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# NATIONAL MUSEUM OF WALES SPECIMEN CONDITION SURVEY FORM FOR GEOLOGICAL COLLECTIONS

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*Abstract.*—The importance of condition surveys of geological collections is widely acknowledged. At the National Museum of Wales a condition survey form has been devised to facilitate this task. The form lists ten parameters that are scored from a master scoring guide. The results, in a format easily entered into a database, show the current state of the collections and provide a baseline against which future deterioration will be measured.

A major, museum-wide, multidisciplinary conservation project was initiated at the National Museum of Wales in October 1989. This was in response to general staff concern that in the past insufficient resources had been allocated the routine care of some of the museum's collections and that as a consequence a backlog of work had developed potentially placing in jeopardy the survival of certain parts of the collections.

As part of this project a dedicated geological conservator was appointed on an initial two year contract, the first such appointment at a national museum in Britain outside the Natural History Museum, London. The first major task the conservator undertook was a condition survey of the collections assessing their present conservation state and future needs. The importance of such a condition survey of geological collections has been stressed recently (Knell and Taylor, 1989).

The geological collections at the National Museum of Wales are divided into three major categories: palaeontological, mineralogical and petrological. The last group was not included in the initial survey because the collection was undergoing reorganization and the conservator and curatorial staff felt that a survey need not be carried out until this process was complete. Due to its scientific importance the entire type and figured fossil collection, of approximately 2,500 specimens, was surveyed.

The condition survey had to be comprehensive and conducted within the time limit of the conservator's contract. Given the size of the collections at the National Museum of Wales (approximately 500,000 palaeontological and 30,000 mineralogical specimens) only a representative sample could be surveyed in this period. The palaeontological collection is arranged in stratigraphical order and then subdivided taxonomically. The mineralogical collection is ordered by the chemical system of Hey (1975). All registered specimens in the National Museum of Wales palaeontological and mineralogical collections have documentation. The sampling method used was to examine one specimen in the front left corner of each drawer of the surveyed collections. This way most groups were sampled and large groups containing many specimens spread over more than one drawer were sampled several times.

The conservation aspects of the palaeontological and mineralogical stores were

<p><b>GENERAL CONDITION</b></p> <ol style="list-style-type: none"> <li>1. Good</li> <li>2. Fair</li> <li>3. Poor</li> <li>4. Very poor</li> </ol>	<p><b>CONSERVATION</b></p> <ol style="list-style-type: none"> <li>1. Untreated—no treatment needed</li> <li>2. Already conserved and satisfactory</li> <li>3. Treatment desirable</li> <li>4. Treatment vital to survival</li> <li>5. Specimen beyond repair</li> </ol>
<p><b>STABILITY</b></p> <ol style="list-style-type: none"> <li>1. Stable</li> <li>2. Slight instability—under control</li> <li>3. Moderate instability</li> <li>4. Severely unstable</li> </ol>	<p><b>PACKAGING</b></p> <ol style="list-style-type: none"> <li>1. Good</li> <li>2. Fair</li> <li>3. Poor, major deficiencies</li> <li>4. Very poor, totally unsuited to item's needs</li> </ol>
<p><b>ABRASION</b></p> <ol style="list-style-type: none"> <li>1. Undamaged</li> <li>2. Slight damage</li> <li>3. Moderate damage</li> <li>4. Severe damage</li> </ol>	<p><b>DIRT</b></p> <ol style="list-style-type: none"> <li>1. Clean</li> <li>2. Slightly dirty</li> <li>3. Moderately dirty</li> <li>4. Extremely dirty</li> </ol>
<p><b>PYRITE DECAY</b></p> <ol style="list-style-type: none"> <li>1. None</li> <li>2. Present—acidic smell</li> <li>3. Present—some decay products</li> <li>4. Present—abundant decay products</li> </ol>	<p><b>EFFLORESCENCE</b></p> <ol style="list-style-type: none"> <li>1. None</li> <li>2. Present—small amount</li> <li>3. Present—moderate amount</li> <li>4. Present—excessive amount</li> </ol>
<p><b>DELAMINATION</b></p> <ol style="list-style-type: none"> <li>1. Not susceptible</li> <li>2. Susceptible—no damage</li> <li>3. Slight delamination</li> <li>4. Extensive delamination</li> </ol>	<p><b>LIGHT DAMAGE</b></p> <ol style="list-style-type: none"> <li>1. Not susceptible</li> <li>2. Susceptible—no damage</li> <li>3. Susceptible—damage unknown</li> <li>4. Damaged</li> </ol>

Figure 1. The ten parameters and score guide of the National Museum of Wales condition survey form.

first assessed. Both stores are environmentally controlled by air conditioning, they have no outside walls and are therefore buffered from external climatic changes. Independent monitoring, in the form of thermohygrographs, was introduced to give immediate visual data on the temperature and relative humidity. These supplement the computer readings provided by the air conditioning system. The conditions are generally stable. The lighting is artificial and there are UV filters on all the lights in the mineralogical store.

#### THE SURVEY FORM

To allow easier completion of the condition survey a form with a check-list format was devised. The form covered all the major problems that can occur in geological collections. It was intended that the results would be in a quantitative format.

The survey form incorporated ten parameters (Fig. 1), of which the first described the general condition of the specimen. Conservation, stability and packaging were then assessed. The final six parameters (abrasion, dirt, pyrite decay,

NATIONAL MUSEUM OF WALES - DEPARTMENT OF GEOLOGY												
CONSERVATION CONDITION SURVEY FORM												
Date / worker: 27.5.92 / C.J.B.												
Location: Palaeontological store												
Sublocation: Bay 17, column 4, drawer 16 - Asteroidea												
N.M.W. reg. no.	Description	General condition	Conservation	Stability	Packaging	Abrasion	Dirt	Pyrite decay	Efflorescence	Delamination	Light Damage	REMARKS
75.35G.406-407	<i>Furcaster</i> sp.	2	3	1	3	2	2	1	1	2	1	
00.283	<i>Protaster miltoni</i>	2	1	1	2	1	1	1	1	1	1	mounted on wooden board
61.221.G2	<i>Lapworthura miltoni</i>	2	1	1	2	1	1	1	1	1	1	

Figure 2. The National Museum of Wales condition survey form.

efflorescence, delamination and light damage) were determined to be the most common problems affecting geological specimens. The parameters were decided upon after an examination of the geological conservation literature (for example, Crowther and Collins, 1986) and discussions with the curatorial staff to identify the most significant causes of deterioration in the National Museum of Wales. The categories of pyrite decay and efflorescence overlap, as a symptom of pyrite decay is a yellow or white efflorescent growth. However two categories were needed because there are other efflorescent growths that can develop, for example calcite (Fitzhugh and Gettens, 1971). Other parameters were considered, including metal oxidation and deliquescence but as these are applicable only to small percentages of the collections they were excluded as standard parameters. Problems not identified by one of the standard parameters and other observations, were noted in the remarks column. The form (Fig. 2) can be adapted to include new parameters by adding extra columns if a particular collection is being surveyed and is prone to a specific problem such as the existence or absence of documentation. Terms used in the remarks column were standardized to assist with sorting and searching if the information is put into a computer database.

Each of the parameters was scored from a master scoring system (Fig. 1). The scores vary from 1–4; 1 meant that the specimen was in good condition and had no problems. A score greater than or equal to 3 implied that there are problems and that conservation was probably necessary. A score of 5 was only applicable for 'conservation' and indicated that the specimen was beyond repair such as the case for material suffering from pyrite decay. The survey form (Fig. 2) included

details on the date on which the survey took place and the identity of the surveyor. There was also information on the location (store) and the sublocation (bay, column and drawer) of the specimens surveyed.

The survey at the National Museum of Wales was performed by only one conservator. This prevented problems with some of the subjective observations scored as different results from different surveyors. The survey form does have limitations though a uniform standard may be achieved when the survey is done by more than one person by having the workers overlap on parts of the survey and comparing the results.

#### ANALYSIS OF RESULTS

The results from the survey were easily collated from the forms. The score sheets alone provided an immediate visual record of a collection by examination of the range of numbers for different parameters. The 'general condition' and 'conservation' columns were scanned for numbers greater than 3. The results from a random condition survey have been extrapolated to provide an indication of the scale of different problems in the whole collection.

The forms were designed so that the information can be entered easily into a computer database, allowing results to be analysed and manipulated rapidly. In describing the general methodology for assessing the condition of museum collections, Keene (1991) discusses computerizing survey data and suggests that it can increase the potential analysis done on the survey results. Work is currently underway at the National Museum of Wales to transfer the survey results onto computer using the package "Microsoft Works." Only a small number of results have been entered to date but, so far, the information seems easy to access and manipulate. When data entry is completed it will be possible to manipulate the data to provide information on specific parts of the collection, for example a listing of all surveyed specimens in the mineralogy store with pyrite decay can be produced. The results of the survey will also provide a baseline against which any further deterioration can be measured.

#### ACTION RESULTING FROM CONDITION SURVEY

The size of the National Museum of Wales collections did not allow time for every specimen to be surveyed. However, the sample survey at the National Museum of Wales has identified problem areas in the collections and it is planned that each specimen in these problem areas will now be surveyed. This will provide precise data on the deterioration so that programmes of remedial conservation can be devised. It is hoped that the information will be entered directly into a notebook computer while the survey is being conducted.

Specimens from the type fossil collection which have been identified as needing conservation will be treated as a priority because of their scientific importance. The survey identified that abrasion is a major cause of damage within the mineralogical collection. As a direct result of this there is now a programme of repackaging underway using chemically inert polyethylene microfoam to support the specimen and reduce abrasion. The conservator in the Department of Geology has been employed for a further five years, to begin the work indicated by the specimen survey.

It is now departmental policy that all potential new acquisitions should have a

condition report prior to registration. The report indicates the current state of a specimen, if any conservation work is needed, and may affect the decision of the curatorial staff whether or not to acquire the specimen.

The condition survey form has proved to be an effective tool to quantify the state of the geological collections at the National Museum of Wales. It should however be emphasised that a survey should only be undertaken if there is to be action taken on the results as it only reflects the state of the collection on the day it was done and may become rapidly out of date. Appropriate action could range from remedial treatment of a few specimens to application for special funding for a major conservation project.

#### ACKNOWLEDGMENTS

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# THE RELIABILITY OF SPOT TESTS FOR THE DETECTION OF ARSENIC AND MERCURY IN NATURAL HISTORY COLLECTIONS: A CASE STUDY

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*Abstract.*—In the past, compounds containing arsenic and mercury were often used during taxidermy to prevent insect infestation. Thus, specimens in natural history collections may contain these hazardous substances. Records of such treatments were not generally kept and as a result the degree of contamination in many collections is not known. In light of this, one of the objectives of this study was to determine the extent to which arsenic and mercury are present in bird and mammal specimens at the Provincial Museum of Alberta (PMA). The second objective of the study was to assess the effectiveness of spot tests for the detection of these substances in the specimens. A suite of 61 samples was examined using both spot tests and X-ray microanalysis. The results indicate that there is arsenic contamination in the bird collection, and to a lesser extent, the mammal collection. From a comparison of the X-ray microanalysis to the spot tests, it was found that the spot test for arsenic gave reliable results for the specimens examined. This suggests that museum professionals who do not have access to analytical equipment can use this test as an indicator of arsenic contamination. Since the spot test for mercury was carried out on a small number of specimens, it is difficult to draw conclusions about its reliability. However, there appear to be difficulties with the use of this test for the sample compositions encountered in natural history specimens.

In the mid-1700s, it was discovered that arsenic and mercury compounds were effective preservatives for natural history specimens. Over the next two hundred years, different methods of applying these substances were developed in an attempt to control the problem of insect infestation. It became common practice for taxidermists to paint the inside of bird and mammal skins with arsenical soap, or dust the skin with arsenic compounds or mercuric chloride. The exteriors of specimens were also often treated with preservative by applying compounds of arsenic and/or mercury to the fur or feathers. Williams and Hawks (1987) and Hawks and Von Endt (1990) provide thorough reviews of the various preparation methods. The use of arsenic and mercury preservatives continued well into the 20th century and it is likely that many bird and mammal specimens which have been treated with these substances exist in today's museums.

The toxic effects of these preservatives on humans are well known and specimens which have been treated with them may pose a health hazard to museum workers and the general public (Muir et al., 1981; Sirois and Taylor, 1988). Since records of such treatments were not generally kept, the extent of contamination in many natural history collections is not known.

Apart from an examination of specimens from the Royal Ontario Museum (Sirois and Taylor, 1988) and a recent survey at the Banff Park Museum (Morrow, 1993), there have been few published studies undertaken to determine the presence of these toxic substances in museum collections. In addition, although some

museum professionals are using spot tests for arsenic (i.e., Hawks and Williams, 1986; Sirois and Taylor, 1988) there is little published information about the reliability of the spot test results.

The purpose of this study was twofold. The first objective was to determine the degree to which bird and mammal specimens at the Provincial Museum of Alberta (PMA) are contaminated with arsenic and mercury. This information will be used in the implementation of appropriate handling, storage and display procedures for the specimens. The second objective of the study was to assess the effectiveness of spot tests for the detection of arsenic and mercury in the specimens. It is important to determine the reliability of these spot tests as many museum professionals do not have access to more complex techniques of analysis.

Two major concerns relating to the reliability of spot tests for detection of arsenic and mercury are addressed in this study. First, although the spot tests have been shown to give correct results in certain cases (Sirois and Taylor, 1988), they may not be reliable for the wide range of sample compositions encountered in natural history specimens. It is possible that other chemical elements present may interfere with the tests and lead to false positive or negative results. Second, spot tests use a small sample from one or more locations on the specimen; this may lead to false results if the samples chosen are not representative of the specimen as a whole.

In order to gain information about the reliability of the spot tests for arsenic and mercury, spot test results for a suite of specimens from the PMA were compared to results obtained by X-ray microanalysis. In order to determine whether incorrect results from spot tests occur due to non-representative sampling, multiple sites on certain specimens were tested and these results compared. Because of the limitations of the spot test for mercury, this multiple site testing was only carried out for the arsenic spot test.

## METHODS OF ANALYSIS

### *Sampling*

A sample set of 24 mammals and 37 birds from the PMA was selected for analysis. The birds were chosen from nine different collections in the museum based on diversity of taxonomy, size, collector, preparator, and preparation date. Sampling of valuable or rare specimens was avoided. The mammals were chosen following similar criteria from three collections in the museum. Appendix 1 lists the specimens which were tested.

A skin, feather or fur sample was collected from each of the specimens in the sample set. In addition, multiple site sampling was carried out on 7 mammals and 9 birds. In these cases, samples were taken from at least six different locations on the specimen.

Skin samples, approximately 2 mm by 2 mm, were removed with a scalpel. In the case of the bird specimens, this was usually done at the base of the tail or along the seam created during preparation of the skin. Mammal skin samples were taken from the corner of the eye, ear, lips, nose, between the horns or antlers, or under the tail.

To obtain feather samples, forceps were used to pull out several feathers from an oily area on the bird. This included areas under the tail, near the uropygial gland, and on the ventrum. Oily areas were chosen since there is some evidence that arsenic may be present in a higher concentration in these areas than in other parts of the specimen (Sirois and Taylor, 1988). Fur samples were taken close to the skin in order to maximize the possibility of detecting arsenic on the fur, even if only the skin had been treated.

It is important to note that it is not always appropriate from an ethical standpoint to remove a sample of skin, fur or feather from a specimen. In such cases, one could carry out spot tests on a swab which has been wiped over the surface of the object. However, since only loose material from

the outer surface of the specimen is collected, this method may not provide reliable results. An evaluation of the reliability of spot tests on samples collected in this manner was not undertaken as part of this study.

### *Spot Test for Arsenic*

The spot test used to determine whether arsenic was present in the sample is a revised Gutzeit method (Feigl and Anger, 1972), developed for natural history specimens by Steven Weber at the University of Pittsburgh. The spot test procedure is outlined by Hawks and Williams (1986). Approximately 1 ml of distilled water was used as a negative standard and 2 to 3 pipette drops of an 800 ppm arsenic standard were used as a positive standard each time a series of tests was carried out. An alternative to this method is the use of commercial test strips for the detection of arsenic, such as those available from Canadawide Scientific (EM Quant Ion Specific Test Strips). However, these test strips may not have the same sensitivity as the spot testing method used in this study.

### *Spot Test for Mercury*

The diphenylcarbazone spot test (Feigl and Anger, 1972) was used to determine the presence or absence of mercury in the samples. Again, the procedure used follows that developed by Steven Weber. Since the spot test for mercury requires powder or crystalline samples, only 5 of the mammal specimens and 2 of the bird mounts were examined using this method. In these samples, particulate deposits in the form of powder, dust or crystals were visible with the unaided eye on the specimens; the deposits were removed with a cotton swab and the entire swab used for the spot test. Mercuric chloride powder was used as a positive control.

### *X-ray Microanalysis*

For comparison with the spot test results, elemental analysis was carried out on duplicate skin, fur, and feather samples from the suite of specimens. X-ray energy spectra were collected with an accelerating voltage of 20 keV using an Hitachi S-530 scanning electron microscope incorporating an X-ray energy spectrometer. This technique, referred to henceforth as SEM/XES, is used to detect elements of atomic number greater than or equal to 11 (sodium), present in concentrations above several percent. In a previous study using this instrumentation (Sirois and Taylor, 1988), the lower limit for the detection of arsenic dispersed in an inert material was determined experimentally to be 0.2%.

A small fragment of each sample was mounted on a carbon planchet and carbon coated to ensure conductivity. If powder was visible on the surface of the sample, this was analyzed in addition to the skin, feather, or fur. In the case of feather samples, the proximal end of the feather was used. Initially, a rapid area scan of a portion of the sample was carried out. If neither arsenic nor mercury was identified, other areas and spots were analyzed. If arsenic or mercury was identified in the initial scan, no other locations were analyzed.

These SEM/XES results are purely qualitative. It is not possible to quantify the results for several reasons. First, the samples which were analyzed are very small portions of the specimen, selected from areas in which the concentration of preservative is thought to be the highest. The quantity of arsenic or mercury in these small areas is not representative of the quantity of the materials in the specimen as a whole. In addition, the substrate composition and morphology change a great deal with sample type, making quantification of the results as a concentration of arsenic or mercury per unit mass or volume impossible. For these reasons, arsenic and mercury are reported simply as present or absent.

## RESULTS

A summary of the results of the spot tests and the X-ray microanalysis is shown in Figure 1. With both techniques, 28 of the 37 bird specimens tested positive for arsenic and none tested positive for mercury. For the mammal specimens, 7 of the 24 specimens tested positive for arsenic using the spot test, while 4 tested positive using SEM/XES. Using the spot test for mercury, 2 of the 5 mammals tested positive. Using SEM/XES, 2 out of the 24 mammal specimens tested pos-

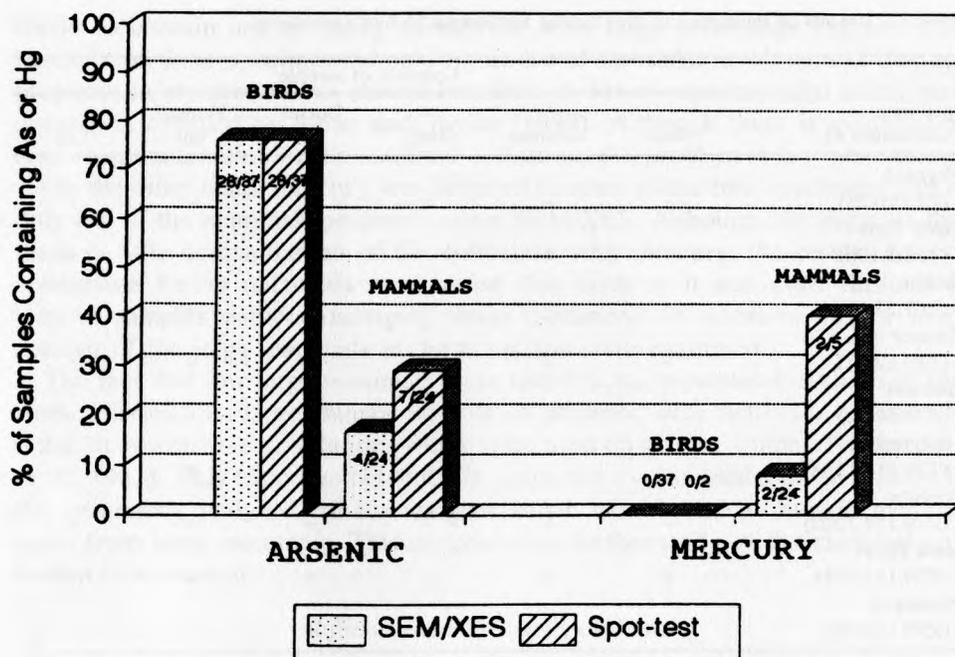


Figure 1. Spot test and SEM/XES results for the presence of arsenic and mercury. (Fractions indicate the positive results out of the total number of samples.)

itive for mercury. Details of sample location and test results obtained for each specimen are shown in Appendix 1.

The results of the multiple site spot testing for arsenic on selected bird specimens are shown in Table 1. Four out of 9 birds tested positive for arsenic regardless of the location of the spot test sample. The remaining 5 birds showed mixed results: samples from some areas on the specimen tested positive for arsenic while other areas did not. The frequency with which samples tested positive for arsenic appeared to be independent of the sample location. Samples from the head, ventrum, leg and ventral base of the tail tested positive in 6 out of 9 birds. Skin and/or feathers collected from the area on the dorsal base of the tail and on the back, breast or wing (collectively called the "body"), indicated arsenic in 5 out of 9 birds.

Table 2 shows the results for multiple site spot testing for arsenic on selected mammals. One out of 7 mammals tested positive for arsenic at every location sampled, while another mammal showed a negative result for all areas tested. The remaining 5 mammals showed mixed results. However, unlike the bird mounts, the frequency of a positive test for arsenic appeared to depend on the sample location. Six out of 6 mammals which showed at least one positive test for arsenic tested positive for samples taken from the ear. However, samples taken from the nose tested positive in 2 out of 6 mammals, and samples from the side of the mouth tested positive in 3 out of 6 mammals. No correlation was found between the species of bird or mammal and the results of the multiple spot testing.

Table 1. Results of multiple site spot testing for arsenic in bird specimens.

Specimen (accession #)	Location of sample					
	Head	Ventrum	Body	Dorsal/ tail	Ventral/ tail	Leg
Wryneck (Z78.96.23)	-	-	+	-	-	-
Black Tern (Z62.3.106)	+	+	+	+	+	+
Grouse (Z67.24.19)	+	-	-	-	-	-
Tanager (Z80.120.71)	+	+	+	+	+	+
Murrelet (Z79.142.2)	-	+	-	-	-	-
Sandgrouse (Z79.114.1148)	-	-	-	-	+	+
Penguin (Z79.114.1202)	+	+	-	+	+	+
Least Petrel (Z79.114.309)	+	+	+	+	+	+
Ptarmigan (Z79.113.75)	+	+	+	+	+	+

+ = positive test, - = negative test.

## DISCUSSION

### *Extent of Arsenic and Mercury Contamination*

From this study it appears that there is arsenic contamination in the bird collection at the Provincial Museum of Alberta. Approximately 1% of the museum's collection of birds was tested, and of these specimens, seventy-six percent were

Table 2. Results of multiple site spot testing for arsenic in mammal specimens.

Specimen (accession #)	Location of sample							
	Tip of ear	Body	Corner of eye	Nose	Side of mouth	Base of tail	Foot	Between ears
Bison (R305.161)	+	+	-	-	-	*	*	+
Moose (#58)	+	-	+	-	-	*	*	-
Caribou (#72)	+	+	+	+	+	*	*	+
Striped Skunk (Z75.21.3)	-	-	-	-	-	-	-	*
Grizzly (Z79.115.197)	+	+	-	-	+	+	-	*
Moose (Z79.129.119)	+	-	+	-	+	*	*	+
Red Squirrel (Z79.115.12)	+	+	+	+	-	+	+	*

+ = positive test, - = negative test, \* = not tested.

found to contain arsenic using SEM/XES. This large percentage suggests that handlers of these specimens should be aware of the risks involved and that appropriate safety precautions should be taken. A list of recommended safety procedures is outlined by Sirois and Taylor (1988). Although there is evidence of arsenic contamination in the mammal collection, the problem is less severe.

On the other hand, mercury was detected in none of the bird specimens and in only 8% of the mammal specimens using SEM/XES. Although this suggests that there is little contamination of the collection with mercury, the results are not conclusive. Fewer mammals were tested than birds as it was more difficult to remove samples without damaging these specimens. In addition, only a small number of the large mammals in the collection were examined.

The fact that few large mammals were tested is an important limitation of this work. Historically, large animals were often prepared with bichloride of mercury rather than with arsenic solutions which were used on smaller animals (Richardson et al., 1983). This historical evidence is supported by the results of this study; in the specimens analyzed, all the samples which were found to contain mercury came from large mammals. This suggests that further study of the mammal collection is warranted.

#### *Effectiveness of the Spot Tests*

From a comparison of the spot tests to the SEM/XES analysis, it appears that the spot test for arsenic on both the bird and mammal specimens produces reliable results. The spot tests and SEM/XES results were in agreement for 87% of the specimens examined. The spot test gave false positive results in 8% of the specimens and false negative results in 5%. An examination of the chemical elements identified by SEM/XES suggests that the incorrect spot test results are not linked to interfering elements.

Although the spot test can reliably determine if arsenic is present in a sample which has been removed from a specimen, the multiple site testing showed that non-representative sampling may lead to misleading conclusions about the presence of arsenic in the specimen as a whole. Five of 9 bird specimens and 4 of 6 mammal specimens gave variable results for the presence of arsenic depending on the location from which the sample was taken. This suggests that more work should be done to determine which areas of a specimen contain high arsenic concentration in order to develop an efficient sampling method for spot testing. To this end, non-destructive X-ray spectrometry (XES) could be used to examine multiple areas on the same specimen. This technique does not require sampling and provides a quick, simultaneous determination of arsenic and mercury (Sirois and Taylor, 1988).

Since the spot test for mercury was carried out on a small number of specimens, it is difficult to draw conclusions about whether it is reliable in detecting mercury. However, there appear to be difficulties with the test. Mercury was not detected by SEM/XES in either of the specimens which produced a positive result for the mercury spot test. In one case, however, a high concentration of zinc was found and in the other, low concentrations of iron, nickel and zinc were identified. Metals such as these are known to produce coloured compounds with the diphenylcarbazone reagent and their presence may lead to false positive results (Feigl and Anger, 1972). In addition, a large number of the specimens were found to contain

high concentrations of chlorine (possibly due to fumigation with chlorinated compounds); this may also interfere with the test results as the presence of chlorides in solution renders the test less sensitive to mercury (Feigl and Anger, 1972). In order to determine the extent to which these interfering elements are present in quantities great enough to produce results, more specimens should be tested, including those which contain no visible powder or crystalline material.

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## Appendix 1.

Collection and specimen (accession number in parentheses)	Sample description	Spot test results		SEM/ XES results	
		As	Hg	As	Hg
Bird Specimens					
A. W. Hardy Least Tern skin (Z78.96.26)	skin/feather, near legs	-	n	-	-
A. W. Hardy Brazilian Ruby skin (Z78.96.31)	feather, ventral base of tail	+	n	+	-
A. W. Hardy European Greenfinch skin (Z78.96.25)	feather, ventral base of tail	+	n	-	-
A. W. Hardy *Eurasian Wryneck skin (Z78.96.23)	feather, ventral base of tail	-	n	-	-
Judge Grey Great Spotted Woodpecker skin (Z62.2.47)	feather, ventral base of tail	+	n	+	-
Judge Grey Hoopoe skin (Z62.4.43)	feather, ventral base of tail	+	n	+	-
Judge Grey Bohemian Waxwing skin (Z62.4.45)	feather, ventral base of tail	+	n	+	-
Judge Grey Hawfinch skin (Z62.4.41)	feather, ventral base of tail	+	n	+	-
Judge Grey European Dipper skin (Z62.4.48)	feather, ventral base of tail	+	n	+	-
Kenneth Racey Wood Pigeon skin (Z80.120.576)	feather and stuffing, ventrum	+	n	+	-
Kenneth Racey *Western Tanager skin (Z80.120.71)	feather, ventrum	+	n	+	-
E. Laing Marbled Murrelet skin (Z80.120.539)	feather, ventral by legs	+	n	+	-
C. F. Holmes Merganser skin (Z80.120.33)	feather, ventral base of tail	+	n	+	-
C. F. Holmes Nighthawk skin (Z80.120.241)	skin, ventrum	+	n	+	-
C. F. Holmes Brown-headed Cowbird skin (Z80.120.527)	feather, ventrum	+	n	+	-
C. F. Holmes Harris' Sparrow skin (Z80,120.448)	feather, ventrum	+	n	+	-
Older In-House *Sharp-tailed Grouse skin (Z67.24.19)	skin, ventral seam	-	n	+	-
Older In-House Northern Shoveler skin (Z67.16.6)	skin/feather, dorsal base of tail	-	n	-	-
Older In-House Yellow-bellied Sapsucker skin (Z64.57.6)	feather, ventral by legs	-	n	-	-
Exchange/Transfer Marbled Murrelet skin (Z79.142.2)	feather, ventral base of tail	-	n	-	-
Exchange/Transfer Scarlet Tanager skin (Z87.30.1)	feather, ventral base of tail	-	n	-	-
Exchange/Transfer Scarlet Tanager skin (Z80.120.389)	feather, ventral base of tail	+	n	+	-
Exchange/Transfer Double-crested Cormorant mount (Z62.1.10)	skin/feather ventral base of tail	+	n	+	-
Exchange/Transfer Black-billed Magpie mount (Z62.1.205)	feather, ventral base of tail	+	n	+	-

## Appendix 1. Continued.

Collection and specimen (accession number in parentheses)	Sample description	Spot test results		SEM/ XES results	
		As	Hg	As	Hg
E. Brown Lady Amherst's Pheasant skin (Z62.3.96)	skin/feather, ventrum	-	-	-	-
E. Brown *Black Tern skin (Z62.3.106)	skin/feather, ventrum	+	n	+	-
E. Brown Franklin's Gull mount (Z62.3.107)	feather, ventral base of tail	+	n	-	-
Riveredge Magpie mount (Z79.114.1196)	skin/feather, humeral joint	+	n	+	-
Riveredge *Penguin skin (Z79.114.1202)	skin, ventral side of tail	+	-	+	-
Riveredge *White-tailed Ptarmigan skin (Z79.113.75)	skin, left thigh	+	n	+	-
Riveredge Pectoral Sand-Piper skin (Z79.113.501)	skin/feather, ventral base of tail	+	n	+	-
Riveredge Northern Waterthrush skin (Z79.113.121)	feather, ventral base of tail	+	n	+	-
Riveredge *Least Petrel skin (Z79.114.309)	feather, ventral base of tail	+	n	+	-
Riveredge Common Kite skin (Z79.114.915)	skin, ventral seam	+	n	+	-
Riveredge Chickadee skin (Z79.114.477)	feather, ventral base of tail	+	n	+	-
Riveredge *Namaqua Sandgrouse skin (Z79.114.1148)	feather/skin, back of neck	-	n	+	-
Riveredge Canada Goose mount (Z79.114.233)	skin/feather, back of neck	+	n	+	-
Mammal Specimens					
Riveredge *Grizzly Bear mount (Z79.115.197)	fur; left side of mouth	+	n	+	-
Riveredge Fur Seal mount (Z79.115.98)	skin/hair; left side of neck	-	n	-	-
Riveredge *Moose Head (#58)	skin; corner of right eye and right ear	+	+	-	-
Riveredge Dall Sheep head (Z79.129.28)	skin/hair; between horns	-	n	-	+
Riveredge *Wapiti head (#69)	skin/hair; left side of mouth, corner of right eye	+	n	+	-
Riveredge *Moose head (Z79.129.119)	skin/hair; tip of ear	+	-	+	+
Riveredge Sheep head (Z79.129.10)	skin/hair; back of neck	-	-	-	-
Riveredge *Caribou head (#72)	skin/hair; right ear	+	+	-	-
Riveredge *Bison head (R305.161)	skin; nose	-	n	-	-
Riveredge Lynx skin (Z79.133.20)	skin/hair; ventrum beside legs	-	n	-	-
Riveredge Pika mount (Z79.115.160)	hair; right thigh	-	n	-	-

## Appendix 1. Continued.

Collection and specimen (accession number in parentheses)	Sample description	Spot test results		SEM/ XES results	
		As	Hg	As	Hg
Riveredge Jackal skin (Z79.133.35)	skin/hair; right shoulder	-	n	-	-
Riveredge Wolf skin (Z79.133.13)	skin/hair; right ear	-	n	-	-
Riveredge Jaguarundi mount (Z79.115.103)	hair; under tail	-	n	-	-
Riveredge European Badger mount (Z79.115.57)	skin/hair; under tail	-	n	+	-
Riveredge *Red Fox head (Z79.129.20)	skin/hair; right ear	-	n	-	-
Riveredge Red Squirrel mount (Z79.115.12)	hair; ventral base of tail	+	n	-	-
Riveredge Musk Ox head (Z79.129.23)	skin/hair; nose and be- tween horns	-	n	-	-
Riveredge Leopard skin (Z79.133.68)	skin; inside of left ear	-	n	-	-
Riveredge Wapiti head (#68)	skin/hair; base of antlers	+	-	-	-
Older In-House Little Brown Bat skin (Z75.21.3)	skin/hair; ventrum	-	n	-	-
Older In-House *Striped Skunk skin (Z75.21.3)	skin/hair; ventral base of tail	-	n	-	-
Unknown Origin Pika mount (Z86.49.24)	hair; left thigh	-	n	-	-
Unknown Origin Wolf mount (Z87.10.2)	hair; left side of mouth	-	n	-	-

Specimens marked with an asterisk were used for multiple site testing.

+ = positive test, - = negative test, n = not tested, i = inconclusive due to spectral overlap with other elements.

# INTERACTION OF RESEARCH, MANAGEMENT, AND CONSERVATION FOR SERVING THE LONG-TERM INTERESTS OF NATURAL HISTORY COLLECTIONS

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*Abstract.*—It is generally accepted that natural history collections have considerable value and that these resources should be maintained for future reference and utilization. However, approaches for serving the long-term interests of collections often vary, depending on whether perspectives are based on research, management, or conservation. An effort is made to objectively assess the strengths and weaknesses of these perspectives, with respect to one another and to the realities of an evolving work force. While it is recognized that each perspective provides definite contributions to serving the long-term interests of collections, it is also recognized that no single or paired combination provides a suitable solution. The future of natural history collections is dependent upon a balance of utilization, management, and conservation; this includes the resources, decision-making, training, and other factors needed to make each function a viable contributor to a common objective.

Natural history research collections serve as the foundation of society's current knowledge of its natural heritage. Without this resource, the understanding of species, species distributions, and basic information about natural history and ecology would be extremely limited. Such a limitation would have severe ramifications for other sciences and social services that depend directly or indirectly on information resulting from these collections (Cato, 1991a; Cohen and Cressey, 1969; Genoways *et al.*, 1976; Miller, 1985). As concerns about global change and natural diversity (Black, 1993) increase, and developing technologies provide new methods of studying natural diversity, the value of natural history collections takes on new dimensions (Danks, 1991; Hoagland, 1989). There is no question about the significant impact these collections have had on society. It is, therefore, understood that this resource is worth preserving for reference and future uses.

Commitment to the long-term care of natural history collections is expressed in many professional and disciplinary proclamations, such as the code of ethics of the American Association of Museums (1993) which states "... institutions ... hold their possessions in trust for mankind and for the future of the [human] race." However, there are diverse ideas on how to fulfill this commitment depending on whether the perspective is based on research, management, or conservation. Many ideas are subjective and some occasionally conflict with one another. For instance, research perspectives currently emphasize natural diversity and molecular technology; management perspectives involve coordinating resources to make collections available for use; conservation focuses on long-term preservation. In 1992, people with these perspectives were brought together in Madrid at the *International Symposium and First World Congress on the Preservation and Conservation of Natural History Collections*, but approaches to serving collections remain subjective.

Research, management, and conservation each provide perspectives that have merit in promoting long-term interests of natural history collections. However, inherent problems also exist; thus, both the strengths and weaknesses of these approaches must be recognized to develop an understanding of how the interests of collections can best be served. The intent of this reassessment is not to cast doubt or blame on any segment of the natural history community; however, it is necessary to acknowledge and critically review a complicated evolution of events before realistically developing direction and strategies for the future. For this reason, the following contribution is presented in terms of three basic functions (research, management, and conservation) with intentional indifference to the individuals, professions, or job titles that may be responsible for one or more of these functions.

#### RESEARCH

The most important contribution to natural history collections provided by research is purpose. Without purpose, there is no justification for using resources for management and conservation. For this reason, it is essential that research and other forms of collection utilization be promoted as much as possible. The long-term interests of the collections are dependent on their continued utilization (Duckworth *et al.*, 1993; Foster, 1982; Simmons, 1993).

Research has served collections in other important ways. For instance, research initiatives have been responsible for documenting the existence of many collections and holdings throughout the world (Arnett and Samuelson, 1986; Banks *et al.*, 1973; Collette and Lachner, 1976; Genoways and Schlitter, 1980; Holmgren and Barnett, 1990; Hurd *et al.*, 1974; Solem, 1975; Wake *et al.*, 1975; Yates *et al.*, 1987). Standards, such as responsible collecting, disposition of voucher specimens, protecting primary types, and ultimately the integrity of published information, have enhanced the value of research collections (see Cato, 1988: Table 1; Knutson and Murphy, 1988).

While research has had a positive impact on many aspects of collections, it is necessary to recognize some important changes of an evolving function. One issue is that scientific methodologies practiced in research have not been carried forward on preservation and treatments of specimens. There has been very little systematic testing or documentation of methods and materials used for preservation purposes (Simmons, 1993; Walker, 1963). As a result, many of the procedures are similar to those practiced in the 1800s (Williams and Hawks, 1987), relying on enduring methods established by early researchers (Simmons, 1993). The lack of preservation documentation is now impacting other collection-related activities. There is currently no foundation for objectively evaluating the long-term effects of preservation procedures. Also, there is a lack of understanding about the suitability of preserved specimens for sophisticated research applications, such as molecular genetics or analysis of environmental pollutants.

Another fundamental issue with research involves a basic evolution of technology. As research interests and priorities have changed, using more sophisticated methods and more complex project designs, there has been a major shift in both academic training and professional involvement with collections. With systematic research in some disciplines increasingly emphasizing molecular applications (Humphrey, 1992), there has been less reliance on whole organisms. This

trend undoubtedly will continue as long as studies take researchers further from hands-on use of the collections. As a result there is a growing concern that the reduced emphasis of whole organismal biology in a growing number of academic programs may eventually result in a generation of new researchers that lacks the basic training or experience required for understanding systematic relationships and taxonomic characteristics (Anonymous, 1991; Hoagland and Mabee, 1988; Humphrey, 1992). Furthermore, because research historically has been a driving force behind the growth and development of natural history collections, there are additional concerns about how effective disassociated researchers can be in providing responsible direction and management of collections, particularly if they do not have meaningful management training or collections experience (Dixon, 1987; Simmons, 1993).

#### MANAGEMENT

Whereas research provides purpose for collections, management provides the mechanisms to fulfill that purpose. This involves processing new acquisitions and associated data from their original state to one which is properly preserved and available for use. Coordination of activities and resources for developing and maintaining collections is fundamental to utilization. Therefore, management is an equally important component of serving the long-term interests of collections (Simmons, 1993).

Historically, management activities in natural history collections have involved researchers. For instance, the effective implementation of modular storage (Jackson, 1926) for museums was initiated by natural history researchers. When research interests are directly dependent on the use of collections, it is not unusual for researchers to help manage and care for collections in a variety of ways, such as providing specimen identifications, organizing parts of the collection, and effectively managing resources for collections.

Management has served collections in other ways. Perhaps the most obvious contribution involves the methodical approach of dealing with entire collections that usually include tens of thousands, sometimes hundreds of thousands, of specimens and associated data. Integral components of this function include preservation, specimen processing, record processing, record management, computerization, storage, and maintenance. As collections are used for research purposes, effective management is essential if the order and integrity of the collection is to be protected. For museum collections in general, computerization had its origins with the management of natural science collections (Anderson, 1976). Subsequent efforts to establish documentation standards (McLeod, 1991; Williams *et al.*, 1979) improved quality of information associated with collections. Computerized information systems are now common tools for managing collections and assimilating information for research and other uses (Chesser and Owen, 1987; Folse *et al.*, 1987; McLaren *et al.*, 1987). Finally, literature involving management of collections (Brunton *et al.*, 1984; Cato, 1986; McGinley, 1989, 1990, 1993; Simmons, 1987; Williams *et al.*, 1977) now provides guidelines and strategies for the field as a whole.

Like research, management also has issues that must be addressed. A fundamental issue is the lack of consensus about the definition and working parameters of "collection management" (McGinley, 1989, 1990, 1993; Simmons, 1993). Part

of this problem is derived from individuals with titles of "collection manager," but having positions that reflect more supporting roles instead of managing roles. Also, "collection management" has been obscured by broadly defined roles and responsibilities as well as substantial overlap with research functions (Cato, 1991b). As a result, the museum community has filled positions without regard for training, experience, or expectations of management positions. This, in turn, has resulted in a broad range of qualifications among individuals responsible for the management of collections; for example, Cato (1991b) reports the highest level of education for individuals managing collections ranges from a high school diploma to a Ph.D. Regardless of the level of management expertise, there is a continuous need for individuals to receive new training to avoid obsolescence in a profession that is rapidly changing.

Another issue with management, resulting from evolving processes related to collections, is that very qualified individuals may be in charge of collection management, but under an institutional system effectively controlled by the research interests directly or indirectly associated with the collection (Simmons, 1993). At least half of the individuals formally charged with managing research collections, do so without the authority for essential decision-making and resource management to address other collection needs when necessary (Cato 1991b; Hoagland and Mabee, 1988). Such situations are often characterized by collections having parts that are unequally managed, as well as management positions that start and remain "plateaued" with respect to career development.

#### CONSERVATION

Conservation is just as important as research and management with respect to serving the long-term interests of natural history collections. It provides a responsible approach to preserving collections so that they will be available in the future. This approach is based on critical examination and extensive documentation for evaluating methods and materials used for collections. It also includes the responsible selection of conditions for collections that will reduce risks of damage or deterioration, as well as maintain research integrity of specimens.

New research technology has influenced the development of philosophies and practices for caring for natural history specimens. Until recently, no one imagined that specimens in natural history research collections would be used for studies of biochemistry, genetics, or environmental monitoring of toxic chemicals (Diamond, 1990; George, 1987; Herrman and Hummel, 1994; Higuchi *et al.*, 1984; Smith and Patton, 1991; Thomas *et al.*, 1990). As these collections continue to be developed, future uses involving more sophisticated techniques must be anticipated, and preservation techniques must be developed in concert to accommodate new research applications. Also, as species become endangered and ecosystems threatened, it is critical that preservation treatments of voucher material maximize specimen utility for research purposes as well as provide long-term stability for future uses. For all practical purposes, this means using methods and materials that will not compromise specimen integrity for research in the future. Therefore, new standards for collection care stress the importance of not exposing specimens indiscriminately to chemicals, such as preservatives, adhesives, or pesticides, because of the risk of losing or modifying the ultrastructural, chemical, genetic, or viable (i.e., seeds and spores) components of the specimen. With regard to en-

vironmental monitoring, for example, it would not be useful to test specimens for heavy metals, if compounds of these metals were applied as preservatives (George, 1987). Furthermore, very little is known about the interaction of many chemicals with the cellular and molecular structures of organic materials and how this might be reflected in research value or stability of specimens.

The need for non-intrusive methods for dealing with natural history materials, makes preventive conservation practices (Rose, 1991) a logical approach for addressing the conservation needs of collections. These practices involve non-interventive actions taken to eliminate or minimize chemical, mechanical, and biological deterioration in collections.

The basis for preventive conservation is providing protection to the specimens by reducing exposure to negative factors of the collection environment. This is done, for example, by turning off lights, avoiding the crowding of specimens, putting specimens in closed storage units when not in use, and practicing integrated pest management. These kinds of activities can and should be practiced by all individuals associated with collections. Other preventive conservation activities require that staff develop a better awareness of collection conditions and needs through improved documentation practices. To provide basic protection, most situations require examination, evaluation, problem recognition, solution development, and solution implementation to achieve the desired results (Cato, 1990; Rose, 1991).

As philosophies and practices of preventive conservation become incorporated in collection operations, the services of the conservation profession must not be overlooked. Other disciplines that maintain extensive collections (i.e., fine arts, anthropology, archives, and libraries) have already realized the benefits of having academically trained conservators associated with collections. These benefits include training staff in proper collection care, anticipating material reactions, recognizing and evaluating active deterioration, providing conservation treatments (if deemed necessary), assisting with preventive conservation measures, and other related activities. For the sake of natural history collections, it must be recognized that such conservation activities must be conducted by only those individuals with appropriate conservation training which includes a strong background in material sciences.

One fundamental issue with conservation is that it has not been an important part of natural history collections until recently. Some parts of the natural history community have assumed that conservation practices have always been in place, when in fact, such activities have contributed to more serious problems (i.e., processing specimens inappropriately, repairing specimens, selection of preservation materials, and pest control). Recent collection care interest and awareness by the natural history community have exposed the seriousness of these practices and the need for immediate corrective measures (Duckworth *et al.*, 1993; Hawks and Williams, 1986; Hawks *et al.*, 1984; Howie, 1992; Rose and Torres, 1992; Tennent and Baird, 1985; Williams, 1991; Williams and Hawks, 1992; Williams *et al.*, 1986, 1989). However, most natural history research collections are 15 to 25 years behind trends of "museum conservation" that started in the 1950s and 1960s (Greathouse and Wessel, 1954; Plenderleith, 1956; Plenderleith and Werner, 1962). This is a serious oversight, particularly when one remembers that the in-

tention of natural history collections is the long-term preservation of objects for research and heritage purposes.

Conservation philosophies and practices are just developing for the natural sciences. Unlike the classical conservation activities of some disciplines (i.e., fine arts) where individual objects are restored to original condition, natural history conservation emphasizes preventive conservation, and equally important, the care of entire collections. Currently, very few individuals possess the necessary levels of training and expertise in natural history conservation. It will be years before sufficient numbers of natural history conservators are available to address the growing needs of natural history collections.

#### COORDINATING INITIATIVES TO MEET NEW CHALLENGES

Specimens in many collections now exceed 100 years in age, and there are many groups of specimens that are irreplaceable. For instance, the most valuable and irreplaceable holdings of a collection are the primary type specimens, the single designated specimen described in the literature as the ultimate representative of a given taxon. Other specimens have historical significance because of their relationship to early natural historians, such as Charles Darwin, John James Audubon, Charles Wilson Peale, and Thomas Jefferson. Still other specimens are irreplaceable because they now represent the primary source of information of extirpated, protected, and rare species, as well as specimens from destroyed habitats or politically inaccessible regions. All of these are prime examples of specimens that might deserve superior levels of collection care. As priorities are established to systematically address the needs of collections, it must be realized that the value of a taxon or population can change dramatically by factors ranging from taxonomic revisions to habitat destruction.

Undoubtedly, ongoing efforts to document natural diversity of the planet before ecosystems are lost or modified as a result of global change, will add new and valuable material to research collections. Many of these new acquisitions may never be duplicated because of habitat destruction or because the lack of resources will close doors to opportunities.

Based on the scenarios presented with research, management, and conservation, it would be a mistake to assume that any single or paired approach can serve the long-term interests of collections. Research and/or management do not provide suitable solutions if the "life" of the collection is shortened as a result of natural processes that cause deterioration. Similarly, superior levels of management and/or conservation do not resolve the issue if the end result is a collection that is orphaned because of lack of use. Finally, utilization and/or conservation have only short-term benefits if the collection is not organized and accessible. Based on the combinations presented, it is clear that to truly serve the long-term interests of collections it is necessary to have an integrated and balanced approach involving research, management, and conservation.

To develop an integrated approach, it is necessary to critically review some of the inherent issues of the current system, and then try to develop strategies to address these issues. The training of new and qualified individuals has been a recent and important issue for research and conservation (Duckworth *et al.*, 1993; Humphrey, 1992). Ironically, for research, it is a matter of replenishing a resource that is disappearing, and for conservation, it is building a resource that has been

lacking in the natural history community. Although there is equal justification to encourage training in collection management as well, the key issues noted for management include defining the scope of the function and establishing conditions to make the management function more effective and responsive to collection needs.

To objectively deal with all of these issues, it is necessary to consider extrinsic factors, such as the economics and demographic patterns in the work force, that may influence these initiatives. It is important to acknowledge that the training of new and qualified researchers may not become a serious priority among academic institutions until governments or corporations make it financially attractive. It is conceivable that this might not happen until the services of systematists become more in demand as a result of attrition of the existing work force *or* the progress of studies involving natural diversity and molecular genetics are hampered by the absence of systematics resources and expertise. It is possible that until systematics research becomes a greater priority, natural history collections will be at high risk of being orphaned, particularly at academic institutions. As this becomes a more serious problem, there may be a growing reliance on the systematics expertise among individuals responsible for managing collections, simply for the sake of identifying and organizing materials so that they may be used.

On the flip-side of research, it is conceivable that collections may become an important resource for molecular genetics, monitoring of environmental pollution, and similar studies. In such a situation, it is important to realize that expertise in these specializations does not necessarily qualify an individual to make responsible decisions for the direction and management of collections.

The training of individuals with expertise in conservation of natural history materials recently has been addressed by the National Institute for Conservation (Duckworth *et al.*, 1993) as well as other initiatives by training centers or projects. At the present time there are very few natural history conservators, and if the conservation programs proposed by Duckworth *et al.* (1993) can be developed in the near future, it will be near the turn of the century before any newly trained conservators will be ready for the job market.

By the end of the current century, it can be expected that collection sizes will increase by 25–35% (Hoagland and Mabee, 1988). This estimate may be very conservative if natural diversity research significantly affects collections. In that time period, hundreds of existing natural history professionals will be reaching the later stages of their careers; some will be reaching retirement age. Based on data presented by Cato (1991b), at the turn of the century the median age of individuals responsible for management will be 48 years. Because new collection positions and newly trained professionals have been slow to develop, the natural history community is faced with a serious problem involving an aging work force. For example, in the United States the aging work force and the attrition of qualified and educated workers are already a growing national concern (Fyock, 1990; Smith, 1989). However, the seriousness of this issue is more acute for the natural history community when one realizes that the average age of American workers, specifically affiliated with collections, is at least ten years ahead of the average age of all workers in the country.

With respect to conservation, it is believed that the use of this existing work

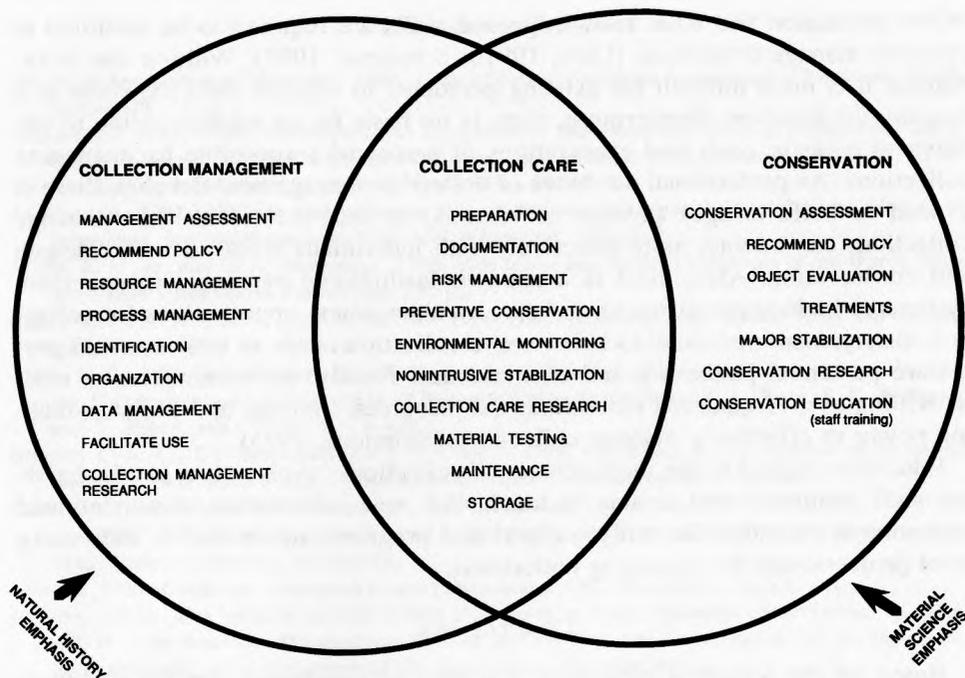


Figure 1. Diagram showing the relationship of management and conservation with respect to providing long-term care of natural history collections (presented by the authors in May 1992, at the International Symposium and First World Congress on the Preservation and Conservation of Natural History Collections, in Madrid, Spain).

force can be an important solution to serving the long-term interests of collections, even though many conservation activities should be conducted only by appropriately trained individuals (Duckworth *et al.*, 1993). To address this possibility it is convenient to examine basic activities included in management and conservation functions, as well as those activities that might be shared (Fig. 1). From such a comparison it is evident that job restructuring, selective guidance, and relevant training might allow individuals responsible for managing collections to provide better care for collections.

For the research and conservation functions, it is necessary to anticipate the possibility that expected changes in the labor force, combined with limitations of educational mechanisms, may mean that appropriately trained personnel will not be available to perform related activities for some time. In this situation, it may become necessary for individuals responsible for management to emphasize some of the overlapping activities that might otherwise be provided by personnel responsible for research and conservation. For example, species identification and preventive conservation are overlapping activities.

Although there is nothing wrong with overlap of activities between research, management, and conservation, the more critical issue is realistically defining the parameters of collection management. Management of collections has not yet evolved as a profession to levels where standards and a basis for professional recognition are clearly established. There is a need for understanding the scope

of the profession and what knowledge and skills are required to be qualified to properly manage collections (Cato, 1991b; Simmons, 1993). Without this information, it is more difficult for existing personnel to upgrade their expertise in a meaningful direction. Furthermore, there is no basis for an administration to understand realistic goals and expectations of personnel responsible for managing collections. As professional attributes of collection management develop, there is a need to build bridges (instead of barriers) so that individuals who manage collections can interact more effectively with individuals involved with research and conservation. Also, there is a need in institutional personnel management systems to include career tracks and career enhancement opportunities for collection management personnel to better serve collection needs as well as avoid premature personnel plateauing and obsolescence. Finally, the administration must be willing to give qualified individuals the resources, training, and decision-making power to effectively manage collections (Simmons, 1993).

Education related to the management of collections involves two levels. Existing staff members need to stay in touch with new information, thus continued education is essential. Secondly, support and programs are needed to train entry level professionals for managing collections.

#### CONCLUSIONS

Based on the scenarios presented, it is easy to understand that the ability to serve the long-term interests of natural history collections is ultimately achieved by several factors, acting in concert. These collections are maintained for the purpose of being used, primarily for research, but also for many other users, including exhibits and education. If the collections do not have utility, it is difficult to justify the use of resources for management and conservation. Researchers can help with the care of collections by employing quality preservation procedures, documenting the methods and materials used with such procedures, administratively supporting management and conservation initiatives, and using materials in ways to promote better management and care. Until the conservation profession becomes more involved with the natural history community, individuals in existing collection positions are the primary resource for promoting long-term care of collections. For this reason there is a desperate need for opportunities and resources to provide training of existing professionals as well as entry level professionals.

An attempt has been made to show that the best way to serve the long-term interests of natural history collections is to provide a balance between utilization, management, and conservation activities. It is clear that an imbalance in favor of one of these functions potentially jeopardizes the future of the collection.

#### ACKNOWLEDGMENTS

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# EVALUATION OF AN INTEGRATED PEST MANAGEMENT PROGRAM, DIVISION OF BIRDS, U.S. NATIONAL MUSEUM OF NATURAL HISTORY

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*Abstract.*—A three-year insect monitoring study was conducted to analyze the effectiveness of an Integrated Pest Management (IPM) program developed in the Division of Birds at the Natural History Museum, Smithsonian Institution (USNM). After implementation of the IPM program (which included monitoring with sticky traps and chemical applications of insecticides to baseboards, cracks, and crevices) a significant decrease was noted in total numbers of insects trapped in the divisional offices and collection area. The target pest was the odd beetle (*Thyodrias contractus*; Family Dermestidae). During the three year period, 65% of all insect categories peaked in spring and summer and had a positive relationship with relative humidity peaks. Monitoring with sticky traps, however, did not indicate any appreciable decrease of insects inside storage cabinets.

A serious concern to managers of natural history collections is the control and eradication of insect pests that threaten collections. At the same time, concerns for staff health and safety (Linnie, 1990), increasing federal and state restrictions on fumigant use, and the possible deleterious effects of fumigants on specimens (Williams *et al.*, 1986) are now requiring a more multifaceted approach to pest control. Natural history museums are responding, in part, by revising collections maintenance procedures (Alpert and Alpert, 1988), developing Integrated Pest Management (IPM) programs (Florian, 1989; Webb *et al.*, 1989) and including IPM programs in policies set forth by managers of natural history collections (Cato and Williams, 1993).

In November 1990, chemical fumigation (Vulcan Formula 72<sup>™</sup>; 29.8% carbon tetrachloride, 72.2% ethylene dichloride) in the Bird and Mammal Divisions, National Museum of Natural History (USNM) was terminated. Because of the prohibition of this long-time staple for prophylactic fumigation, an IPM program, including an insect monitoring schedule, was developed specifically for the Division of Birds. The following IPM program is provisional, as we are still developing procedures within the available resources and limited budget allotted for this purpose. Due to increased budget constraints imposed upon the museum community at large, we have kept monetary and personnel costs of this program to a minimum. Because the physical properties of the collection area are diverse, much experimentation was necessary in developing the IPM program.

The Division of Birds occupies 15,715 square feet and contains 16 offices, a library, spirit collections, and approximately 2,000 wooden or metal storage cabinets holding about 500,000 specimens prepared as study skins and/or skeletons. An additional 35,000 egg sets and nest collection are stored at the Museum Support Center. On average (1990–93) there are 1,500 newly acquired specimens, 150 shipping transactions, 120 loan returns, and 300 visitors annually, making this collection one of the largest and busiest worldwide.

The division is located on the sixth floor of a wing that was added in 1961 to the original 1910 structure. All windows are permanently sealed, and there are two drains and five doors (one opens to the exterior) in the area. Potted plants and eating are permitted in offices. Former pest control measures involved semiannual weekend prophylactic application of approximately 35 cubic ml (Vulcan 72<sup>®</sup>) to each storage cabinet. This application took about six hours for 5–7 staff members. Staff were allowed to return to offices the following week. This method was assumed to be effective since infestations were seldom reported; therefore no insect trapping or monitoring was conducted prior to the IPM program. Because the collection is “contained” within four walls, maintained by a relative small staff (one collections manager and three museum specialists) and financed from a limited divisional budget, the IPM program presented here may be applicable to smaller collections.

Our first goal in combating pest infestations was to determine what insects were present in the division. Insect monitoring (using sticky traps) has been continuous since January 1991, shortly after the last collection-wide fumigation. Monitoring is viewed as our “watchdog” on pest populations, target species, and effectiveness of IPM applications.

Results from monitoring have allowed us to build an empirical database to communicate our pest control concerns to other staff members and visitors. We also use these data to substantiate collection management decisions and policies that we feel are necessary.

#### METHODS AND MATERIALS

Our IPM program is continually evolving, some of the procedures discussed here are new, while others have been in effect since monitoring with sticky traps began. The following represents aspects of the IPM program developed in the Bird Division and does not reflect a museum-wide policy.

*Housekeeping.*—Staff members are responsible for keeping their office areas clean of food and dirty dishes. Routine custodial cleaning includes daily trash pickup, weekly dust mopping, vacuuming one carpeted office, and semiannual wet mopping and floor waxing. Closets and baseboards are cleaned and vacuumed by the collection management staff (CMS) prior to application of baseboard contact poison and a crack and crevice flushing agent (see Chemical Treatments section). The CMS is also responsible for dusting surfaces, clearing cluttered workspaces, eliminating unwanted cardboard boxes, and other general cleanup as time allows. Maintaining a hospital-like environment is an unrealistic goal in a heavily used collection of this size, however every effort is made to keep the entire area as clean as possible.

Because the packing area has greater potential for pests from dust, incoming boxes, packing material, and many hard-to-reach areas, it is cleaned on a weekly basis. Packing cotton and boxes that are to be reused undergo freezer treatment; cotton is then placed in tightly sealed plastic bags. If packing containers or materials look suspicious, they are taken immediately to a dumpster outside the museum.

*Visual inspections.*—Visual inspections are conducted in the skin collection by the CMS on a weekly basis. Approximately one hour per week is spent for routine inspection of storage cabinets. Careful examination of specimens, debris in drawers, identification of frass and casings, and vacuum cleaning of all drawers in the cabinet is part of the inspection. This usually allows for close inspection of 9–15 different cabinets per week.

Visual inspections of cabinets revealed frass and insect carcasses in many cabinets, indicating a history of low level infestations that may have been controlled previously by periodic fumigation. Cabinets that have been checked are labeled with green dots to indicate that the cabinet has been examined for pests. If insect damage to a specimen is noted, efforts are made to determine if the damage is recent. The area of damage, as well as the date when the damage was discovered, are recorded on the specimen labels to alert future users and to prevent repeated alarm. Volunteers and

visitors are requested to watch for insect damage and to bring any damage or frass to the attention of the CMS.

*Lining drawers.*—Drawer lining is an ongoing conservation project that has become a part of the IPM program. Thus far, most of the half-unit cabinets have been vacuumed and drawers have been lined with six mil polyethylene that is covered with 36 lb. acid-free unbuffered ledger paper. The plastic protects specimens from acid migration from direct contact with the wooden or masonite drawer bottoms. Lining drawers improved curatorial aesthetics, provided preservation value, and aided in visual detection of frass and insects.

*Freezing.*—All incoming USNM specimens and field equipment are frozen for ten days at  $-10^{\circ}\text{F}$  in a chest freezer (Kenmore 23<sup>™</sup>) designated specifically for pest control. A two-inch styrofoam lid fits inside of the top of the freezer to help maintain a stable temperature (see Pinzl, 1993 for additional freezer modification specifics). The freezing method used basically follows that described by Florian (1990). USNM field and loaned specimens are unpacked as soon as they arrive, put in cardboard trays, and tightly closed in plastic bags labeled with the date placed in the freezer. When specimens are removed from the freezer, they are brought to room temperature before they are removed from the bag. Because reports by Strang (1992) and Gilberg and Brokerhof (1991) do not give specific freezing times for our target pest (*Thyrodrias*), and literature on non-agricultural pests is limited, a ten day period was arbitrarily chosen. Preliminary results from experiments with freezing resulted in complete mortality of *Thyrodrias* larvae (five different instars placed inside study skins) after five hours of freezing. We realize, however, that these data are incomplete because adults and eggs were not tested. We have not observed any specimen damage to study skins, skeletons or their labels from this procedure.

Skeletal specimens from the processing lab and incoming boxes and packing materials that are to be saved are also frozen for ten days. Material that is too large for the chest freezer is placed in a walk-in freezer for a similar length of time.

*Infestations.*—If insects are found inside cabinets during visual inspections or trapping, the following steps are taken immediately:

1. Identify pest and amount of damage.
2. Examine entire storage cabinet and adjacent cabinets.
3. If infestation is severe, remove and freeze all specimens and drawers, clean cabinet and treat it with para-dichlorobenzene (PDB). If insects are trapped inside cabinets or specimen damage is local, remove specimens and vacuum all drawers and cabinet, treat cabinet with PDB. Freeze only specimens that show damage.
4. Line drawers with polyethylene and acid-free paper.
5. Note specimen damage on labels or file a specimen condition report.
6. Keep cabinet closed until all PDB sublimates.

*Chemical treatments—Ficam/PT 230 Tri-Die/PDB.*—Two CMS members are certified by the District of Columbia Pesticide and Hazardous Waste Management Branch to apply Ficam W<sup>™</sup> insecticide (Nor-Am Chemical Co., Wilmington, DE) and PT 230 Tri-Die<sup>™</sup> (Whitmore Research Labs, St. Louis, MO) crack and crevice aerogel. Ficam W<sup>™</sup> is a wettable powder consisting of 24% inert ingredients and 76% bendiocarb (2,2-dimethyl-1,3-benzodioxol-4-yl methylcarbamate). It is applied as a liquid to the perimeter of all ground-level cabinets (2" × 4" base) and baseboards with a three-inch paint brush attached to a broom handle. The entire outer perimeter of each cabinet row in the collection area and selected offices are treated. Cracks and crevices are treated once annually with PT 230 Tri-Die<sup>™</sup> (schedule based on monitoring results). PT 230 Tri-Die<sup>™</sup> contains activated pyrethrins in silica aerogel. PDB is used to fumigate hold-up and problem cabinets (a ¼ lb. is applied per half-unit cabinet measuring approximately 26 cubic feet) and left sealed in the cabinet until all crystals have sublimated. Pesticide application reports and Material Safety Data Sheets (MSDS) are kept on file in the division.

Ficam W<sup>™</sup> was applied in the fall 1991. Ficam W<sup>™</sup> and PT 230 Tri-Die<sup>™</sup> in the spring of 1993 and 1994. These specific chemicals were selected because they are safe to use, easy to apply, and designed to kill a variety of dermestid (target) species.

*Temperature and relative humidity monitoring.*—Four Oakton<sup>™</sup> thermohygrometers were installed in the collection area in September, 1991 to determine if correlations existed between internal environmental factors and insect population peaks. Monitoring of temperature (T) and relative humidity (RH) is conducted daily (Mon–Fri) within the collection area. For this study, data were compared

annually by location and averages were calculated using SYSTAT<sup>®</sup> for Windows<sup>™</sup> (SYSTAT Inc., 1992).

*Pest monitoring.*—Trapping and identification were the responsibility of the CMS and were made by using field guides and references (Borror and White, 1970; Edwards *et al.*, 1980; White, 1983; Zycherman and Schrock, 1988; Gorham 1991). In the beginning, we were assisted with identifications by entomologists (Department of Entomology, USNM). Single, tent-type unbaited sticky traps were maintained in 56 locations in the divisional offices and throughout collection areas continuously for 30–40 day periods. Commercial pest control companies were unable to provide us with specific information on minimum numbers, or traps per square feet, required to adequately sample an area. They agreed that experimentation is the best policy when deciding how many traps to place and when to increase trapping. However, one sticky trap every ten square meters in a grid pattern was recommended for initial monitoring (M. Gilberg, pers. comm.). Traps were labeled with the date and number of the fixed location and placed next to walls or corners when possible as insects often travel along such pathways.

Sticky traps were also used to monitor inside storage cabinets. Flaps were removed from the trap which was placed between the bottom drawer and the base of the cabinet, usually in the bottom-most of the tiered cabinets. Each trap was labeled with cabinet number and date. Cabinet traps were not replaced as often as office traps because the sticky material on the trap did not dry out as quickly. Cabinets were continuously monitored and checked four times per year (fall, winter, spring, summer for 75–90 days). The number of cabinet traps ranged from 49–86 in 1991, 45–51 in 1992, and stabilized at 45 in 1993. Results, actions, and daily observations of trap and visual inspection monitoring activities were recorded in a pest control log. Based on preliminary assessments, we concluded that the trapping period and the number and location of cabinet and office traps were adequate to yield a valid yearly cross-section and spatial representation of the division.

Traps were examined for insects with a dissecting scope and results were entered to a database. This system, designed by Kim Robinson (IPM Coordinator, National Park Service, Lanham, Maryland) facilitated compilation of species and trap location listings. For each trap, the number, date set, species name, and number and type of insects found were recorded.

## RESULTS

The monitoring program in this division was the first of its kind to be implemented as a regular collection management activity in this museum and has proven to be the most important part of the IPM program. Monitoring has been used to detect outbreaks, determine target insect species, and reveal seasonal population fluctuations.

The results of monitoring have allowed us to identify our main pest as the odd beetle (*Thylo-drias contractus*) and to determine peaks in its population cycle. An inventory of all arthropods observed in the Division of Birds is also maintained (Table 1), but only populations of the most numerous or potentially dangerous insects were graphed and closely monitored (Fig. 1).

The major species collected during 1991–93 were compared (Fig. 1). As expected, spring and summer were peak periods for 65% of the species on these combined lists. "Miscellaneous" insects such as thrips, flies, mosquitoes, spring-tails, and midges were not identified to species. Their abundance increased throughout the study. Populations of cockroaches (*Periplaneta*, *Blatta*), an indicator species of general building sanitation, were consistently low during all trapping periods. Pillbug outbreaks occurred in the fall/winter of 1991 and were attributable to some staff members who brought houseplants indoors for the winter. However, the number of pillbugs dropped to zero in the summer when the plants were removed (pillbugs did not wander far from the area of house plants). Predators such as house crickets, centipedes and spiders were not common in the division. Male *Thylo-drias* (odd beetles) were more numerous than females, es-

Table 1. Cumulative list of arthropod pests found in the Division of Birds since 1991.

Pest order	Common name	
Orthoptera	American Cockroach	
	Oriental Cockroach	
	German Cockroach	
Hymenoptera	Bee	
	Ant	
Coleoptera	Cabinet Beetle	
	Click Beetle	
	Confused Flour Beetle	
	Fungus Beetle	
	Flower Beetle	
	Ground Beetle	
	Odd Beetle	
	Rove Beetle	
	Scarab	
	Spider Beetle	
	Varied Carpet Beetle	
	Diptera	Fly
		Gall Midge
Gnat		
Mosquito		
Lepidoptera	Moth	
	Webbing Clothes Moth	
Isopoda	Pillbug/Sowbug	
Psocoptera	Psocid	
Thysanura	Silverfish	
Thysanoptera	Thrips	
Acarina	Mite	
Homoptera	Aphid	

pecially in the spring. Only two other species of destructive beetles were found in the collection after monitoring began—the varied carpet beetle (*Anthrenus*), spring 1991, and a cabinet beetle (*Trogoderma*), spring 1992. Only one of the three moths trapped, a webbing clothes moth (*Tineola bisselliella*), was considered harmful to the collections.

Because the most destructive stage of odd beetles is the larval instars, population fluctuations were monitored closely (Fig. 2). Numbers of odd beetle larvae peaked in spring and summer seasons all three years but an overall decline was observed from 1991 to 1993.

The percentage of empty traps has increased steadily since the monitoring program began: 1991 (32%), 1992 (47%), 1993 (51%). An increase in the number of empty traps and a decrease in odd beetle larvae were noted after implementation of the IPM program and chemical applications. Data from storage case traps (Fig. 3) indicated total numbers of insects in 1991 (13), 1992 (19), and 1993 (11). Psocids were the most numerous pests found; 70% of the insects trapped inside cabinets were associated with the skeleton collection.

Results for 1993 (Fig. 4) show an overall average temperature just below 70°F and extreme variation in relative humidity in the division. Analysis of variance (ANOVA) indicates that variation in temperature and relative humidity within and between locations are significant at each station ( $P = 0.000$  in all cases). Variation

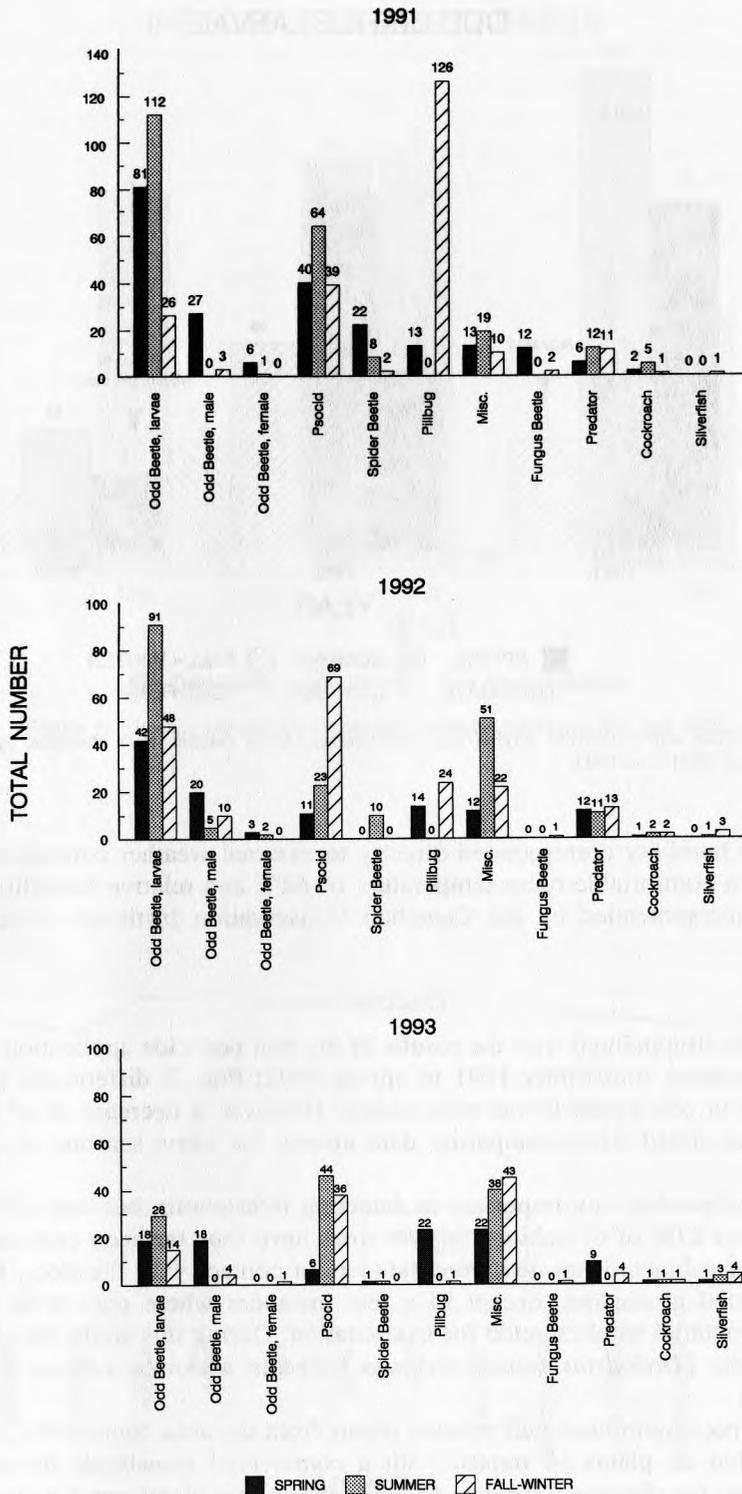


Figure 1. Trap results for offices and collection area between 1991 and 1993.

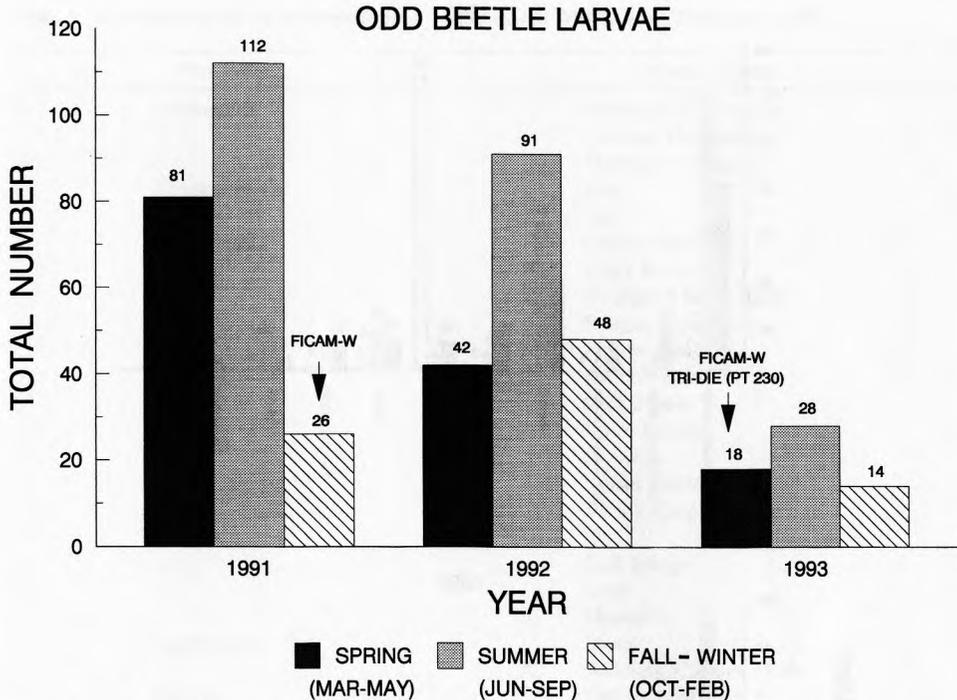


Figure 2. Office and collection *Thylophorus* (odd beetle) larvae catches with chemical applications noted between 1991 and 1993.

in relative humidity corresponded directly to external weather conditions. Deviations from comfortable room temperature of 68°F and relative humidity of 45–55% (as recommended by the Canadian Conservation Institute) occurred frequently.

#### DISCUSSION

We were disappointed with the results of the first pesticide application because between seasons (fall/winter 1991 to spring 1992; Fig. 2) differences were not significant in odd beetle larvae populations. However, a decrease in all harmful species was noted when comparing data among the same seasons of different years.

Visual inspections are important in detecting infestations, but only 2% of 100 cabinets and 27% of 67 cabinets in two rows have thus far been examined. The majority of cabinets inspected were cabinets in contact with the floor. Cabinets were selected at random, except in a few instances where ones with recently collected material were targeted for examination. During this study, one live odd beetle larvae (*Thylophorus contractus*) was found in a storage cabinet by visual inspection.

We did not require that staff remove plants from the area. Since 1992, we have required that all plants be treated with a commercial insecticide before being brought into the division. Our data do not suggest that plants are a major contribution to the pest problem at this time. Plant-loving insect species (mainly pill-

INSECTS: STORAGE CABINETS

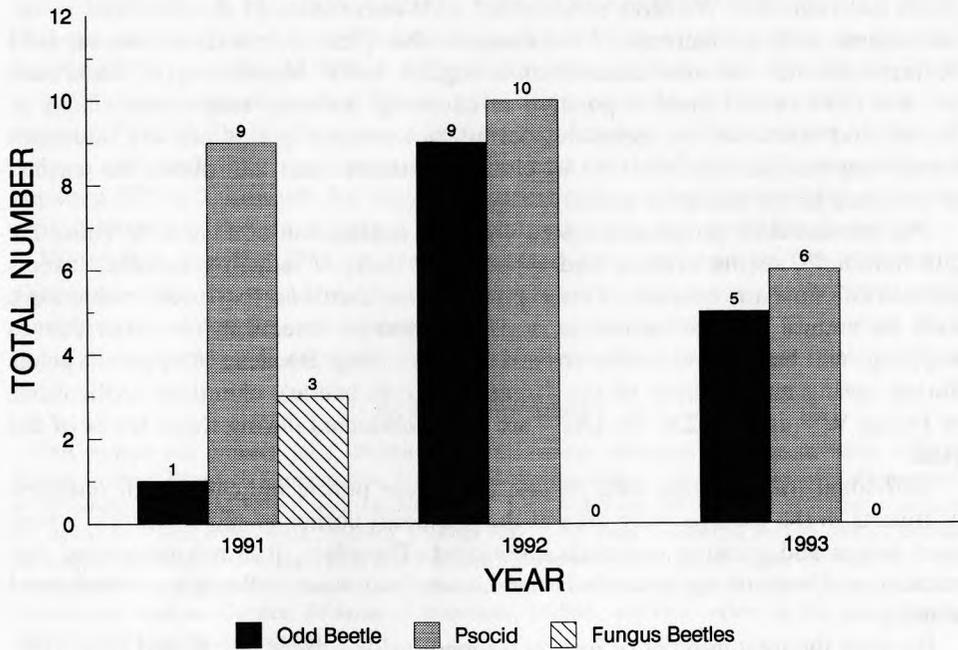


Figure 3. Insects trapped inside storage cabinets between 1991 and 1993.

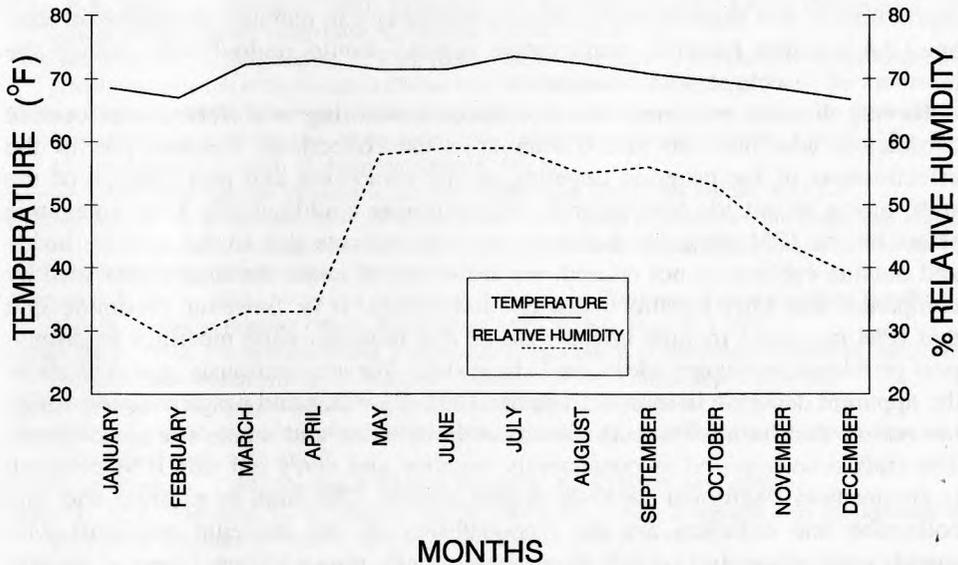


Figure 4. Monthly average temperature/relative humidity results for 1993.

bugs) peak with the influx of plants, but their populations drop to zero when plants are removed. We have not noticed a co-occurrence of detritus-feeding insects when pillbugs increase. We do require that plant debris (dead leaves, soil) be removed and the area cleaned on a regular basis. Monitoring of cockroach catches has not indicated a positive relationship between employees eating in offices and insect levels; therefore, we are not restricting this activity, although we do require that food be kept in closed containers and that dishes be washed or returned to the cafeteria quickly.

The current IPM program coupled with the application of Ficam W<sup>™</sup> and PT 230 Tri-Die<sup>™</sup>, seems to have had a positive effect on reducing harmful insects outside of museum cabinets. Other possible explanations for insect reductions, such as natural population trends or elimination of insects in one area due to trapping, will be determined by continued monitoring. Because of apparent peaks during spring and summer of the target pest (odd beetle), chemical applications of Ficam W<sup>™</sup> and PT 230 Tri-Die<sup>™</sup> are now conducted during those times of the year.

Individual trap location data for the three-year period indicated high numbers of insects in the loan packing area at the southeast corner of the collection where used boxes and packing materials are stored. Therefore, it is recommended that packing and box storage areas be located away from main collections, and cleaned weekly.

Because the total number of insects trapped inside cabinets increased from 1991 to 1992, it does not appear that the baseboard and crevice chemical treatments had a positive effect on activity inside cabinets. PDB is the only chemical treatment used in this collection; however, we are currently experimenting with painting the cabinet floors with the contact poison Ficam W<sup>™</sup> and sending disarticulated, greasy skeletal specimens to the processing lab for recleaning.

The humidity problem is serious and appears to have a positive relationship with insect peaks. High humidity provides ideal conditions for insect and mold reproduction, and fluctuations in relative humidity can damage specimens in storage. An equable humidity-temperature regime would undoubtedly reduce the numbers of insects at peak abundance.

Having division personnel conduct insect monitoring is preferred over outside contractors who have no vested interest in the collections. Because part of the effectiveness of the program depends on the awareness and participation of the staff, hiring an outside contractor to do monitoring could actually have a negative effect on the IPM program. Because our data indicate that insect activity inside and outside cabinets is not related, we are skeptical about the results provided by companies that only monitor hallways and offices. It is, however, recommended that IPM programs include interdivisional and museum-wide meetings to discuss pest problems, exchange ideas, and share data. We are cautiously gratified about the apparent decrease in insects from the 1991-93 office and range trapping study, but realize that harmful insects remain in the division and inside storage cabinets. The staff time required to consistently monitor and carry out this IPM program is greater than traditional methods of pest control. The main monitoring and data collection and collation are the responsibility of one museum specialist who spends approximately two full days every month, plus additional time at the end of the year to prepare reports and summaries to inform other staff of results. Time

required for other IPM program duties such as cleaning, pesticide application, and visual inspection is extremely variable, requiring up to three days (one staff member) per month. Based on 1994 estimates, direct costs of sticky traps is approximately \$200/year; Ficam W™ is \$23 per ten package box, and PT 230 Tri-Die™ is \$105 for a case of twelve 16 oz. cans. Two packets of Ficam W™ and two cans of PT 230 Tri-Die™ are required per application in the division. Although money and staff time may seem high, the cost for local pesticide companies is between \$75–\$200/month for only monitoring with sticky traps; additional costs (possibly several thousand dollars) are incurred when any pesticide is needed.

We realize that the IPM program presented here may not be the solution to pest control for the world-wide museum community. However, we feel this study confirms that knowing what pests are present, where they are, and when their populations fluctuate is currently the most important tool in any pest control effort.

#### ACKNOWLEDGMENTS

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

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