects' capability to survive temperature extremes, a wariness of generalizations in literature, the need for justification of capital expenditure on new equipment, and suspected or known effects on artifacts and specimens.

In most of the recently published thermal control methods for museums, entomological literature is sparingly cited. Many of the earlier published recommendations were derived from experience with only a few species. Recommendations for controlling particular insect species have also been generalized in subsequent publications, so there is a danger of failure to control a species which was not included in the original recommendation.

This paper was written to address concerns rooted in the lack of comprehensive information on the thermal mortality limits of museum pest insects. Thermal mortality data are presented as a provisional guide for users of temperature extremes to control insects. The data are also provided for potential users of thermal insect control who require evidence of efficacy. Control methods from conservation and museology literature are reviewed and compared to an extensive source of entomological literature on temperature sensitivity of museum pest insects. The data on thermal limits to the insects are organized in the Appendix to this paper and provided as a basis for further study or individual need. This paper is restricted to a discussion of museum pest insects and excludes theorized and described effects on materials.

DATA

The food processing and storage industry has used thermal insect control methods for nearly a century (Mullen and Arbogast, 1984; Sheppard, 1984). This application has initiated many studies of temperatures lethal to insects as well as

Table 1. Fatal and limiting temperatures for museum pest insects.

Species	Temperatures that limit breeding & development (°C)	Lethal temperatures	
		Low temp. (°C)	High temp. (°C)
Coleoptera: Anobiidae			
Anobium punctatum (De Geer)[1]	30[2]	−16[3]	48[4]
Gastrallus sp.[5]		−29[6]	
Lasioderma serricorne (Fabricius)[7]	16[8]	−12[9]	49[10]
Stegobium paniceum (L.)[11]	17[12]	−18[13]	49[14]
Coleoptera: Bostrychidae			
Rhyzopertha dominica (Fab.)[15]	23[16]	−1[17]	
Coleoptera: Cerambycidae			
Hylotrupes bajulus (L.)[18]			56[19]
Coleoptera: Cucujidae			
Laemophloeus ferrugineus (Steph.)[20]	15[21]	−6[22]	
Oryzaephilus mercator (Fauvel)[23]	15[24]		
Oryzaephilus surinamensis (L.)[25]	17[26]	−18[27]	52[28]
Coleoptera: Curculionidae			
Sitophilus granarius (L.)[29]	2[30]	−18[31]	54[32]
Sitophilus oryzae (L.)[33]	5[34]	−18[35]	54[36]
Coleoptera: Dermestidae			
Anthrenus flavipes LeConte[37]		−18[38]	above 40[39]
Anthrenus museorum (L.)[40]	4[41]	below −20[42]	
Anthrenus scrophulariae (L.)[43]	4[44]		
Anthrenus verbasci (L.)[45]	14[46]	−20[47]	above 40[48]
Attagenus pellio (L.)[49]		−18[50]	52[51]
Attagenus unicolor (Brahm)[52]	10[53]	−24[54]	above 41[55]
Dermestes coarctatus Harold[56]			55[57]
Dermestes lardarius L.[58]	15[59]	below −2[60]	54[61]
Dermestes maculatus De G.[62]	8[63]	−23[64]	60[65]
Dermestes vorax Motschulsky[66]		−15[67]	
Reesa vespulae (Milliron)[68]		−20[69]	
Trogoderma granarium Everts[70]	15[71]	−19[72]	60[73]
Trogoderma versicolor (Creutzer)[74]	20[75]	below −2[76]	
Coleoptera: Lyctidae			
Lyctus africanus Lesne[77]			54[78]
Lyctus brunneus (Stephens)[79]			58[80]
Lyctus planicollis LeConte[81]			55[82]
Coleoptera: Ptinidae			
Ptinus tectus (Boieldieu)[83]	10[84]	below −8[85]	
Coleoptera: Tenebrionidae			
Tenebrio molitor (L.)[86]		−18[87]	52[88]
Tenebrio obscurus (Fab.)[89]		−18[90]	52[91]
Tribolium castaneum (Herbst)[92]		−10[93]	
Tribolium confusum Jacq. duVal[94]	21[95]	−20[96]	54[97]

Table 1. Continued.

Species	Temperatures that limit breeding & development (°C)	Lethal temperatures	
		Low temp. (°C)	High temp. (°C)
Hymenoptera: Formicidae			
Camponotus herculeanus L.[98]		−29[99]	
Camponotus obscuripes (I.)[100]		−10[101]	
Camponotus pennsylvanicus (De G.)[102]	0[103]		
Isoptera: Kalotermitidae			
Cryptotermes brevis (Walker)[104]		−34[105]	
Incisitermes minor (Hagen)[106]		−20[107]	51[108]
Lepidoptera: Tineidae			
Tineola bisselliella (Hummel)[109]	9[110]	−18[111]	49[112]
Lepidoptera: Pyralidae			
Anagasta kühniella (Zeller)[113]	8[114]	−18[115]	
Ephestia elutella Hübner[116]		−16[117]	64[118]
Plodia interpunctella (Hübner)[119]	18[120]	−17[121]	
Orthoptera: Blattellidae			
Blattella germanica (L.)[122]			45[123]
Orthoptera: Blattidae			
Blatta orientalis L.[124]	2[125]	−8[126]	46[127]
Periplaneta americana (L.)[128]		−15[129]	45[130]
Thysanura: Lepisimatidae			
Lepisma saccharina L.[131]	4[132]		37[133]
Thermobia domestica (Packard)[134]	22[135]	0[136]	55[137]

the economics and implementation of thermal control methods. Several authors have described utility to household sanitation. The major sources for finding papers with mortality data for this study were: Hinton (1945), Solomon and Adamson (1955), Mathlein (1961), Cornwell (1968), Story (1985), and Dawson (1987). The major sources for insect selection, nomenclature and authorship for this study were: Hinton (1945), Schrock (1988), Hickin (1985), Dillon and Dillon (1972) and Kingsolver (1988).

Table 1 is an index to larger sets of data from the entomological literature on the thermal limits of 46 species of insect pests which affect museums, galleries, and archives. The reference numbers correspond to notes in the Appendix. The values in Table 1 are only representative temperatures chosen from the full listing in the corresponding note. When known, the common names for each species are listed in boldface type in the Appendix. The Appendix can be scanned to find species with the desired common name. Note that identical common names are sometimes applied to more than one species listed in the Appendix.

Under the heading "Lethal temperatures," all values are for 100% mortality unless otherwise noted. When 100% mortality data were not available, the most extreme, albeit ineffective lethal temperatures for that insect are reported and marked as "above" or "below" that temperature. One would have to extend the

Table 2. High temperature control recommendations for extermination of insect pests.

Temperature (°C)	Time (hours)	Reference
49	4	Webster 1883, in Dean 1911[138]
52 to 66	—	Howard and Marlatt 1902[139]
60	—	Prümers 1905, in Rathgen 1924[140]
48 to 50	—	Dean 1911[138], 1913a[141]
52	—	Headlee, in Dean 1913a[141]
50 to 55	1 to 2	Goodwin 1914[142]
60	—	Holt 1917[143]
49 to 60	several	Back 1920[144]
52 to 60	8 to 10	Guyton 1926[145]
52 to 60		Back and Cotton 1926a[146]
60 to 70	24	Zacher 1927[147]
49	0.5	Clark 1928[148]
60	6	Gibson and Twinn 1929[149]
54	6 to 12	Leechman 1931[150]
77	5	Schlossberg, in Back and Cotton 1931[151]
60	4	Austen and McKenny Hughes 1932[152]
60 to 63	6	Cressman 1935[153]
77	4 to 5	O'Neill 1938[154]
54	12	Back 1947[155]
60	4	Wood 1956[156]
52 to 60	3 to 50	Forest Product Res. Lab. 1962[157]
49 to 54	10 to 12	Cotton 1963[158]
60 to 70	0.2	Cotton 1963[158]
49 to 55	12	Munro 1966[159]
60	12	Yonker 1985[160]
55	3	Parker 1987[161]
51	2 to 4	Forbes and Ebeling 1987[162]
49	0.5 to 6	Ebeling, Forbes and Ebeling 1989[163]
42	—	Watling 1989[164]
55	—	Anonymous 1990[165]

exposure or change the temperature in the indicated direction to achieve 100% mortality.

The values listed under "Temperatures that limit breeding and development" in Table 1 indicate temperatures that, while not necessarily eradicating an infestation, can prevent damage or eventually lead to decline of a population by interrupting breeding or feeding activity.

Note that values reported in Table 1 do not always represent control temperatures for all stages as, sometimes, only data for a few stages of the life cycle are available. Table 1 is used to index further data in the Appendix notes. Some of the values listed in the notes are contradictory. This is possibly due to unreported conditions such as strain variability, differing amounts of insulation that affect cooling rates, and humidity. The notes in the Appendix contain information on the insect stage, exposure time, mortality (only stated if not 100%) and the source of the information; the exposure time is usually the shortest exposure reported for 100% mortality. The information in the Appendix should be consulted before designing a thermal eradication temperature schedule for any specific insect.

Values reported in literature as general recommendations for control of an insect were not included in notes to Table 1 when there were no data or citation of an

Table 3. Low temperature control recommendations for extermination of insect pests.

Temperature (°C)	Time (hours)	Reference
−8, warm, −8	—	Read, cited in Howard 1896[166]
−10, warm, −10	—	Runner 1919[167]
−8, +10, −8	longer than 72	Back 1923[168]
−18	48	Back and Cotton 1926a[146]
below −18	12–24	Gibson and Twinn 1929[149]
below −18	longer than 24	Leechman 1931[149]
−18	—	Back and Cotton 1931[151]
below −6	720	Bovingdon 1933[169]
−11	204	Swingle 1938[170]
−18	—	Back 1947[155]
−8, +10, −8	—	Rice 1968[171]
−23	48	Remington, cited in Edelson 1978[172]
−10, −30	—	Toskina 1978[173]
−46	0.25	Appleby and Farris 1979[174]
−20	24	Arevad 1979[175]
−18	48	Crisafulli 1980[176]
−18	—	Moore 1983[177]
−40	24	Smith 1984[178]
−29	72	Nesheim 1985[179]
−18	96 to 120	Yonker 1985[160]
−20	48	Florian 1986[180], 1990[181]
−20	48	Norton 1986[182]
−20	0.5	Forbes and Ebeling 1986[183]
−35	72	Stewart 1988[184]
−25	72	Lawson 1988[185]
−20	336 to 504	Brokerhof 1989[186]
−20	168	Preiss 1990[187]
−20	40	Younghans-Butcher and Anderson 1990[188]
−20	48	Wilson 1990[189]

experiment. This was done to reveal lack of data for insects and reveal areas for research. When specific insects are reported to be exterminated by testing one of the general recommendations, the time and temperature data were included in notes to Table 1.

Tables 2 and 3 list thermal control methods in chronological order of their publication. Reference numbers refer to notes in the Appendix which give summaries of the techniques. Table 2 contains published recommendations for elevated temperature control, primarily for pests of museums, herbaria and archives, stored food products, furniture and structures. Table 3 contains the literature recommendations for low temperature control, primarily for pests of museum and archives. In Tables 2 and 3 some of the noted times refer to killing insects which were insulated within an infested object, while others note time required to kill uninsulated insects. The experimental apparatus is infrequently described in many of the sources.

Table 4 lists reported instances of failure to control insects when following recommended procedures. Some of the recommendations in Tables 2 and 3 are presented as minimum measures by the authors who, in this way, recognize the potential for failure, although very few discuss failure directly.

Table 4. Failure to control an insect by thermal methods.

Temperature (°C)	Time (hours)	Reference
−18	48	Stansfield 1985[190]
−18	24	Watling 1989[164]
−30	24	Brokerhof 1989[191]
−26	40	Brokerhof 1989[191]

Discussion

The data for 100% mortality found in the notes to Table 1 are shown in a plot of temperature against exposure time in Figure 1. Data for 46 species are shown; the upper cluster represents the conditions required to kill 26 insect species using heat, and the lower grouping shows exposure to low temperature required to kill 32 species. To aid comparison, Figure 1 is plotted in subsequent graphs and noted as 100% mortality in their keys.

As many of the researchers cited appear to have inspected their subjects at daily or longer intervals, it is likely that they have not always reported a minimum time of exposure to attain 100% mortality. This bias forces Figure 1 to be somewhat conservative. Similarly, any insulation or growth media in the experimental apparatus adds additional conservative bias by slowing the cooling rate and possibly allowing the insects time to increase their ability to survive. Rates of cooling are certainly different amongst the reviewed sources. However, in practice, cooling rates will never be uniform within mixed collections that may be subjected to low temperature control measures, and the aggregate data of Figure 1 represents this fact because of the unstandardized range of cooling rates of the experiments. Aggregation of many experiments over time also tends to reduce the effect of different responses by strains of any one species. For the purpose of recommending a general eradication technique, all these biases are beneficial.

A negative bias is the lack of data for some species, as is revealed by Table 1. Contributing to this is the occasional lack of experiments at the lower temperature commonly achieved by modern freezers. Illustrating these areas of missing information is one of the aims of this paper.

The shape of the lower cluster indicates that as temperature drops, less time is required to kill insects. The spread of this cluster illustrates the ability of many museum pests to survive lowered temperature for a considerable period of time.

In contrast, the high temperature cluster is much more tightly grouped, indicating that all stages of these insects have a lesser resistance to high temperatures than to low. At temperatures above 40°C, 100% mortality is achieved within a day for the cited species.

Figure 2a shows the recommended control methods (shown by solid horizontal lines) that have been published for eradication of insects using high temperature (Table 2) superimposed over the 100% mortality data from Figure 1. Figure 2b shows similar data from Table 3 superimposed on the low-temperature data from Figure 1. Note that the scales on the graphs vary in order to show the distribution of points more clearly. In both Figure 2a and 2b, to the right of the data cluster and overlying horizontal lines representing recommended exposures to kill insects,

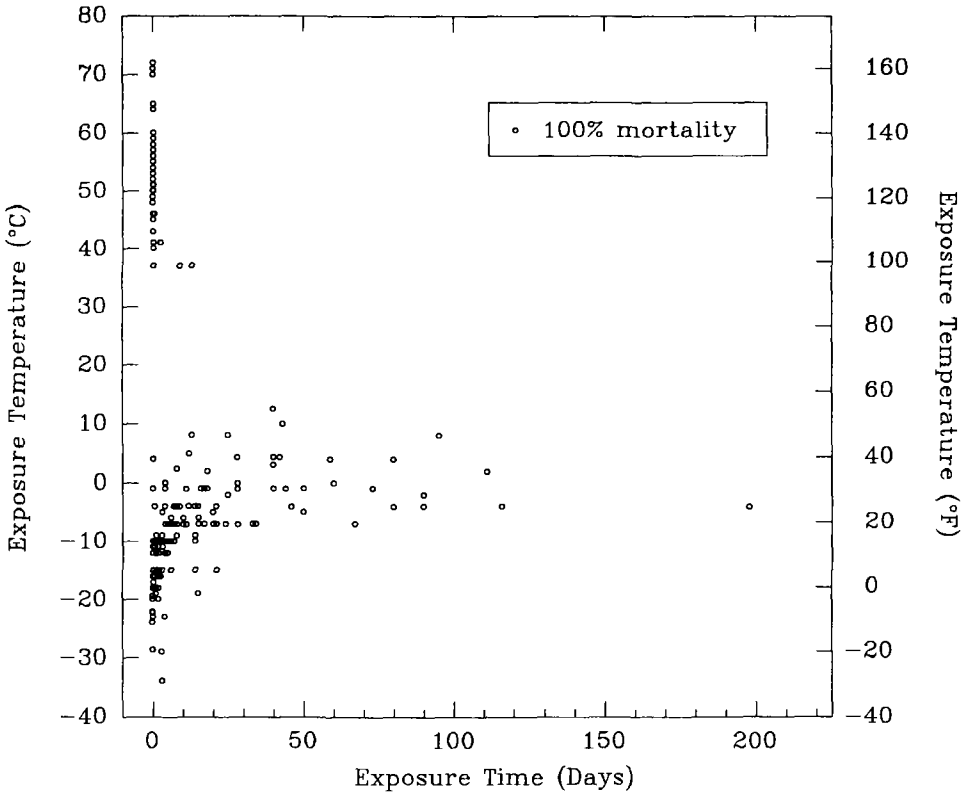

Figure 1. Thermal mortality of 46 museum pest insect species (Table 1).

a heavy solid line indicates what is described in this paper as the "lethal boundary." The lethal boundary is the approximate limit of the 100% mortality data.

The control methods shown in Figure 2a and 2b were generally developed from data from the entomology literature for a restricted number of species. It is, therefore, to be expected that the control methods bear some resemblance to the mortality data. Many of these recommended conditions, however, fall short of the lethal boundary in Figure 2b. This illustrates how failure to achieve complete eradication can result when such recommendations are extrapolated for use as a general preventive measure. A general method should embrace the mortality data of as many pest species as possible.

Another problem with the control methods is that they recommend fixed temperatures with no guideline to adapt to new coolants or other sources of variability, such as insulating effects of artifacts or the mechanical performance of refrigeration systems. The lethal boundary model facilitates adaptation to different temperatures.

The lethal boundaries of the data clusters marked by heavy lines in Figure 2a and 2b can serve as a provisional guide to thermal eradication of museum pest insects. Exposing infested material to temperature-time regimes that exceed these lethal boundaries should eradicate the listed insects. Any planned thermal control exposure should also include additional time needed to cool or heat the object.

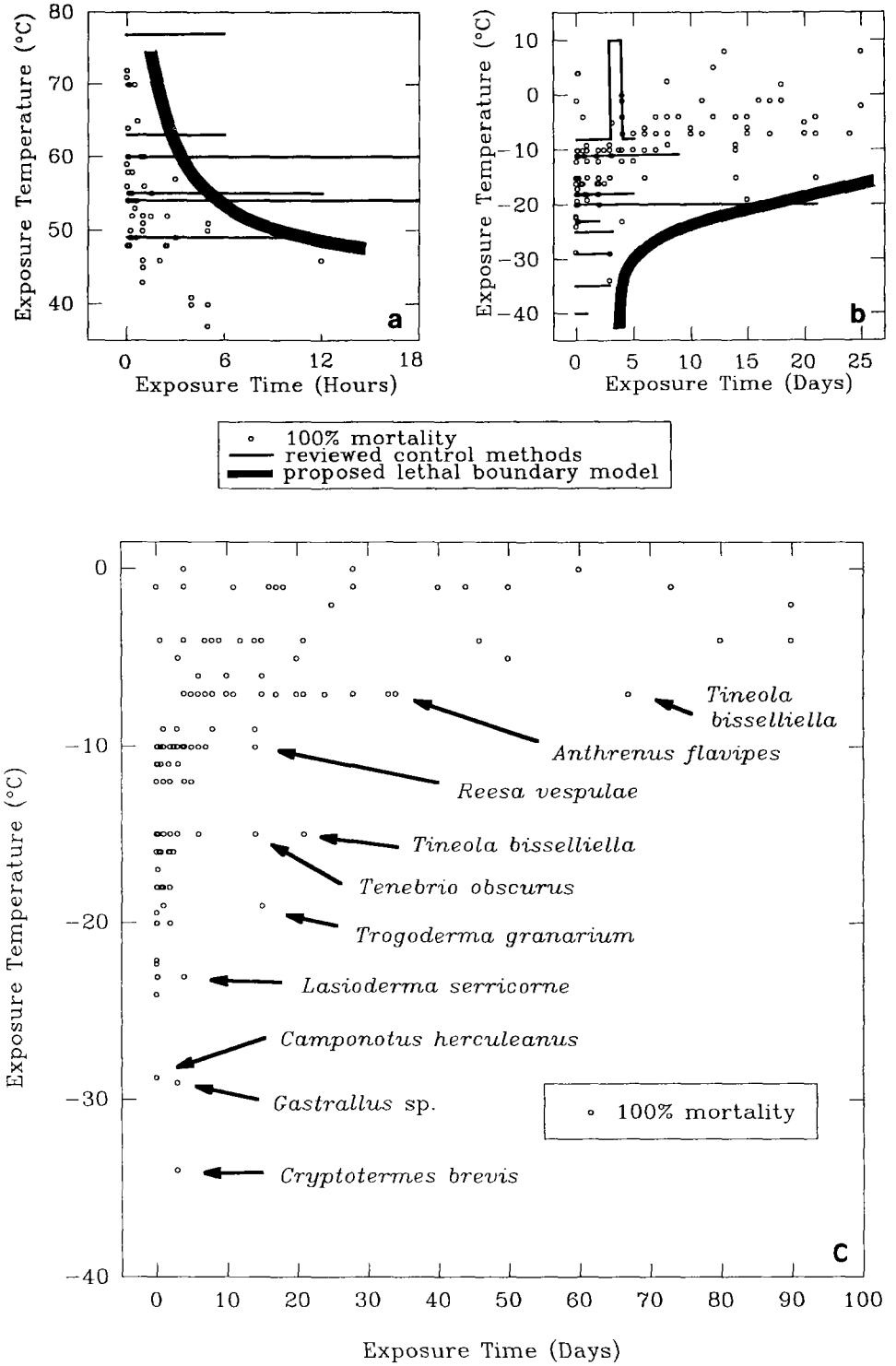

Figure 2. a. Reviewed thermal control recommendations: high temperature exposures (Table 2). b. Reviewed thermal control recommendations: low temperature exposures (Table 3). c. Species mortality data that defines the low temperature lethal boundary.

When the infesting insect is unknown, the lethal boundary model can provide a minimum recommendation that is already known to control many species.

Figure 2c shows points that define the low temperature lethal boundary labelled with species names. In general, the lower temperature points are successful treatments while the higher temperature points are efficacy data. *Cryptotermes brevis*[105] (Stewart, 1988[184]) and *Gastrallus* sp.[6] (Edelson, 1978[172]; Nesheim, 1985[179]) mark successful treatments of books in blast freezers and do not represent a minimum required exposure on unprotected insects. *Camponotus herculeanus*[99] notes a super-cooling point, the minimum temperature that conditioned insects sustained without freezing (Sømme, 1964). The point labelled *Lasioderma serricorne*[9] is an experimentally derived treatment schedule for tobacco products that ensured killing this species (Tenhet *et al.*, 1957). *Trogoderma granarium*[72] marks the exposure required to kill 400 to 500 larvae with no protective insulation (Mathlein, 1961). *Tenebrio obscurus*[90] labels the exposure required to kill larvae (Cotton and St. George, 1929). The points labelled *Tineola bisselliella*[111] are exposures required to kill larvae (Back and Cotton, 1927). *Reesa vespulae*[69] notes the exposure required to kill larvae (Mehl, 1975). *Anthrenus flavipes*[38] marks the exposure required to kill larvae (Back and Cotton, 1926a).

Threshold temperatures that limit breeding and development of insects are noted in the second column of Table 1. These temperatures support such general recommendations as cooling objects to 10°C to stop larval feeding (Story, 1985) and are the basis of economic use of cold storage in the fur industry (Howard, 1896, 1897). Some of these limiting temperatures can be used to slow the rate of damage until the insects can be eradicated, for example, by chilling a room with air-conditioning. Such use of these temperatures may increase the insects' hardiness to cold, and most of the insects would usually revive on warming.

There is concern as to whether or not museum pest insects can adapt to and thus survive temperatures recommended for low and high temperature control. Solomon and Adamson (1955) relate increased resistance to cold elicited by non-lethal exposure in *Tineola bisselliella, Tenebrioides mauritanicus, Blattella germanica, Blatta orientalis* and *Sitophilus oryzae.* The reported increases in tolerance, however, do not exceed several degrees below non-acclimated controls and are included in the data graphed in Figure 1. In the work of Solomon and Adamson, the minimum reported exposure temperature was −15°C. Figure 1 shows longer survival at −15°C than at lower temperatures that are easily achieved by modern refrigeration. The adaptive responses reported in Solomon and Adamson appear to be minor when compared to the low temperature survival of insects that are not museum pests (−20° to −50°C, Storey and Storey, 1983).

While few of the experiments reviewed in this paper were specifically designed to reveal acclimation, there are no examples of museum pest insects exhibiting a high degree of either freeze tolerant or freeze avoidant behaviours that would prevent their death below −20°C, with the exception of *C. herculeanus*[99]. There is no evidence for the ability for museum pest insects to adapt to temperatures higher than 50° to 60°C (Evans, 1986).

The majority of the low temperature data collated in this paper are for single periods of exposure to a low temperature. Leechman (1931) appears to have been the first to recommend this control of insect pests in museums. However, there are reports for three insect species describing the results of repeated exposure to

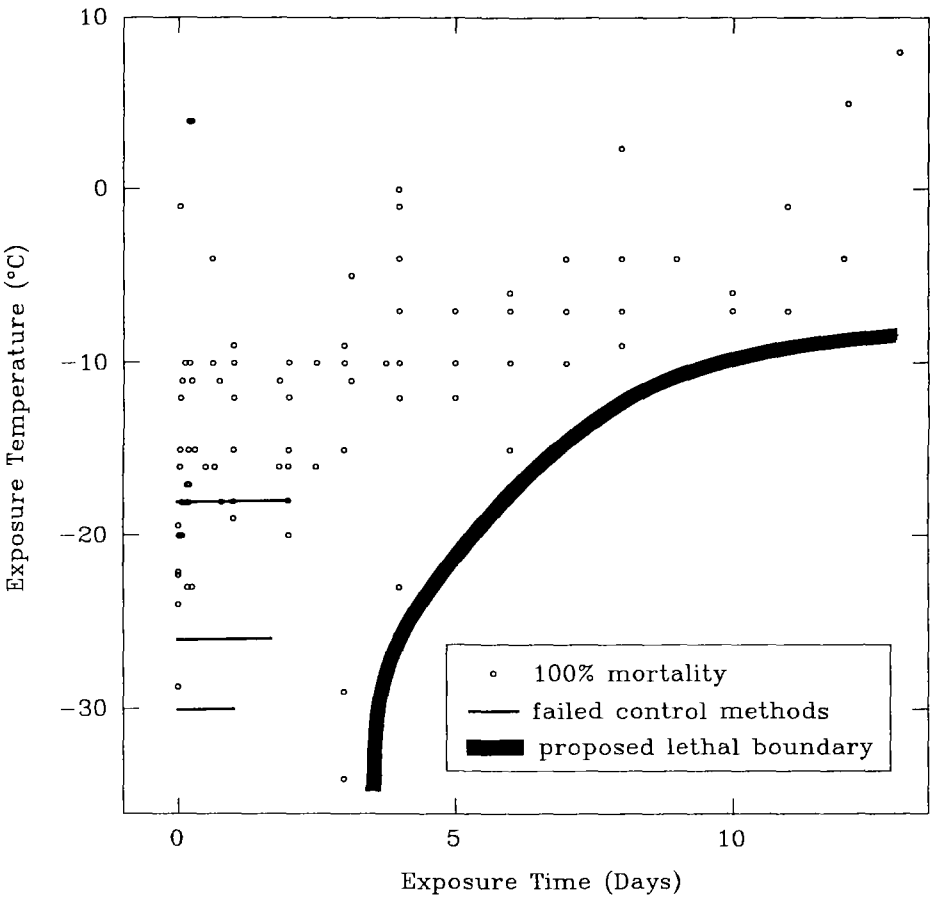

Figure 3. Reviewed thermal control recommendations: failure to control (Table 4).

regimes that did not cause 100% mortality with one exposure. In these experiments increased mortality or complete extermination during the subsequent exposures were noted: *Tineola bisselliella* (A. M. Read, cited in Howard, 1896[111,166]), *Lasioderma serricorne* (Runner, 1919[9,167]), and *Trogoderma granarium* (Voelkel, 1924[72]). Repeated exposure was first incorporated in a general recommendation for the disinfecting of wool and fur goods by Howard (1896), for combating household pests by Back (1923), for the preservation of museum textile collections by Rice (1968), and most recently by Florian (1986). Repeated exposure may require additional handling of the infested goods, however, it would be a useful procedure in combating these three species if one cannot use a lower temperature that achieves 100% mortality in a single exposure.

Reports of failure to control by low and high temperature exposure rarely appear in the literature discussing thermal control methods (see Table 4), but this cannot be taken as proof of efficacy. Figure 3 compares reported failures to the thermal mortality data. In all instances, exposure times fell short of the lethal boundaries proposed in this paper. The insects which these treatments failed to control include *Tineola bisselliella, Stegobium paniceum, Trogoderma granarium, Lasioderma*

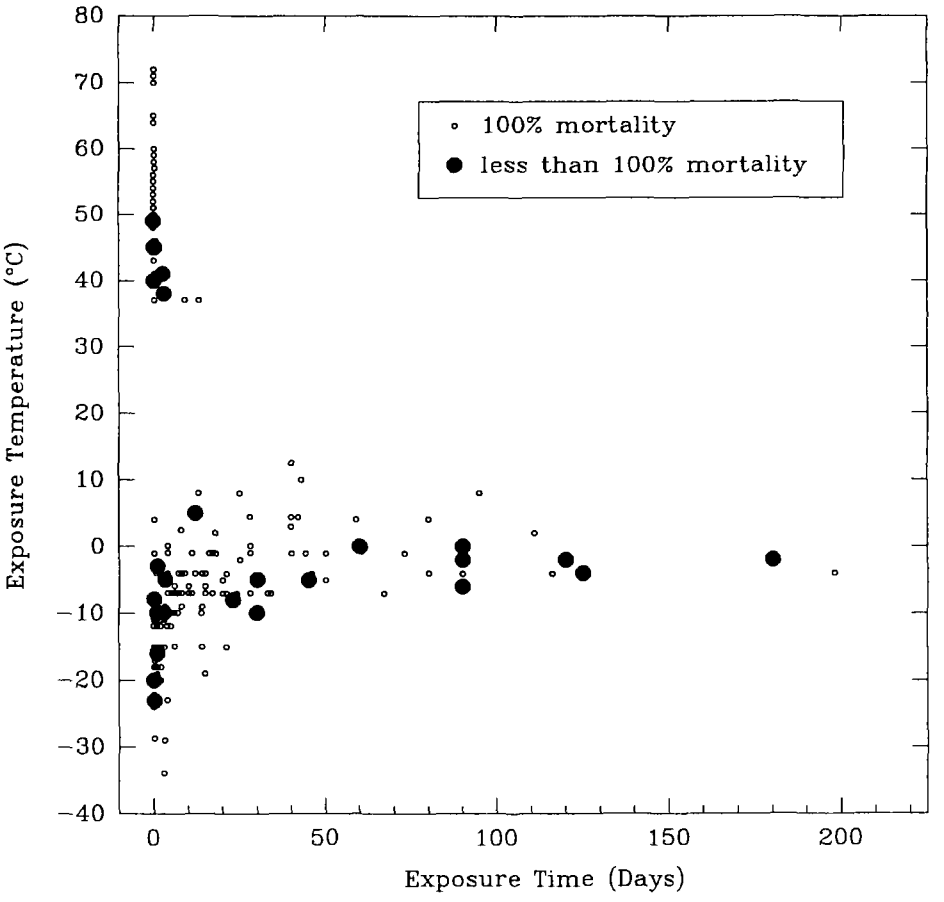

Figure 4. Distribution of less than 100% mortality data for museum pest insect species.

serricorne and *Anthrenus* species[164,190,191]. In actual museum applications, reinfestation could wrongly be attributed to inadequate exposure; therefore, rigor in treatment methodology, post treatment investigation, and publication are necessary.

Figure 4 shows the distribution of thermal exposures which have been reported as resulting in less than 100% mortality in insect populations. This incorporates the data noted by the words "above" and "below" in Table 1 and in the Appendix. The upper cluster indicates that a provisional threshold for high temperature eradication lies above 50°C. The lower cluster emphasises the need for temperatures below −10°C and certainly below −20°C when relatively short exposures are required.

Comparing Figures 3 and 4 indicates that a conservative approximation of the lethal boundary is required for treating infested objects. The incursion into the region below −20°C by control failures (Fig. 3) and less than 100% mortality data (Figure 4) show that, even below −20°C, several days exposure will be required.

A method to account for thermal insulation of objects is also necessary and can be empirically determined by temperature-time measurements of test objects in

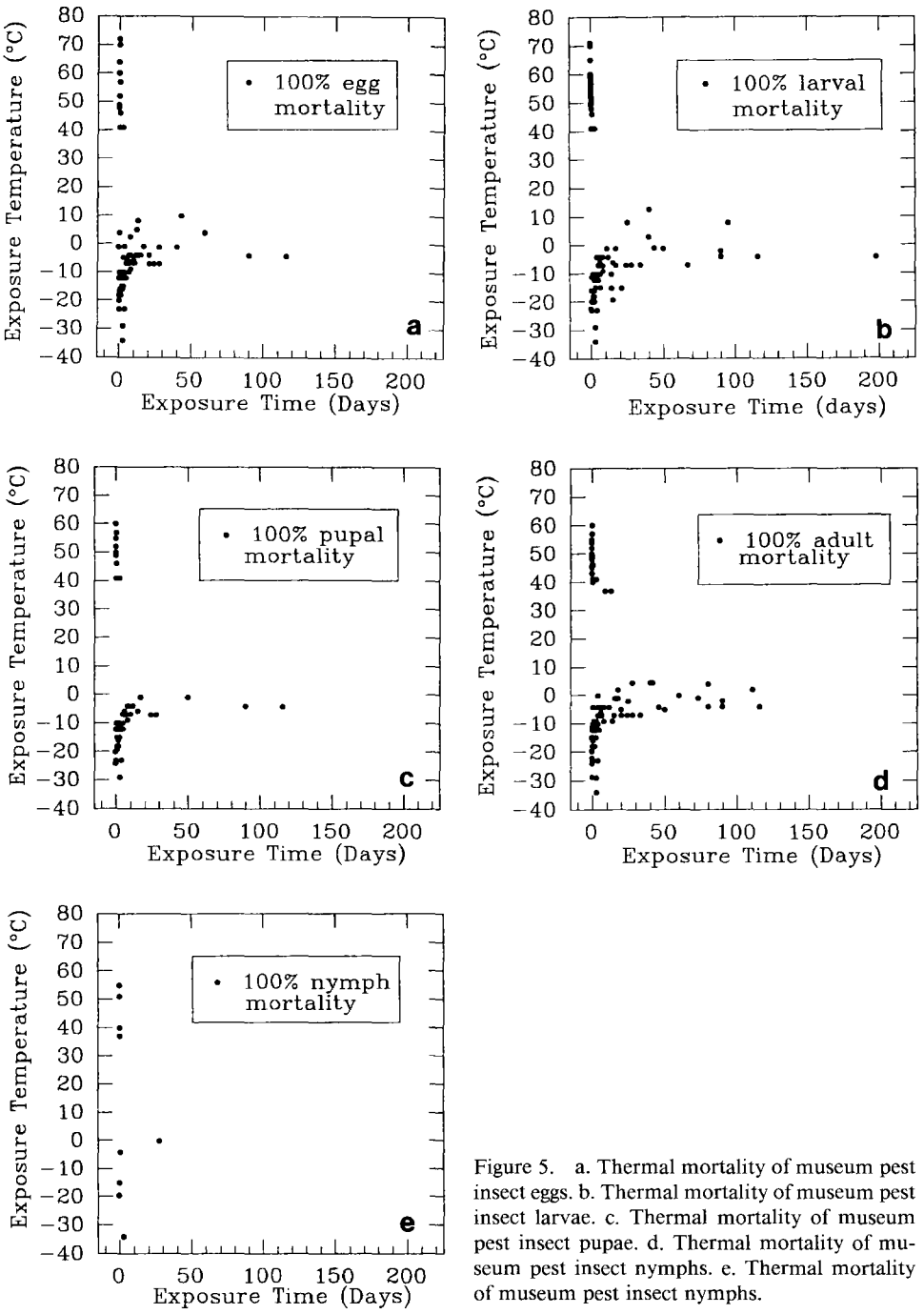

Figure 5. a. Thermal mortality of museum pest insect eggs. b. Thermal mortality of museum pest insect larvae. c. Thermal mortality of museum pest insect pupae. d. Thermal mortality of museum pest insect nymphs. e. Thermal mortality of museum pest insect nymphs.

the cooling or heating system, or calculated when physical constants are known for the materials.

The data were also grouped by developmental stage and plotted in Figure 5a to 5e. In aggregate, larvae are somewhat better adapted than other stages to survive

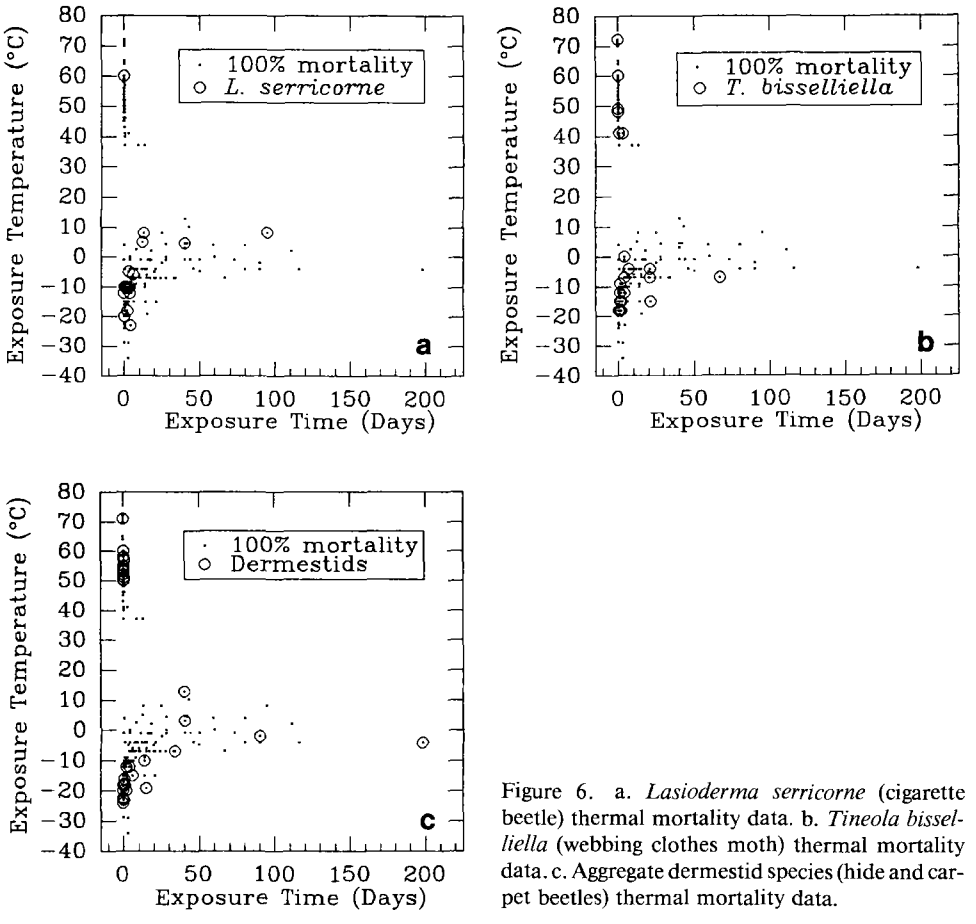

Figure 6. a. *Lasioderma serricorne* (cigarette beetle) thermal mortality data. b. *Tineola bisselliella* (webbing clothes moth) thermal mortality data. c. Aggregate dermestid species (hide and carpet beetles) thermal mortality data.

temperatures in the range of −10° to −20°C (Fig. 5b). The larval stage is often the most damaging. It is encouraging to note that eggs (Fig. 5a) are generally less able to survive than larvae, since eggs are often harder to detect due to their small size, lack of motion and cryptic placement. Pupae exhibit temperature tolerances similar to eggs (Fig. 5c).

When the specific pest insect is identified, and if sufficient mortality data exist, a tailored thermal control method can be proposed. Figure 6a and 6b show the 100% mortality data for two common museum pests superimposed on the general 100% mortality data from Figure 1. The cluster in Figure 6a illustrates that *Lasioderma serricorne* is more susceptible to low temperature mortality than the lethal boundary of the aggregate data would indicate. *Lasioderma serricorne* can be controlled by warmer temperatures or shorter exposures than those proposed by the lethal boundary (cf. the recommendation of Crisafulli, 1980[176]). This is in contrast to the cluster in Figure 6b for *Tineola bisselliella* and Figure 6c for dermestid species, both of which contribute to the lethal boundary in the aggregate low temperature data.

Conclusion

Data accumulated over the last century show that low and high temperature control of insect pests can be very effective. Extending the data on the thermal limits of the listed insects would increase confidence for eradicating infestations of any one species; however, researchers must be mindful of population and strain variability, must investigate the potential of the population to acclimate, and must include systematic identification of the examined species. Investigation and publishing on pest insects not listed here is also encouraged. Cooperation among interested parties with systematists, stored product pest laboratories, extension entomologists and cryobiologists is productive. Similarly, continued documenting and publishing of successful and failed control attempts is important to the museum community.

The lethal boundary model is offered as a provisional guide for lethal exposure where the right boundaries of the two data clusters as delineated in Figure 2a and 2b describe the minimum time and temperature for thermal control. The thermal mortality data are provided as a guide to set recommendations for the thermal eradication of insect pests in museums. Increased exposure time to compensate for the insulating properties of infested materials should be made when determining the length of exposure.

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Appendix

The following notes give detailed information on insect mortality data in Table 1, and annotate references in Tables 2, 3, and 4.

Entries on insect mortality use the following format: Insect stage, temperature in Celsius, relative humidity (if stated), exposure time, mortality (only noted if not 100%); further data in this format, source. The first entry in each note is the source for temperatures cited in Table 1. Temperatures that were converted from Fahrenheit to Celsius or reported as decimal fractions have been rounded to the nearest degree.

1. *Anobium punctatum* (De Geer). **Furniture beetle, common furniture beetle, woodworm, house-borer.** Previously *A. striatum* (Olivier) and *A. domesticum* (Geoffroy).
2. Adult female egg laying capability destroyed, 30°C, several days (Toskina, 1978).
3. Larvae, −16° to −17°C, 48 hours (Parfentiev, 1947).
   Larvae, −5° to −30°C, 3 months outdoor exposure (Toskina, 1978).
4. Larvae, 48°C, 150 minutes; 54°C, 30 minutes; 58°C, 20 minutes (Becker and Loebe, 1961).
   Larvae, 54°C, 1 minute; 50°C, 16 minutes; 49°C, 32 minutes (Cymorek, 1971).
   Eggs, 34°C (Toskina, 1978).
5. *Gastrallus* sp. **Unidentified anobiid.** C. L. Remington, cited in Nesheim (1985).
6. All stages, −23°C, 6 hours, 99% mortality, −29°C for 72 hours was the adopted treatment for books (Remington, cited in: Rasie, 1977; Nesheim, 1985).
7. *Lasioderma serricorne* (Fabricius). **Cigarette beetle.**
8. Feeding stopped, 16° to 18°C (Tenhet *et al.*, 1957).
   Adults inactive below 18°C (Runner, 1919).
   Eggs and young larvae non-viable in prolonged storage, 10° to 16°C (Crumb and Chamberlin, 1934).
   Minimum for population develpoment, 22°C (Howe, 1965).

9. Eggs, −12°C, 1 hour; adults, 4.4°C, 40 days (Strong, 1936).
Adults, pupae, larvae, −11° to −12°C, 4 days; −10° to −9°C, 4 days; eggs, −10°C, 24 hours (Runner, 1919).
All stages, rapid alternation of temperature, −9° to −10°C, 48 hours, room temperature for 24 hours, −9° to −10°C, 24 hours (Runner, 1919).
All stages, −5° to −10°C, 3 days; −3° to −6°C, 6 days (Skalov, 1931).
Eggs, −12°C, 1 hour; −10°C, 3 hours; larvae, −10°C, 60 hours; pupae, −12°C, 1 hour; −10°C, 3 hours; adults, −12°C, 1 hour; −10°C, 5 hours (Swingle, 1938).
Larvae and adults dead after three months between +10° and −2°C (Mansbridge, 1936).
All stages, −23°C, 4 days, in tobacco products; eggs, 8°C, 13 days; larvae, 8°C, 95 days (Tenhet *et al.*, 1957).
Eggs, 5°C, 290 hours; −5°C, 75 hours; −20°C, more than 1 hour, all the preceding cause 95% mortality (Mullen and Arbogast, 1979).
Larvae, pupae, adults, −18°C, 48 hours, treating herbarium material (Crisafulli, 1980).
10. All stages, 47° to 49°C (Goodwin, 1914).
All stages, 54° to 60°C, 1 hour (Runner, 1919).
All stages, 63°C air temperature in infested library, 6 hours (Cressman, 1935).
11. *Stegobium paniceum* (L.). **Drugstore, bread, or biscuit beetle.** Previously *Sitodrepa panicea* L.
12. Minimum for population development, 17°C (Howe, 1965).
13. Eggs, −18°C for 4 hours (Billings, personal communication in Florian, 1986).
Larvae and adults, three months between +10° and −2°C (Mansbridge, 1936).
Eggs, −20°C for 2 hours; larvae, pupae and adults, −20°C, 30 minutes (Gilberg and Brokerhof, 1991).
14. All stages, 47° to 49°C, not affected by humidity (Goodwin, 1914).
15. *Rhyzopertha dominica* (Fab.). **Lesser grain borer.**
16. Minimum for population development, 23°C (Howe, 1965).
17. Adults, conditioned at 16° to 13°C, −1°C, 18 days (Mathlein, 1961).
Adults, 4.4°C, six weeks (David *et al.*, 1977).
18. *Hylotrupes bajulus* (L.). **Old house borer, house longhorn beetle.**
19. Larvae, 56°C, 1 minute; 52°C, 20 minutes (Cymorek, 1971).
Larvae, 52°C, 150 minutes; 56°C, 65 minutes; 60°C, 50 minutes (Becker and Loebe, 1961).
20. *Laemophloeus ferrugineus* (Steph.). **Red rust grain beetle.**
21. Adult breeding limit, 15°C (Mathlein, 1961).
22. Adults, 0°C, 60 days; −5°C, 30 days; −7°C, 20 days (Mathlein, 1961).
23. *Oryzaephilus mercator* (Fauvel). **Merchant beetle, merchant grain beetle.**
24. Egg hatching limit, 15°C; larval development incomplete, 40°C (Howe, 1956).
25. *Oryzaephilus surinamensis* (L.). **Saw-toothed grain beetle.**
26. Lower limit for larval, pupal and adult development, 17°C (Mathlein, 1961).
Upper limit for larval development, 40°C (Howe, 1956).
27. All stages, −18°C, 1 day; −7°C, 1 week (Back and Cotton, 1926b).
Adults, −7°C, 15 days; −5°C, 20 days; −2°C, 25 days (Mathlein, 1961).
28. All stages, 52°C, 1 hour (Back and Cotton, 1926b).
Larvae, pupae, adults, 45°C (Goodwin, 1914).
29. *Sitophilus granarius* (L.). **Granary weevil.** Previously *Calandra granaria* L.
30. Adults, chill-coma temperature is 2°C when acclimated at 15°C, chill-coma temperature is 5°C when acclimated at 27°C (Evans, 1977b).
Eggs not laid above 34°C (Back and Cotton, 1924).
Minimum for population development, 15°C (Howe, 1965).
31. Eggs, −1°C, 28 days; larvae, −1°C, 44 days; adults, −18°C, 5 hours; −15°C, 7.5 hours; −9° to −7°C, 14 days; −7° to −4°C, 33 days; −4° to −1°C, 46 days; −1° to 2°C, 73 days; 2° to 4°C, 111 days (Back and Cotton, 1924).
Eggs 4°C, 59 days; −1°C, 40 days; −4°C, 15 days; −6°C, 10 days; larvae and pupae, −1°C, 50 days; −4°C, 30 days; −6°C, 15 days; adults, −4°C, 80 days; −7°C, 33 days (Mathlein, 1961).
32. Adults, 54°C, 0.5 hours; 49°C, 3 hours; 35° to 37°C, 13 days (Back and Cotton, 1924).
33. *Sitophilus oryzae* (L.) **Rice weevil.** Previously *Calandra oryzae* L.
34. Adults, chill-coma temperature is 5°C when acclimated at 15°C, chill-coma temperature is 8°C when acclimated at 27°C (Evans, 1977a).

Eggs not laid below 13°C or above 35°C (Birch, 1953).
Eggs not laid above 34°C (Back and Cotton, 1924).
Minimum for population development, 17°C (Howe, 1965).

35. Eggs, −1°C, 4 days; larvae, −1°C, 11 days; adults, −18°C, 4 hours; −15°C, 4.5 hours; −9° to −7°C, 3 days; −7° to −4°C, 6 days; −4° to −1°C, 8 days; −1° to 2°C, 16 days; 2° to 4°C, 18 days; 4° to 7°C, 80 days (Back and Cotton, 1924).
Adults, 4.4°C, 4 weeks (David *et al.*, 1977).
Eggs, −8.5° to −10°C, 90 hours; −4° to −6°C, 12 days; adults, −4° to −6°C, 4 days; −8.5° to −10°C, 15 hours (Ushatinskaia, 1950).
36. Adults, 54°C, 0.5 hours; 49°C, 3 hours; 35° to 37°C, 9 days (Back and Cotton, 1924).
All stages, 27°C increasing over 64 hours to 41°C (Kenaga and Fletcher, 1942).
Adults, 48°C, several minutes; 46°C, 12 hours (Dean, 1913b).
37. *Anthrenus flavipes* LeConte. **Furniture carpet beetle.** Previously *Anthrenus vorax* (Waterh.), *Anthrenus fasciatus* Herbst.
38. All stages, −18°C, 1 day; eggs, larvae and adults, −15° to −18°C, 1 day; larvae, −12° to −9°C, 2 days; −7° to −4°C, 34 days; adults, −12° to −9°C, 4 days (Back and Cotton, 1926a).
Adults and larvae survive −2°C all winter (Herfs, 1936).
39. Larvae, 40°C; pupae, 40°C, 40% RH; pupae, 40°C, 50% to 60% RH, 80% mortality (Herfs, 1936).
40. *Anthrenus museorum* (L.). **Museum beetle.**
41. Store skins at 4°C to prevent damage (Clark, 1929).
42. First instar larvae, adults, −20°C, 1 hour; eggs survived −20°C, 6 hours (Arevad, 1979).
Larvae survived −20°C, 2 hours (Arevad, 1974).
43. *Anthrenus scrophulariae* (L.). **Common carpet beetle, buffalo carpet beetle, buffalo moth, buffalo bug, old-fashioned carpet beetle, European carpet beetle.**
44. Storage to prevent damage, 4° to 6°C (Howard and Marlatt, 1902).
45. *Anthrenus verbasci* (L.). **Varied carpet beetle, buffalo carpet beetle.**
46. Cold torpor, 14°C (Harrison, 1944).
47. Eggs, −20°C, 2 hours, some survived; pupae, −20°C, 30 minutes; adults, −20°C, 30 minutes (Arevad, 1979).
Larvae, −20°C, 1 hour (Arevad, 1974).
Eggs, −18°C, 2 hours (Billings, personal communication in Florian, 1986).
Larvae survived after three months between +10° and −2°C (Mansbridge, 1936).
48. Heat torpor and death, above 40°C (Harrison, 1944).
49. *Attagenus pellio* (L.). **Black carpet beetle, furrier's beetle.**
50. Eggs, −18°C for 4 hours (Billings, personal communication in Florian, 1986).
51. Eggs, larvae, 52°C, 20 minutes (Zacher, 1927).
52. *Attagenus unicolor* (Brahm). **Black carpet beetle.** Previously *Attagenus megatoma* (F.) and *Attagenus piceus* (Olivier).
53. Feeding ceases, 10°C (Yamada, 1939).
Adult and larval motion stopped, 6° to 7°C (Read, cited in Howard, 1896).
No eggs laid at 13°C (Griswold and Greenwald, 1941).
Larval growth ceases and pupation shortened, 15°C (Baker, 1982).
54. Larvae, −22°C, several minutes; pupae and adults, −24°C, several minutes (Salt, 1936).
Larvae, 3° to 9°C, 40 days (Read, cited in Howard, 1896).
Larvae, −4° to −1°C, 198 days (Back and Cotton, 1926a).
55. Adults, 90% mortality, 27°C increasing over 64 hours to 41°C, less fatal to immature stages (Kenaga and Fletcher, 1942).
56. *Dermestes coarctatus* Harold.
57. Larvae, pupae, adults, 50°C, 1 hour; 55°C, 15 minutes (Yokoyama, 1927).
58. *Dermestes lardarius* L., **Larder beetle, bacon beetle.**
59. Lower limit for pupal development, 15°C; no eggs laid above 30°C (Coombs, 1978; Jacob and Fleming, 1980).
Lower limit for copulation, 16°C (Kreyenberg, 1929), 15°C (Coombs, 1978).
Adults, chill-coma, −3°C, not killed with 24 hours exposure (Kreyenberg, 1929).
60. Larvae dead and adults survived after three months between +10° and −2°C (Mansbridge, 1936).
Larvae, 12°C, 40 days (Coombs, 1978).

61. All stages, 54° to 57°C, 3 hours (Tessier, 1941).
Eggs, larvae, 52°C, 20 minutes (Zacher, 1927).
62. *Dermestes maculatus* De G., **Hide beetle, leather beetle, tallow beetle.** Previously *Dermestes vulpinus* (Fabricius).
63. Larvae motionless at 4°C, feeding at 8°C, (Read, cited in Howard, 1896).
Lower limit for copulation, 16°C (Kreyenberg, 1929).
Minimum for population development, 20°C (Howe, 1965).
64. All stages, −23°C, 4 hours; −12°C, 48 hours (Ketcham, 1984). Larvae and adults dead after three months between +10° and −2°C (Mansbridge, 1936).
65. All stages, 60°C, 1 hour (Kimura and Takakura, 1919).
Eggs, larvae, pupae, adults, 45°C, 50% mortality, respectively, at 3 hours, 45 minutes, 4 hours, 3 hours (Rosenthal, 1938).
Eggs, larvae, 52°C, 20 minutes (Zacher, 1927).
Dermestes vulpinus (Fab.) destroyed by treating books at 52°C, (T. J. Headlee in discussion, Dean, 1913a).
66. *Dermestes vorax* Motschulsky.
67. Larvae, −15°C, six days (Dawson, 1984).
68. *Reesa vespulae* (Milliron). **Carpet beetle.**
69. Larvae, −20°C, 2 days; −10°C, 2 weeks (Mehl, 1975).
Larvae, −20°C, 1 hour (Arevad, 1974).
70. *Trogoderma granarium* Everts. **Khapra beetle.**
71. Larvae inactive, 6.5°C, feeding minimum, 15°C (Mathlein, 1961).
Larvae and egg development halted, 5°C (Zacher, 1927).
Larvae inactive, 8° to 10°C; adults inactive, 10°C; male fertility destroyed, −8°C, 30 hours; adult male, lower copulation limit 10°C, upper copulation limit 42°C (Voelkel, 1924).
Minimum for population development, 24°C (Howe, 1965).
Minimum for breeding between 20° and 25°C (Mathlein, 1961).
Larvae and egg development halted, 48°C (Zacher, 1927).
72. Larvae, −19°C, 15 days; −10°C, 30 days, 97.5% mortality; −6°C, 90 days, 23% mortality; −2°C, 180 days, 44.7% mortality (Mathlein, 1961).
Eggs, −18°C, 19 hours (Billings, personal communication in Florian, 1986).
Larvae, 4th instar most cold tolerant, −10°C, 50% mortality, 25 hours (Zacher, 1938).
Larvae, −10°C, 72 hours, 11% mortality; repeated fast cooling to −10°C, 25 hours, 73% mortality; compared with −16°C, 98% mortality, 24 hours; adults, −16°C, 16 hours, 100% mortality (Voelkel, 1924).
Larvae alive after three months between +10° and −2°C (Mansbridge, 1936).
73. Larvae, 50°C, 5 hours; 54°C, 20 minutes; 60°C, 4 minutes (Husain and Bhasin, 1921).
Mason (1924) states that 50°C allowed growth and also "at the anomalous temperature of 56°C."
Larvae, 50° to 51°C, 5 hours; 52°C, 1.5 hours; 53°C, 0.5 hours; 54°C, 20 minutes; 55°C, 10 minutes; 58°C, 5 minutes; 71° to 77°C, 1 minute; 82° to 100°C, 0.5 minutes (Zacher, 1927).
74. *Trogoderma versicolor* (Creutzer).
75. Development slowed at 20°C (Hadaway, cited in Solomon and Adamson, 1955).
76. Larvae alive after three months between +10° and −2°C (Mansbridge, 1936).
77. *Lyctus africanus* Lesne.
78. Larvae, 59°C, 1 minute; 54°C, 24 minutes (Cymorek, 1971).
79. *Lyctus brunneus* (Stephens). **Powderpost beetle.**
80. Larvae, 48°C, 145 minutes; 54°C, 35 minutes; 58°C, 20 minutes (Becker and Loebe, 1961).
Larvae, 49° to 65°C, 40 minutes, infested wood blocks and structures (Ebeling *et al.*, 1989).
Larvae, 56°C, 1 minute; 54°C, 20 minutes (Cymorek, 1971).
81. *Lyctus planicollis* LeConte. **Flat-necked powder post beetle, southern Lyctus beetle.**
82. Larvae, 55°C, 90 minutes in steam kiln; 38°C not effective in killing larvae after several days; 49°C dry heat not effective (Snyder and St. George, 1924).
83. *Ptinus tectus* (Boieldieu). **Australian spider beetle.**
84. Minimum for population development, 10°C (Howe, 1965).
85. Adults, −8°C, recover after short exposure (Hickin, 1985).
Larvae, −2°C, 90 days; −5°C, 50 days; conditioned 60 days at 0°C then exposed to −5°C for

45 days, 50% mortality; adults, −5°C, 30 days, 70% mortality; 0°C, 90 days, 77% mortality (Mathlein, 1961).

86. *Tenebrio molitor* (L.). **Yellow mealworm.**
87. Eggs, −1°C, 1 hour; larvae, −18°C, 24 hours; adults, −12°C, 24 hours (Cotton and St. George, 1929).
88. All stages, 52°C, 1 hour (Cotton and St. George, 1929).
89. *Tenebrio obscurus* (Fab.). **Dark mealworm.**
90. Eggs, −1°C, 1 hour; larvae, −18°C, 24 hours; −15°C, 14 days; pupae, −15°C, 24 hours; adults, −12°C, 24 hours (Cotton and St. George, 1929).
91. All stages, 52°C, 1 hour (Cotton and St. George, 1929).
92. *Tribolium castaneum* (Herbst). **Red flour beetle.**
93. All stages, −1°C, 17 days; −4°C, 8 days; −7°C, 5 days; −10°C, 1 day (Cotton, 1950).
94. *Tribolium confusum* Jacq. duVal. **Confused flour beetle.**
95. Minimum for population development, 21°C (Howe, 1965).
96. Adults, −18.5° to −19.4°C, 5 minutes (Forbes and Ebeling, 1986).
    Adults, −15°C, 1 hour (Knipling and Sullivan, 1957).
    Eggs, −17°C, 5 hours; 4°C, 6 hours (Adler, 1960).
    All stages, −1°C, 17 days; −4°C, 12 days; −7°C, 5 days; −10°C, 1 day (Cotton, 1950).
97. Adults, 46°C, 123 minutes; 54°C, 4 minutes (Forbes and Ebeling, 1987).
    Larvae, 49°C, 15 minutes (Dean, 1911).
    All stages, 46°C, 12 hours (Dean, 1913b).
98. *Camponotus herculeanus* L., **Carpenter ant.**
99. Workers, conditioned 12 weeks at 0°C, −28.7°C supercooling point; conditioned 2 weeks at 20°C, −22°C supercooling point (Sømme, 1964).
100. *Camponotus obscuripes* (I.).
101. Workers, males, −10°C, 3 days (Tanno, 1962).
102. *Camponotus pennsylvanicus* (De G.). **Black carpenter ant.**
103. Adults immobile below 0°C, gained glycerol in 6 days at 0° to 5°C, lost glycerol in 3 days at 20° to 25°C (Dubach *et al.*, 1959).
104. *Cryptotermes brevis* (Walker). **West Indian drywood termite.**
105. All stages, −34°C, 3 days (Stewart, 1988).
106. *Incisitermes minor* (Hagen). **Western drywood termite.**
107. Nymphs and alates, 5 minutes, −18.5° to 19.4°C (Forbes and Ebeling, 1986).
108. Nymphs, 51°C, 1 hour (Forbes and Ebeling, 1987).
109. *Tineola bisselliella* (Hummel). **Webbing clothes moth, clothes moth.**
110. Larval feeding ceases, 9°C; larval movement ceases, 4° to 6°C (Read, cited in Howard, 1896).
    Store at 4° to 6°C to prevent feeding. Developed larvae can survive one year at 4°C (Back and Cotton, 1927).
    Adults inactive below 13°C (Clark, 1928).
111. All stages, −18°C, 1 day (Back and Cotton, 1926a).
    Eggs, −18° to −15°C, 1 day; −15° to −12°C, 2 days; −12° to −9°C, 4 days; −7° to −4°C, 21 days; −4° to −1°C, 21 days (Back and Cotton, 1927).
    Larvae, −18° to −15°C, 2 days; −15° to −12°C, 21 days; −7° to −4°C, 67 days; −4° to −1°C, greater than 125 days (Back and Cotton, 1927).
    Adults, −18° to −15°C, 1 day; −15° to −12°C, 1 day; −12° to −9°C, 1 day; −9° to −7°C, 1 day; −7° to −4°C, 4 days; −4° to −1°C, 7 days (Back and Cotton, 1927).
    Adults, 0° to 4°C, 4 days; larvae survived −8°C, 23 days; larvae all died when cooled to −8°C, warmed to room temperature then returned to −8°C (Read, cited in Howard, 1896).
    Eggs, −18°C, 3 hours (Billings, personal communication in Florian, 1986).
    Larvae survived after three months between +10° and −2°C (Mansbridge, 1936).
    Eggs, 48°C, 12 minutes; 72°C, 4 minutes (Titschacks, 1922 in Rathgen, 1924).
112. All stages, 49°C, 11 minutes; 60°C water, immediately (Back, 1923).
    Adults and eggs, 100% mortality, larvae 90% mortality, 27°C increasing to 41°C over 64 hours (Kenaga and Fletcher, 1942).
    All stages, 70% RH, 41°C, 4 hours (Rawle, 1951).
    Eggs, 21°C, 1.5 hours of direct sunlight; adults, 21°C, several minutes, no measurement of the surface temperature given (Clark, 1928).

113. *Anagasta kühniella* (Zeller). **Mediterranean flour moth.** Also seen as *A. kuehniella,* and *A. kuhniella.* Previously *Ephestia kühniella.*
114. Adult, egg laying and breeding limits, 8°C; egg hatching limit, 10°C (Mathlein, 1961).
115. Eggs, conditioned at 0° to 4°C for 3 days prior to exposure, −18°C, 1 day; −10°C, 7 days; −7°C, 10 days; 10°C, 43 days; larvae, −19°C, 1 day; −10°C, 6 days; −7°C, 17 days; pupae, −19°C, 1 day; −10°C, 5 days (Mathlein, 1961).
Eggs, −4°C, 14 days; −7°C, 11 days; −11°C, 75 hours; −16°C, 60 hours; larvae, −4°C, 7 days; −7°C, 8 days; −11°C, 18 hours; pupae, −4°C, 9 days, −7°C, 10 days; −11°C, 44 hours; −16°C, 44 hours; adults, −11°C, 2 hours (Bovingdon, 1933).
All stages, −4°C, 116 days; −7°C, 24 days; −10°C, 7 days; −12°C, 4 days; −15°C, 3 days; −18°C, 1 day (Cotton, 1950).
116. *Ephestia elutella* Hübner. **Cacao moth, warehouse moth, cocoa moth.**
117. Eggs, −4°C, 7 days; −7°C, 7 days; −11°C, 18 hours; −16°C, 12 hours; larvae, −4°C, 4 days; −11°C, 6 hours; −16°C, 1 hour (Bovingdon, 1933).
118. Eggs, 70°C, 30 minutes; larvae and pupae, 70°C, 10 minutes (Noyes, 1930).
Larvae, 64°C, 5 minutes (Mokrzecki, 1930).
119. *Plodia interpunctella* (Hübner). **Indian meal moth.**
120. Minimum for population development, 18°C (Howe, 1965).
121. Eggs, −17°C, 4 hours; 4°C, 5 hours (Adler, 1960).
Eggs, 2.4°C, 192 hours (Cline, 1970).
Larvae, 8°C, 25 days (Stratil and Reichmuth, 1984).
All stages, −4°C, 90 days; −7°C, 28 days; −9°C, 8 days; −12°C, 5 days (Cotton, 1950).
122. *Blattella germanica* (L.). **German cockroach, steamfly.**
123. Adults, 45°C at 0% RH, 1 hour; 43°C at 90% RH, 1 hour (Gunn and Notley, 1936).
Adult males, 46°C, 1 hour (Forbes and Ebeling, 1987).
124. *Blatta orientalis* L. **Oriental cockroach, black beetle.**
125. Nymphs and adults, acclimated at 14° to 17°C, chill-coma at 2°C; acclimated at 30°C, chill-coma at 7.5°C (Mellanby, 1939).
126. Nymphs and adults, −4° to −8°C, 15 hours, acclimated at 15°C and 30°C (Mellanby, 1939).
127. Adults, 46°C at 0% RH, 1 hour; 43°C at 90% RH, 1 hour (Gunn and Notley, 1936).
Adults, 40°C, 4 hours, independent of humidity (Gunn, 1933).
128. *Periplaneta americana* (L.). **American cockroach.**
129. Nymphs and adults, −15°C, 1 hour (Knipling and Sullivan, 1957).
130. Adults, 45°C at 0% RH, 42°C at 90% RH, 1 hour (Gunn and Notley, 1936).
Adults, 99% mortality, 27°C increasing to 41°C over 64 hours, less fatal to immature stages (Kenaga and Fletcher, 1942).
131. *Lepisma saccharina* L., **Silverfish, fish-moth.**
132. Cold torpor, 4°C (Zacher, 1927).
133. Nymphs, 37° to 40°C, independent of humidity; adults and nymphs, greater than 32°C, a few hours (Sweetman, 1939).
134. *Thermobia domestica* (Packard). **Firebrat.**
135. No eggs laid above 42°C and below 29°C at 76% RH. Eggs do not hatch below 22°C or above 48°C, independent of humidity;
Nymphs do not mature below 22°C or above 47°C, independent of humidity (Sweetman, 1938).
Nymphs immobile below 0°C (Sweetman, 1938).
136. Nymphs, 0°C, 4 weeks (Sweetman, 1938).
137. Nymphs, adults, 55°C, 5 minutes (Sweetman, 1938).
138. Dean (1911) cited work of Webster in 1883 for eradication of *Sitotroga cerealella* (Angoumois grain moth) infestation. Heated a mill to 49°C for 4 hours to kill pests. Reported no ill effect on germination of grain after 8 hour exposure to 66°C.
139. Howard and Marlatt (1902) gave a general recommendation for destruction of "most" insects by exposure to 52° to 66°C. They also recommended the protection of goods by storage at 4° to 7°C.
140. Rathgen (1924) cited work by Prümers (1905) on the destruction of pests of wood and paper by heating at 60° to 70°C. Clothes moth pests were destroyed by "safe and inexpensive" use of 60°C heat. Rathgen (1924) also cites Titschacks' (1922) use of heat to kill *Tineola bisselliella* eggs, 48°C, 12 minutes; 72°C, 4 minutes.

141. Dean (1913a) used heat in grain mills. Approximately 18 hours exposure, heating to 46° to 54°C was effective in killing insect pests. Heating to 66°C for 30 hours did not damage wooden machinery. In discussion following Dean's paper, T. J. Headlee related the use of 52°C heat to kill *Dermestes vulpinus* (F.) in books.
142. Goodwin (1914) gave a general recommendation to eliminate cereal pests, 50° to 55°C for 1 to 2 hours. Revival of insects after several days of inactivity was noticed after sub-lethal heating.
143. Holt (1917) described good housekeeping practice. Used 60°C heat to disinfest dried foods. Used a damp towel and a hot iron to steam and kill carpet moths, with two further applications at weekly intervals to kill insects missed by the process.
144. Back (1920) recommended killing psocids (book lice) with 49° to 60°C heat for several hours.
145. Guyton (1926) describes superheating houses. Exposure to 52° to 60°C for 8 to 10 hours to get penetration, especially in stuffed furniture. This recommendation was given for *Attagenus unicolor* and *Anthrenus scrophulariae.*
146. Back and Cotton (1926a) described clothes moths, carpet beetles, psocids and tobacco beetles as common furniture pests, the first two being the more damaging. Life cycle, food preference, optimal temperatures for development and control measures discussed. Notes use of vacuum, dry cleaning, heat, cold, and gas fumigation to kill pests in furniture. 52° to 60°C recommended. Cites use of heat to exterminate bedbugs and flour mill pests. States "cold storage is excellent for either preventing injury or in actually killing the insects" then discusses use of cold weather to kill pests. Notes −15° to −18°C kills clothes moth and furniture carpet beetle stages in one to two days.
147. Zacher (1927) described the use of heat to combat insects. *Liposcellis divinatorius* (book louse), 50° to 60°C dry heat. *Dermestes lardarius, D. vulpinus, Attagenus piceus, A. pellio,* larvae and eggs, 52°C dry heat for 20 minutes; 67°C hot water for 5 seconds.
Gave a recommendation of 60° to 70°C for 24 hours to kill *Stegobium panicea.*
148. Clark (1928) reviewed control methods, fumigants, and mothproofing in the textile industry. Cited control temperatures: moths, all stages, 49°C, 11 minutes; some dermestids, all stages, 49°C, 30 minutes, but noted that higher temperatures are required to kill other dermestids; eggs and larvae, 60°C water, 5 seconds.
149. Gibson and Twinn (1929) discussed heating and cooling buildings. Heat, 49°C for several hours. Heat upholstered furniture, 54° to 60°C, more than 6 hours. Open building for 12 to 24 hours when temperature goes below −18°C. General methods recommended for *Plodia interpunctella, Ptinus, Dermestes* and Anobiid species. *Camponotus pennsylvanicus* infestation treated with hot water.
150. Leechman (1931) suggested low temperature control in museums. Recommended less than −18°C for 24 hours. Leechman also recommended high temperature control using 54°C for 6 to 12 hours while cautioning about possible damage to artifacts.
151. Back and Cotton (1931) reported work of Schlossberg stating that external air must be 74° to 77°C for 5 hours to kill clothes moths in stuffed furniture. Several hours exposure to −18°C also recommended.
152. Austen and McKenny Hughes (1932) recommended 60°C for 3 to 4 hours to disinfest upholstered furniture and cited Back (1923), Back and Cotton (1931). Recommended use of cold storage during warm seasons to prevent damage to goods.
153. Cressman (1935) reported the heating of a library to 60°C to 63°C for 6 hours to kill a *Lasioderma serricorne* infestation, without disrupting the use of the building. Gas burners used with electric fans to ensure even heating of the space. No living insects found when the library was inspected 37 days later. Wood furniture, sheepskin and buckram bindings were not considered injured in any way.
154. O'Neill (1938) recommended the use of 77°C air temperature to heat herbarium plant bundles to 60°C for 4 to 6 hours. Dermestids, weevils and cockroaches killed.
155. Back (1947) recommended one to two days exposure to −18°C to kill moths. Heating for a "short time" to 54°C said to kill all stages. Mentioned superheating of houses for 12 hours to kill clothes moths, carpet beetles and bedbugs.
156. Wood (1956) reviewed heat treatments to eradicate book infesting insects. Psocids, "bookworm" and *Tineola bisselliella* mentioned, 60°C for 4 hours.
157. Forest Product Research Laboratory (1962) published a kiln schedule for heat sterilization of timber against *Lyctus* infestation. Temperatures from 52° to 60°C and relative humidities

between 60% and 100% are related to timber thickness and equilibrium moisture content. *Anobium punctatum* and species of Bostrychidae were also killed by this schedule. Cellulose, paint, and turpentine varnish surface finishes were not affected below 55°C and 80% RH. Wax finishes were affected at all temperatures in the schedule.

158. Cotton (1963) recommended temperatures of 49° to 54°C for 10 to 12 hours to kill insect pests in mill structures. Grain and grain products were heated to 60° or 70°C for 5 to 10 minutes to kill pests.
159. Munro (1966) related the use of heat in mills, 49° to 55°C, 10 to 12 hours.
160. Yonker (1985) gave general recommendations for *Lasioderma serricorne,* 60°C, 12 hours; −18°C, 4 to 5 days.
161. Parker (1987) noted use of heating to 60° to 63°C for 6 hours to disinfest structures. Recommended a 54°C oven for 3 hours with a water source to maintain moisture content for disinfesting books or botanical specimens. Noted it is easier to kill insects by heat than cold.
162. Forbes and Ebeling (1987) described heat treatments of building mock-ups and reported mortality data for several insect species. *Blattella germanica* (German cockroach), *Tribolium confusum* (flour beetle), *Incisitermes minor* (drywood termite), *Iridomyrmex humilis* (Argentine ant), and *Ctenocephalides felis* (cat flea). Also reported the treatment of a house infested with *Cryptotermes brevis* (drywood termite).
163. Ebeling, Forbes and Ebeling (1989) treated historic buildings for a powderpost beetle infestation. The heating required 3 to 6 hours and was stopped after maintaining 49°C for 30 minutes at thermocouples placed throughout the structure.
164. Watling (1989) recommended using a 40° to 42°C drying cabinet to kill mycophagous insects during fungal collection preparation. Watling also reported the herbarium practise of using −18°C for 24 hours to exterminate herbarium pests and cited a failure to control *Ceracis cucculatus* (tree-fungus beetle), *Trogoderma granarium, Stegobium paniceum* and *Liposceles bostrychophilus* by this method.
165. Anonymous (1990) note stated that temperature above 55°C kills wood destroying insects.
166. Howard (1896) described experiments by commercial firms using cold storage for fur and woollens (0° to 4°C) and their need to optimize the temperature for reasons of economy. Moth infested goods were normally treated with a "general cleaning and heating". Howard reported the work of A. M. Read on *Tineola bisselliella, Attagenus unicolor* and *Dermestes maculatus,* to find optimal storage temperature that would inhibit feeding. 10°C was reported as the feeding threshold although movement was still seen at several degrees lower. Read was the first to report that *Tineola bisselliella* larvae were killed by cooling to −8°C, warming and return to the cold. In contrast, continuous storage at −8°C for 23 days did not kill all the larvae. Temperatures below −8°C were not used in the experiments.
167. Runner (1919) used alternating temperatures to kill a *Lasioderma serricorne* infestation in tobacco; −10°C, 48 hours, warm for 24 hours, −10°C for 24 hours. A control experiment with infested tobacco held at −10°C had survivors.
168. Back (1923) recommended refrigeration for control of webbing clothes moth and black carpet beetle larvae, −8°C for "several days," brought up to 10°C for a "short time" then returned to −8°C with a final long term storage temperature of 4°C. The quick change in temperature and repeated cooling was credited with the killing effect since long term survival at −8°C was demonstrated. This procedure was first published by Howard (1896).
169. Bovingdon (1933) investigated the temperature and time for killing *Anagasta* (Ephestia) *kühniella* in bales of tobacco. Bovingdon noted that labour was the major cost of the process. Thermocouples were recommended to tell when a low core temperature was achieved.
170. Swingle (1938) treated *Lasioderma serricorne* infested tobacco hogsheads and bales, −11°C, 9 days.
171. Rice (1968) described the moth eradication method originally proposed by Reid (Howard, 1896[166]) and suggested its use on textile collections.
172. Edelson (1978) reported that Remington normally used −23°C for 48 hours to kill insects. Rasie (1977) reported Remington's control method, −23°C, 6 hours, 99% mortality. In practice, books were cooled to −29°C for 72 hours to kill *Gastrallus* sp. (Nesheim, 1985).
173. Toskina (1978) described a successful treatment for *Anobium punctatum* infested icons by exposure to ambient winter conditions for 3 months. Temperatures averaged −10°C with two cold periods of several days duration, reaching −20°C and −30°C.

174. Appleby and Farris (1979) used −46°C to kill lepidoptera larvae before freeze drying.
175. Arevad (1979) recommended −20°C for 1 day to control *Anthrenus verbasci* and *Anthrenus museorum.*
176. Cristafulli (1980) recommended exterminating *L. serricorne* in herbarium collections with −18°C for 48 hours, as was done at the Royal Botanic Gardens at Kew. Other institutions used temperatures as low as −40°C. See Watling (1989[164]).
177. Moore (1983) suggested using a deep freeze on wood objects, −18°C or lower for several days.
178. Smith (1984) gave a general recommendation of −40°C to ensure mortality and states 24 hour exposure is sufficient.
179. Nesheim (1985) described a blast-freezer treatment, −29°C for 72 hours to control *Gastrallus* sp. in a 37,000 volume rare book collection. Nesheim reported that Remington recommended −29°C for 72 hours to treat books.
180. Florian (1986) recommended −20°C for 48 hours to kill insect pests in museums.
181. Florian (1990) cited Florian (1986). Stated that control failures occur when the recommended temperature of −20°C for 48 hours was not adhered to.
182. Norton (1986) mentioned the use of −20°C for 48 hours to control clothes moths.
183. Forbes and Ebeling (1986) reported that *Incisitermes minor* (drywood termite) infestations were controlled with spot applications of liquid nitrogen. Wall sections were cooled to −20°C in 75 minutes. In controlled experiments the termites were killed by a 5 minute exposure to −20°C.
184. Stewart (1988) exterminated a *Cryptotermes brevis* (West Indian drywood termite) infestation of books with −35°C for 72 hours.
185. Lawson (1988) described a 1983 treatment of books to kill an unidentified insect, −25°C for 78 hours. A three year follow-up examination showed no further insect activity.
186. Brokerhof (1989) reported on the State Museum for Natural History in Leyden, the Netherlands' control method for pests of stuffed animals, −20°C, 2 to 3 weeks.
187. Preiss (1990) reported a dermestid infestation of woollen tapestries treated by exposure to −20°C for 9 days. Preiss recommended a minimum exposure of 7 days to ensure an effective treatment.
188. Younghans-Butcher and Anderson (1990) cited Florian (1986), −20°C for 40 (sic) hours.
189. Wilson (1990) cited Florian (1986), −20°C for 48 hours.
190. Stansfield (1985) cited failure to control *Niptus hololeucus* (golden spider beetle) and *Tineola bisselliella* by exposure to −18°C for 48 hours.
191. Brokerhof (1989) reported the failure of the State Museum for Natural History in Leyden's treatment for *Lasioderma serricorne* (Herbarium beetle), −30°C for 24 hours. Failure was attributed to insulation by material surrounding the insects. Brokerhof also reported the Herbarium in Utrecht's use of −26°C, 40 hours to control *Anthrenus* species sometimes failed to kill larvae and eggs.

NEW MATERIALS FOR SEALING OLD CROCKS

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Abstract.—Preliminary tests indicate that closed-cell foam weatherstrip tape and extruded polyethylene rope work in sealing a type of museum jar long out of production, but which still may be in wide use. The seal is water-proof, but observation confirms vaporization of alcohol continues, albeit at greatly reduced levels.

Although a large, glass, storage jar, herein referred to as a glass crock, is no longer in production, it was once widely used for storage and exhibition, and is still in use in many museums and collections today (J. E. Simmons, personal communication). Because of its qualities of complete transparency, large volume, and few confining obstructions (e.g., narrow necks), glass crocks have remained valuable storage devices in the Ichthyology collection at Bishop Museum for specimens of large size or odd shape, for which other kinds of commonly available jars are unsuited.

Unfortunately, the sealing characteristics of glass crocks leave a lot to be desired. When normally sealed with hard rubber gaskets, the crocks often leak when tipped and frequent topping with preservative is required. Free leakage is an indication that gaps in the seal exist, gaps that allow evaporation of preservative to go unchecked.

DESCRIPTION OF MATERIALS

The glass crock apparently was designed for display, made entirely of clear glass of uniform diameter from bottom to top (Fig. 1). Glass crock diameters in the Ichthyology collection range from 7.6 cm to 33 cm (3 in. to 13 in.); heights range from 20.3 cm to 94 cm (8 in. to 37 in.). All measurements are approximate and do not include lids or retaining bands.

The glass lid usually bears the markings WHITALL, TATUM (&) Co./PHILADELPHIA/NEW YORK in raised letters on the outer surface around the edge; some have PAT. JUNE 11th 1895 on the inside surface. There may be one or two glass tabs on the inside surface, with holes through them for stringing with cordage to suspend specimens within the crock.

A glass girdle encircles the crock top. This provides a lip upon which the lid and gasket rest. A metal retaining band runs over the top of the lid along the diameter, and is hooked under the girdle on each end. A turn-screw, either threaded through or into the metal band, is seated into a small depression in the center of the lid. Rotating the turn-screw clockwise (as viewed from above) exerts a downward pressure against the lid, compressing a gasket between lid and crock lip. Figure 1 depicts two kinds of retaining bands, with different kinds of turn-screws. The mechanics and the principle of sealing are identical.

For some reason (possibly the flow of glass in the crock walls over time due to gravity, or perhaps imprecision of the manufacturing process), some lids wobble when seated on the crock lip without a gasket, indicative of an uneven surface on the lid or the glass girdle. The resultant gaps cannot be filled by the gaskets

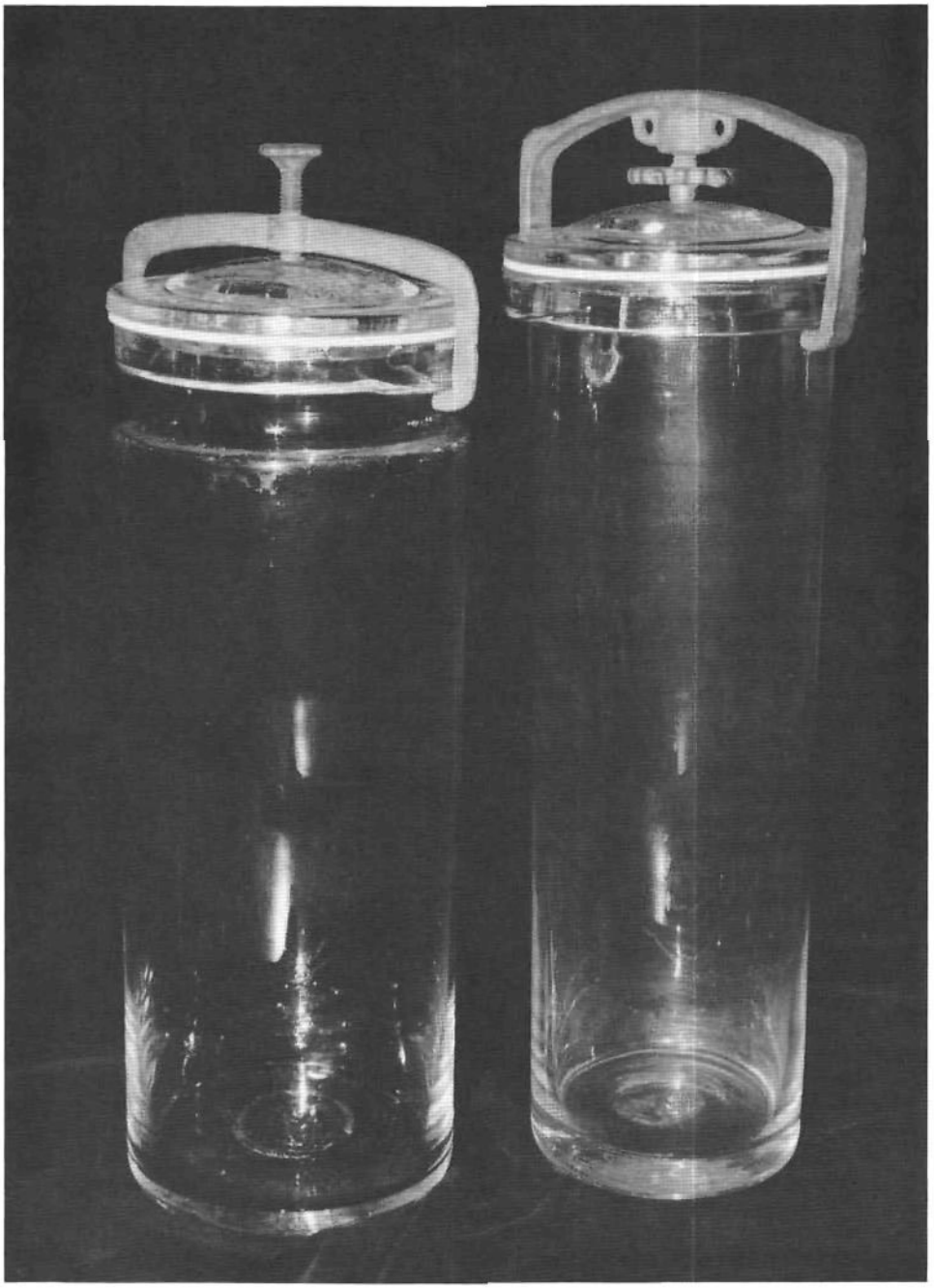

Figure 1. Two glass crocks, one on left exhibiting a narrowing near the mouth. Note the two types of retaining bands and turn-screws.

commonly used with this crock (white or black hard rubber or neoprene, about 2 mm thick) without excessive force being applied to the glass lid, usually resulting in the lid cracking.

The foam weatherstrip tape employed is a commercially-available, closed-cell sealing product designed to insulate doors and windows against moisture and air leaks (see Appendix for supplier). When used as a gasket, this product is 9.5 mm (⅜ in.) thick at first, but collapses to about 4 mm over a period of a day or two. As the gasket compresses, it conforms to fill the gaps, yet has sufficient regain to allow the lid to seat and seal if removed and repositioned. It is necessary that a closed-cell foam (as opposed to an open-cell foam) be utilized as it prevents seepage of fluids through the material.

The extruded polyethylene rope employed is a product widely used in the building industry to seal small gaps (usually around window casings). Polyethylene (PE) "backer rod" of 12 mm (½ in.) diameter serves well as a general gasket for all sizes of glass crocks when compressed to half its thickness. PE backer rod is usually closed-cell, but this quality should be specified whenever ordering this product.

Installation Procedure

Foam weatherstrip gasket.—Because the foam weatherstrip tape comes coiled in a roll, any length removed is somewhat prone to curving. It is easiest to apply as follows. Run a length of foam tape around the raised ridge on the inside surface of the lid (tacky side of tape towards the raised ridge). Overlap the ends by about two centimeters and cut the length from the roll.

Keeping the ends overlapped, remove this gasket ring from the lid. With sharp scissors, cut through the overlapped ends at an angle of about 45° from the ring radius. Glue the wedge-cut ends together with contact cement formulated for neoprene (such as divers' wet-suits) following instructions provided with the product. Allow the adhesive to set and dry. The overlapping wedge arrangement at the ends will ensure that the bead of cement won't crumple and disrupt the seal at the join when compressed.

To install the gasket, make sure that the glass surfaces the gasket will contact are clean and dry. Twist the gasket to adhere the tacky surface to the lid, slightly stretching the gasket around the raised ridge. Seat the gasket uniformly around the lid.

With the gasket installed on the lid, the crock is ready to be sealed. The fluid level may reach to the top of the crock. In our experience, it didn't matter whether the lip was dry or wet when the lid was seated. Place the lid on the crock, and press down firmly to seal. Slip the retaining band over the lid, and seat the turn-screw onto the lid, compressing the lid and gasket gently. Carefully adjust the turn-screw over the course of a few hours to compress the gasket.

PE backer rod gasket.—Using the crock lid as a guide, run a length of PE backer rod around the raised ridge on the inside surface of the lid. Overlap the ends by about three centimeters and cut the length from the roll.

Using a sharp scalpel or knife, slice each end of the PE backer rod down the middle for the length of the overlap section. Be sure the cuts are in the same plane; do not exceed the overlap length. Bring the two ends together (with the cuts in the ring plane) and cut reciprocal pieces from each end. Join the overlapping

ends with hot melt glue following instructions on product packaging. Be sure to use a hot melt glue that works on polyethylene (some are not effective) and that liquefies within a temperature range below that of the melting point of polyethylene (about 70°C/160°F). As most hot melt glue guns are not available with temperature controls and melting ranges for most hot melt glues aren't easily determinable, some practice is required in allowing the glue or the gun to cool a little before application. It is easy to exceed the melting point of polyethylene. When the hot melt glue sets (several seconds), the PE backer rod gasket may be installed as any of the hard rubber gaskets normally accompanying glass crocks.

Once correct sizes are ascertained, many PE backer rod gaskets may be made in advance of need, since there is no adhesive associated with the product that could attract grime while in storage.

Discussion

Overtightening does not seem to be a problem with either gasket described above, as it is with hard, more unyielding gaskets. Lids firmly sealed using the foam weatherstrip or PE backer rod gasket seem not as prone to stress-cracking as they are with hard gaskets. However, in collections subject to sharply fluctuating temperatures, lid conditions should be carefully monitored.

A glass crock sealed using either gasket can be inverted without losing preservative fluid through seepage, indicating that the closed-cell nature of the materials is retained, even though greatly compressed. Observations indicate that the seal against glass surfaces remains effective over time as well. No leakage has been noted in the crocks sealed in 1987 (foam weatherstrip) or 1990 (PE backer rod).

Although long-term tests have not been conducted, this solution is superior to others proposed to solve this problem (e.g., utilization of beeswax, roofing sealants in place of gaskets; silicone greases applied to hard rubber gaskets). Indications are that vaporization of preservative is reduced, but not entirely stopped. A test crock (92-mm diameter mouth) sealed for 41 months with a foam weatherstrip gasket lost about 140 cc of fluid (about 4.7 ounces; 20% of total volume). The alcohol (isopropanol) concentration fell from 55% to about 47%. Crocks containing ethanol (75% concentration) have shown similar drops in levels.

A similar crock sealed for 23 months with an experimental *open*-cell PE backer rod gasket lost about 85 cc of fluid (about 2.9 ounces; 9% of total volume). The alcohol (isopropanol) concentration fell from 55% to about 51%. It is expected that a closed-cell PE backer rod gasket would perform better.

Conclusion

While the gaskets described above are not viewed as ideal solutions, their use is regarded as far better than over-tightening the lid against a hard rubber gasket (which creates enough stress to crack the glass lid), and certainly obviates the need for topping with preservative every mouth.

An experiment qualifying the foam weatherstrip gasket's reactivity with alcohols is being conducted. PE backer rod is stable in alcohols of the concentrations commonly found in fluid-preserved collections.

The pressure-sensitive adhesive factory-applied to the foam tape helps in seating the gasket onto the crock lid, but indications are that alcohols may be solubilizing agents. No information is yet available about possible deleterious effects of the

adhesive or breakdown products thereof on fluid-preserved specimens. Keeping the foam gasket as dry as possible certainly seems prudent. Both the neoprene cement and the hot melt glue used to bond the respective gasket materials seem unaffected by immersion or exposure to alcohols, and especially so as utilized.

Despite potential downsides to the use of the above-described gaskets, their use can turn a labor-intensive storage container into one of great value and stability.

Acknowledgments

Sincere thanks are due all my volunteers and technicians, most notably David Preston and Richard L. Pyle, who sat patiently through my tedious explanations on installation procedure and rationale, and to whom this project wasn't a complete crock.

Appendix

Suppliers

Heavy-Duty Weatherstrip Tape: a closed-cell, heavy-duty, adhesive foam tape for eliminating air and moisture leaks around doors and windows. ⅜ in. thick; ½ in. wide (10 ft roll).—Macklanburg-Duncan, Oklahoma City, OK 73118.

Neoprene cement.—Seal Cement™, McNett Corporation, Bellingham, WA 98227.

Polyethylene backer rod.—Applied Extrusion Technologies, Inc., P.O. Box 582, Middletown, DE 19709.

Hot melt glue.—Bostik, Boston Street, Middleton, MA 01949.

SHIPPING OF PINNED INSECTS

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Abstract.—Pinned insects are very fragile but can be shipped successfully if correct materials and procedures for packing them are used. Specimens are pinned securely into an inner box which is set amid shock-absorbing material in a larger box. A faster mailing rate is preferred because less time in route requires less handling, thereby reducing likelihood of damage.

Shipping of natural history specimens to other institutions is an important and necessary means of increasing their use by the scientific community. Packing methods and materials for most natural history artifacts and specimens are straightforward, relying on common sense and respect for the scientific or cultural value of the research material. Successful transport of pinned insects through the postal system is not difficult, but requires specialized material and procedures if damage is to be avoided. Opportunities to have specimens hand-carried between institutions should be taken whenever possible.

The purpose of this paper is to provide basic information to anyone who needs to mail pinned insects, whether or not they have an entomological background. I have sent and received many packages containing pinned insects during the past 17 years. Results have generally been successful, but I have occasionally sent or received a package that incurred major damage during shipment. Usually this can be attributed to some deficiency or failure in the packing methods or materials.

Most of what is known about how to ship pinned insects has been passed on individually from one entomologist to another; there is scant literature available on the subject. Some entomological books have a small section dealing with this topic (Borror *et al.*, 1989; Martin, 1977; Walker and Crosby, 1988; Shaw, 1990). Janse (1939) described packing and shipping unpinned insects, but his omission of a discussion of pinned insects implies that he did not think they should be shipped. The single paper by Sabrosky (1971) stands as a unique treatment of this topic; his paper cited no other works. The present paper is formatted to provide a more easily accessible set of instructions than those of Sabrosky (1971), and offers some points not found in his paper.

In order to gage the levels of knowledge and experience about shipping pinned insects, I circulated a non-quantitative questionnaire to many collections managers and advanced entomologists who occasionally or routinely mail pinned insects. Of more than 50 copies distributed, I received 15 responses. Only two persons were aware of the Sabrosky (1971) paper. All respondents indicated that they had experienced damage at least occasionally in shipments. Most respondents indicated that proper packing procedures are poorly known or poorly standardized, and more information about this subject needs to be communicated.

PACKING MATERIALS

Pinned insects must be shipped in an inner box with a pinning bottom, which is then placed in an outer box. A shock-absorbing, cushioning material is placed

between the inner and outer boxes. This may seem obvious, but I have received four shipments with pinned material in pinning boxes merely wrapped in paper, two of which came from professional entomologists. Of these four, in two domestic and one overseas shipments, the result was total destruction of the specimens. In one shipment sent by air to Colorado from an Asian country, virtually no damage occurred, an unexpected and likely non-reproducible result! One should not hesitate to offer basic shipping advice to colleagues out of fear of insulting their professionalism. As described below, severe damage can occur for other reasons even when material is double-boxed.

Pinning box.—The inner box should be strong, yet light in weight. Shaw (1990) advocated cardboard boxes over wooden ones. Harder, heavier boxes probably do not resist shock as well. Unit trays that are fitted with cardboard lids that cover the tops and sides are fine.

Pinning bottom.—This should be at least 1 cm thick and must hold the insect pins firmly, yet be soft enough to absorb shock. Plastizote foam, available from BioQuip Products (17803 LaSalle Avenue, Gardena, CA 90248-3602), is ideal. Cork and ethafoam also work well. Styrofoam and corrugated cardboard are unacceptable. The pinning bottom must be glued or stapled firmly to the bottom of the pinning box.

Outer box.—The outer box should be strong enough to protect the inner box from being crushed. It must be large enough that ten or more centimeters of cushioning material can be fitted between the inner and outer box *on all sides* (Walker and Crosby, 1988). During shipment, the box may be upside down, on one side, or under heavier boxes. The package will probably be subjected to rough handling while in transit. Do not use a smaller or lightweight box to reduce postal costs; the scientific value of specimens cannot be measured in monetary terms.

Cushioning material.—This material should hold the pinning box in the center of the outer box, but must not be packed too tightly. Properly packed cushioning material will absorb shocks instead of merely transferring them to the inner box. Cotton, cotton batting, polyester fiber, crumpled newspaper, or foam peanuts work well if not compressed too tightly (Martin, 1977). Postal costs will be increased most by crumpled newspaper since it adds the greatest weight among the available packing materials.

Packing and Mailing Procedures

Having selected the proper materials, the following procedures should be used.

Packing.—Do not allow any pins or other materials to come loose during transit, as these will shake about and damage specimens. Be certain that the pin of each insect is firmly pushed into the pinning substrate. Insert pins alongside the abdomens of large insects or those with long abdomens to prevent spinning and to reduce likelihood that these parts will break off during transit. To avoid the possibility of pins coming out, cut a piece of cardboard that will fit inside the pinning box and place it on the pinheads (all pins should be approximately of the same height), then put in a piece of cotton to hold this down before putting on the lid of the pinning box. Other materials which may damage specimens include pinned cocoons or nests, specimens in vials of alcohol, and microscope slides. These are often pinned into corners of boxes containing pinned insects. Their extra weight may result in their coming loose and causing extensive damage.

Likewise, it would be foolish to include one large, heavy pinned scarab beetle in a box among many tiny insects. Use separate inner boxes in these cases. Valuable specimens of extinct species or type specimens are best packed in small individual pinning boxes.

With the increased availability of softer pinning bottoms (ethafoam instead of cork) in collections and very thin insect pins (sizes 00 and 000), many tiny specimens that formerly were double pinned on minutens and then pinned into small foam cubes placed on larger insect pins are now being pinned directly on the thin pins. This is disadvantageous for mailing, because the main pin receives much of the shock in transit and transfers it directly to the specimen; in double mounts less shock reaches the specimen (J.-F. Landry, 1991, and personal communication). This is also true for tiny insects glued onto card points instead of pinned directly onto very thin pins.

If there is concern about pest activity during shipment, fumigate or freeze the inner box prior to shipping, but never include fragments of naphthalene or paradichlorobenzene in the pinning box during shipment. These will shake about and damage the fragile insects. Wrapping the outer box with paper and taping all seams will prevent insect pests from entering the box during transit (C. Durden, personal communication).

Labeling.—The outer box should be properly labeled. A small label reading "Dead insects for scientific study" is generally used. For international shipments, a customs declaration stating "of no commercial value" is used with a zero filled in for the monetary value. This facilitates movement through customs and reduces the likelihood that an inspector will open the parcel and damage specimens. A warning that the contents are extremely fragile should go on the inner box in case the box is inspected in route. Large labels saying "fragile" on the outer box will not guarantee any significant difference in treatment in transit. Instead, you must rely on your own packing materials and methods to avoid damage.

Mailing.—The less time a parcel is in transit, the less handling it will be subjected to. Airmail rates for overseas shipments, or First Class or Overnight for domestic shipments, are probably advisable if the specimens are extremely valuable, if cost is not a concern, or the package is very small. However, I have sent many large packages overseas via Sea Mail (i.e., surface rate) and via Third or Fourth Class mail to domestic destinations without any problems. The small additional cost paid for "special handling" will speed up by a few days domestic packages sent by slower, cheaper rates.

In shipments containing large numbers of specimens or several very valuable ones, it is advisable to divide the consignment into more than one parcel, thereby reducing the chances of the entire shipment being lost or destroyed. Registration of parcels is recommended to enable the sender to trace those that may become lost in transit (C. Durden, R. Oberprieler, personal communication).

Discussion

In order to provide an illustration of damage to pinned insects, I sent a package containing ten pinned honey bees and ten pinned moths (both common; collected and pinned solely for the purposes of this project) to Sacramento, California, using the proper methods. All arrived in perfect condition (M. J. Smith, personal communication). I requested that the inner box be simply wrapped in brown paper

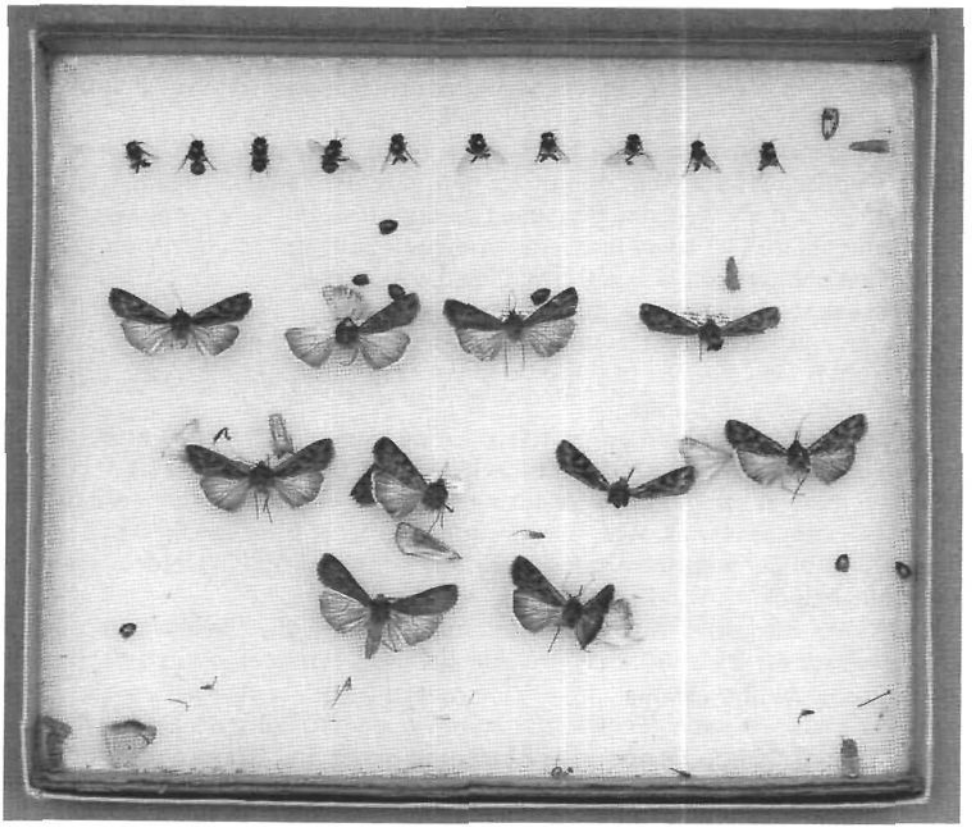

Figure 1. Shipment of pinned moths and honey bees damaged due to poor packing procedures.

and sent back to Denver via Third Class mail. Figure 1 shows that abdomens of seven honey bees and nine moths became detached. Additionally, several legs, antennae, and wings were detached and loose in the box. No pins became dislodged. If these had been valuable research specimens with data, it would have been impossible to reassociate the parts.

In my questionnaire I asked if there were any insects that should be considered too fragile to mail. Nine respondents said that no specimens should be considered as such. The remaining respondents expressed concerns about the fragility of old, historical specimens, or large elongated specimens in groups such as walkingsticks, praying mantises, very large moths or grasshoppers.

Acknowledgments

I thank all the persons who responded to my questionnaire. Particularly useful information or literature assistance came from J. P. Donahue (Natural History Museum of Los Angeles County), B. A. Drummond (Woodland Park, Colorado), C. J. Durden (Texas Memorial Museum, Austin), J. C. Morse (Clemson University), R. G. Oberprieler (National Collection of Insects, Pretoria, RSA), and M. J. Smith (Sacramento California). Figure 1 was made by Rick Wicker, photographer at the Denver Museum of Natural History.

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CONDITIONS ON OUTGOING RESEARCH LOANS

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Abstract.—Research loans create fewer unpleasant surprises when borrower and lender have agreed in writing on the terms of the loan. This article outlines considerations related to responsibility, written permission, duration, shipping, insurance, publication and copyright that may need to be addressed in drafting agreements for outgoing research loans.

Among some in the museum community research is regarded as a "gentleman's profession" where professional courtesy and trust are presumed to govern transactions. Those holding this view consider it discourteous to require that a visiting researcher be supervised in the collections, or have his or her packages searched upon exiting, or to require a colleague to sign a loan agreement spelling out the conditions of the loan. In fact this is not a matter of courtesy or respect, or discourtesy or disrespect. It is a matter of basic accountability and good management. Two parties, with the best intentions in the world, can approach a transaction with completely different unspoken assumptions. A written contract prevents misunderstandings by making the operational rules clear from the beginning.

This paper discusses some of the misunderstandings that commonly occur in the process of making loans of collection objects. It offers suggestions, drawn from loan forms from many institutions, as to the sorts of clauses that can be included in a loan agreement to resolve these points. The emphasis is on research loans, but many of these points apply to loans for educational or exhibit purposes as well. The Appendix includes a checklist of major concerns for easy reference.

Responsibility for the loan.—When drafting a standard loan form, consider to whom the institution will be lending objects. There are many variations on the story of a loan that proved difficult to retrieve because the loan had migrated; when the individual borrowing the specimens moved to a new institution, he took the specimens with him, and neglected to inform the lender. When loaning to employees or affiliates of an institution, stipulate that responsibility for the loan rests jointly with the individual and the institution, and specify that the individual involved may not take the loan objects with him or her to another institution without prior written permission. When loaning to students, consider making the loan the responsibility of the student's advisor or another institutional employee. Consider carefully under what situations you will loan to unaffiliated individuals. Lastly, it is not unheard of for a borrower to lend the object in turn to a third party. Specify that this cannot be done without prior written permission.

Care of loan objects.—Another source of great unhappiness in loans is conflicting assumptions as to how the specimens will be treated. We are still far from having one standard of proper museum care for an object, and what is standard procedure at one museum may be anathema to another. Some specimens may require very specific instructions about how they are to be stored. Loans of fluid specimens should specify the type of solution they are to be kept in (ethanol, propanol, formaldehyde). The borrower may routinely use a different medium than the

lender, and changing the specimen from one solution to another may cause damage (Jones and Owen, 1987).

A loan agreement should also spell out what can and cannot be done to the specimen. At one museum it may be standard to photograph fossils using sublimated ammonium chloride to enhance the contrast, while the lender may not approve of this procedure. It is prudent to require written permission for restoration, conservation or cleaning of objects, pest treatment, destructive sampling and for further preparation of specimens. When granting permission for these procedures, ensure that you are supplied with a record of the materials and techniques employed.

What about the researcher who may wish to make changes or additions to the specimen record? Most agreements stipulate that the label is not to be removed from specimens, and some add that it is not to be altered. Specify that changes in designation are to be made in pencil, or on a separate comment card.

Copyright.—If you grant permission for the borrower to photograph or to cast a specimen, specify under what conditions these products are to be used. Are you retaining copyright on the resulting product, or does the borrower then own an image of your specimen that they can reproduce at will? If this is not spelled out, the presumption will be that the copyright belongs to the person producing the image or to their employer (Anon., 1992).

Duration.—Loans should be made for a specific duration. There should be no such thing as a "permanent loan"; if your museum doesn't care whether it gets an object back, it should make the transaction a donation rather than a loan. If your institution can't or won't transfer title, you are still responsible for the object, and as a matter of accountability must check periodically on its welfare and whereabouts. A "permanent" loan that is left unattended falls prey to any of a number of hazards: the borrower neglects to inform you that the object was damaged or lost; the borrower forgets where the object is or what happened to it; or as time passes the borrower forgets he does not own the object and treats it as his own, even to the extent of selling it. A "permanent" loan is in fact deaccession by default. If you wish a borrower to have use of an object indefinitely, then make the loan renewable on a yearly basis. A yearly renewal form that makes the lender certify that the loan is in good condition and that the lender wishes to renew involves a minimum of paperwork. It ensures that the borrower remembers from whence the objects came, and that they are to be returned if no longer needed.

Loans should be for a specified duration, either a standard period, commonly six months or a year, or a period tailored to the borrower's projected use of the object. The latter is better for the object, as it ensures that the loan is returned after use, rather than being stored at the borrower's institution until the due date prompts its return. Many institutions retain the right to recall loans at any time, to cover the eventuality of the material being needed in-house for exhibit or research. In all cases, the loan should specify that loan extensions must be confirmed by the lender in writing.

Shipping.—Some agreements cover shipping by a general statement that the loan "must be packed in a manner comparable to that in which it was received," shipped using "safe methods using adequate material to pack the specimen," or that the borrower must "return the loan in the same packaging in which it was shipped." More detailed instructions might include specification of packing ma-

terial (for example, polyester batting rather than cotton for wrapping study skins) or mailing instructions (e.g., extra address label inside, ship insured, receipt return, registered).

Insurance.—Instructions on insurance should include the amount of coverage to be included in transit, and the amount and type of coverage for the duration of the loan. Many institutions require only token insurance for loans of research specimens. If an institution lends ethnographic or archaeological objects with significant monetary value, the agreement should specify that the coverage be "wall-to-wall" (coverage from the time that the object leaves its storage place in the museum to the time it is returned to that place), all-risk with standard policy exclusions, and that the lender be provided with a copy of the insurance certificate upon request.

Publications.—Finally, lenders would do well to specify how they wish to be credited for the loan, including the correct abbreviation, if any, to be used for their institution. This is not only an issue of proper acknowledgement, but also to prevent confusion in the literature. Specify that the researcher is to request a catalogue number from the lending institution before publication and not assign their own numbers or letters. In consideration for your institution's records of an object's history, request that a specified number of the resulting publication be given to the lending institution.

Further reading.—For more in-depth exploration of the issues concerning outgoing loans, consult the following references:

Dudley, D. H., I. B. Wilkinson *et al.* 1979. *Museum Registration Methods.* American Association of Museums, Washington, DC., 437 pp. An overview of standard procedures and record-keeping for many museum functions, including lending. Includes sample forms.

Hounsome, M. V. 1984. Research: Natural Science Collections. Pp. 150–155 in *Manual of Curatorship: A Guide to Museum Practice* (J. M. A. Thompson, ed.). Butterworths, London, 553 pp. Some comments on appropriate conditions for loans of research collections, including type material.

Malaro, M. C. 1985. *A Legal Primer on Managing Museum Collections.* Smithsonian Institution Press, Washington, DC., 351 pp. Chapters VI, VII and VIII deal extensively with issues such as liability, insurance, unclaimed loans, and international loans. Includes sample forms.

Malaro, M. C. 1989. How to protect yourself from not-so-permanent loans. Museum News, 68(5):22–25. Some choice comments on the legal consequences of loans made in the absence of written loan agreements.

Perry, K. D., ed. 1990. *Museum Forms Book,* revised edition. Texas Association of Museums and the Mountains-Plains Museum Association, Austin, TX. Sample forms of all conceivable types (including loan) from many museums.

Registrar. 1991. 8(2):47 pp. Compilation of information on loans made by the Registrars Committee of the American Association of Museums. Includes the RC's Statement of Practice for Borrowing and Lending, their Loan Survey Report (the results of polling over 200 museums about their loan policies and procedures), and an article by Linden Havemeyer Wise about old (abandoned) loans.

Conclusion

Some of the events postulated above may seem rare, but to borrow an epigrammatic form from Yogi Berra "it's not a problem until it's a problem." Good management is foreseeing potential problems and taking preventive measures. A well-written loan agreement is a document that communicates your expectations, and institution's formal policies, to the borrower and leaves nothing to chance.

Literature Cited

Anonymous. 1992. *Copyright Basics.* U.S. Government Printing Office, Washington, DC., 12 pp.

Jones, E. M., and R. D. Owen. 1987. Fluid preservation of specimens. Pp. 51–64 in *Mammal Collection Management* (H. H. Genoways, C. Jones, and O. L. Rossolimo, eds.). Texas Tech University Press, Lubbock, 219 pp.

Appendix

Checklist of Concerns for Outgoing Research Loans

A. Responsibility
   1) Institutional loans
      a. joint responsibility of the individual and the institution
      b. no transfer to another institution, without prior written permission
   2) unaffiliated individuals (consider carefully)
   3) loans made to faculty advisor rather than students

B. Require written permission for:
   1) restoration, conservation or cleaning
   2) pest treatment
   3) further preparation of specimens
   4) casting
   5) photography
   6) use of sublimated ammonium chloride (in photographing fossils)
   7) destructive sampling
   8) loan extensions
   9) transfer of the loan objects to a third party

C. Specify details such as:
   1) kind of solution fluid specimens are to be kept in (ethanol, propanol, or formaldehyde, etc., and the concentration)
   2) procedures for changes in designation/identification

D. Tenure of loan
   1) standard renewable period, or
   2) tailor to loan request
   3) retain the right to recall loan at any time
   4) *never* make "permanent" or "indefinite" loans

E. Shipping instructions
   1) method of packing
   2) method of shipping (UPS, return receipt, insured)

F. Insurance
   1) postal insurance during transit
   2) for duration of loan
      a. all risk, "wall to wall"
      b. provision of an insurance certificate upon request

G. Publication
   1) how to credit the lending institution, including the correct abbreviation

2) researcher to request a catalogue number from the lending institution before publication, and not assign their own numbers or letters
3) a specified number of the resulting publication be given to the lending institution

H. Copyright considerations:
1) photographs taken of objects
2) casts made of objects

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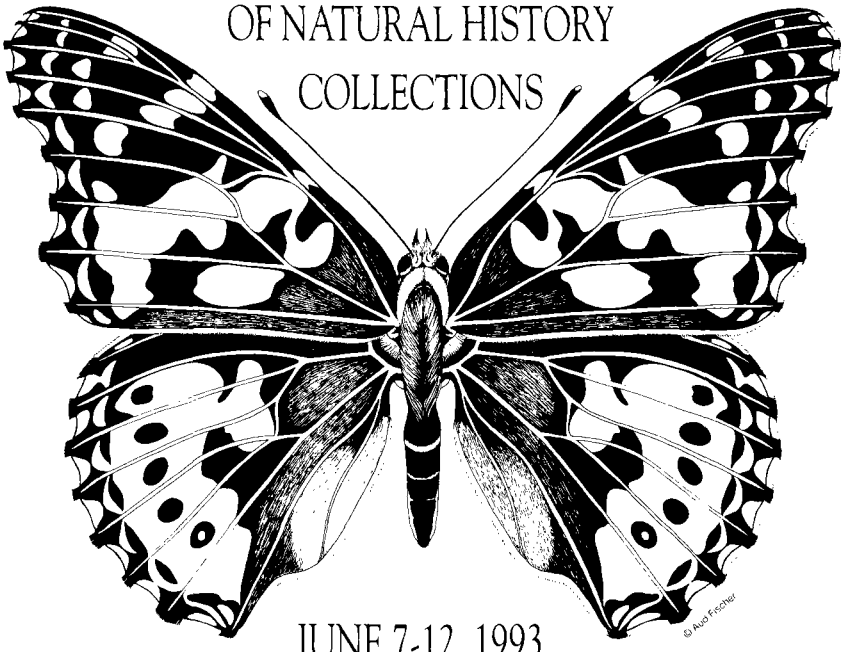

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1993 ANNUAL SPNHC MEETING

The eighth annual meeting of the Society for the Preservation of Natural History Collections will be hosted by the Royal British Columbia Museum, 7–12 June 1993. The conservation workshop will focus on archival concerns. Details will be provided in the January 1993 "Call for Papers", which will be mailed out to each SPNHC member. For further information contact the Local Committee Chair: Grant Hughes, Royal British Columbia Museum, 675 Belleville St., Victoria, British Columbia V8V 1X4 Canada. Tel: (604) 387-5706.

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Each page of the manuscript should be numbered. Do not hyphenate words at the right-hand margin. Each table and figure should be on a separate page. The ratio of tables plus figures to text pages should generally not exceed 1:2.

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Jones, E. M., and R. D. Owen. 1987. Fluid preservation of specimens. Pp. 51–64 in *Mammal Collection Management* (H. H. Genoways, C. Jones, and O. L. Rossolimo, eds.). Texas Tech University Press, Lubbock, 219 pp.

Sarasan, L. 1987. What to look for in an automated collections management system. Museum Studies Journal, 3:82–93.

Thomson, G. 1986. *The Museum Environment,* 2nd ed. Butterworths, London, 293 pp.

Tables and illustrations.—Tables and illustrations should not repeat data contained in the text. Each table should be numbered with arabic numerals, include a short legend, and be referred to in the text. Column headings and descriptive matter in tables should be brief. Vertical rules should not be used. Tables should be placed one to a page, after the references.

All figures must be of professional quality as they will not be redrawn by the editorial staff. They may include line drawings, graphs or black and white photographs. All figures should be of sufficient size and clarity to permit reduction to an appropriate size; ordinarily they should be no more than twice the size of intended reductions and whenever possible should be no greater than a manuscript page size for ease of handling.

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