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VARIABILITY IN MEASUREMENTS RESULTING FROM MICROSCOPIC ANALYSES OF COLLAGEN SHRINKAGE-TEMPERATURE

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Abstract.—A statistical study was conducted on the microscopic method of analyzing collagen shrinkage-temperature (T_s) to determine its value for studies relating to the care of biological research collections. Initial T_s, T_s at time of birefringence change, final T_s, and T_s range were variables found to be most useful for analysis. Variation of T_s measurements attributed to sampling location, sample preparation, and preservation treatments of samples were examined. This study shows that these factors do affect T_s measurements, demonstrating the need for standard procedures and the usefulness of adequate sampling. The amount of variability may provide a mechanism of interpreting the thoroughness of preservation treatments of collagen.

The shrinkage phenomenon has been used for many years as a method of determining stability of collagen, particularly for various leather tannages (Borasky and Nutting, 1949; Gustavson, 1956; Hobbs, 1940; Nayudamma, 1958; Witnauer and Wisnewski, 1964). As collagen is subjected to increasing temperatures, generally in the vicinity of 65°C, the hydrogen bonds holding the three chains of the molecule together will break causing a collapse or "shrinkage" of the twisted structure. This characteristic of collagen provides a mechanism for measuring its structural stability in units of temperature (Theis and Steinhardt, 1942). It has only been recently that shrinkage temperatures (T_s) have been used for examining museum materials (Haines, 1985, 1987; Young, 1987). Of the procedures used for analyzing T_s, the method involving a hot-stage with a microscope (Borasky and Nutting, 1949; Young, 1987) is of particular interest because the procedure can be performed with as little as a few collagen fibers. However, this method has been questioned because of the difficulty of duplicating T_s values obtained by previously established methods (Borasky and Nutting, 1949; Haines, 1987). There are also other factors, such as pH, the presence of salts, and heating rate, that may alter results (Ciferri *et al.*, 1965; Haines, 1987; Theis and Steinhardt, 1942; Weir and Carter, 1950). However, Young (personal communication) points out that manipulation of these parameters can provide more flexibility for T_s analyses.

The study described below has similarities to that of Borasky and Nutting (1949) which compared microscopic T_s analysis to methods endorsed by the American Leather Chemists Association. However, the current study deviates from industrial interests by focusing on T_s analyses for evaluating and comparing preservation treatments of collagen that would occur in vertebrate research collections of museums. Treatments examined involve preservatives that historically have been applied to skins of specimens. In addition to some points addressed by Borasky and Nutting (1949), such as the effect of certain chemicals and temperature range, the current study includes observations of birefringence, greater variety of preservatives, and a greater use of standard statistics.

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Materials and Methods

Preparation of samples.—In 1985, 3 × 3 cm sections were removed from the fresh skin of a single specimen of otter (*Lutra canadensis*). Each section was labeled and pinned out on a polyethylene surface with the flesh side of the skin up so that various chemicals could be applied in a manner consistent with treatments used in the past. The chemicals used represent some of the most common preservatives that have been used on the skins of mammals (Williams and Hawks, 1987). The preservatives chosen for the study were ammonium aluminum sulphate (alum; $AlNH_4(SO_4)_2$), arsenic trioxide (AsO_3), magnesium carbonate ($MgCO_3$), mercuric chloride ($HgCl_2$), potassium nitrate (KNO_3), sodium borate ($Na_2B_4O_7$), sodium chloride (NaCl, saturated solution), sodium fluosilicate (Na_2SiF_6), and formalin (CH_2OH_2O; 40%). Except for sodium chloride and formalin, all chemicals were applied as solids. The samples were allowed to dry for 24 hours before they were unpinned. Each skin sample was stored in an open polyethylene-terephthalate bag, and maintained in conditions free from light, dust, and fumigants for four years. The control sample received identical processing except a preservative was not applied.

In 1989, the samples were used for shrinkage temperature (T_s) analyses. A hole-punch was used to remove 3 mm discs of the skin for testing. Layers of the disc, measuring 0.2 mm or less in thickness (approximate weight, 0.0025 gm), were removed with a scalpel blade. Except where noted, the outermost layer of the flesh side of the skin was used in these studies.

pH measurements.—Separate 3 mm discs of the skin samples were placed in 0.5 ml of distilled water for monitoring changes in pH, and to determine if the isoelectric point of collagen might be affected by any of the treatments. A Fisher Accumet pH meter (Model 640) with a flat-surface electrode was used to measure pH at 0, 5, 15, 30, and 60 minutes. A final reading was taken 24 hours later.

Soaking procedure.—To evaluate the influence of soaking collagen fragments, two procedures were tested. The first method involved teasing collagen fragments directly from the disc of the sample onto the slide used for T_s analysis. Collagen fibers were rehydrated with distilled water in the well of the slide without any effort to remove residual chemicals. The second method involved soaking the disc in about 25 ml of distilled water for at least five minutes after it became saturated and would not float. It was intended that residual chemicals present would be washed off or dissolved by the procedure, ultimately resulting in a substantial dilution of any chemical present. Collagen fragments were teased away under fluid conditions in the well of the slide.

Both procedures described above were concluded by placing a coverslip over the well containing collagen fibers and distilled water. Microscope immersion oil was placed along the perimeter of the coverslip to reduce water evaporation around the sample. Generally, the procedures used for preparing slides for collagen samples followed methods described by Young (1987).

T_s measurement.—Instrumentation used for the analyses included a Mettler central processor (FP 80), hot stage (FP 82), and printer (GA 44). The process was observed through polarized film at 100× magnification using an Olympus binocular microscope. The calibration of the Mettler central processor and hot stage was verified with phenacetin crystals which melt at 133–136°C. Once the temperature range for the sample was determined by preliminary T_s analysis, the central processor was programmed to increase 2°C per minute, starting at a temperature that was 5–10°C below the initial T_s. The rate of temperature increase followed the methods defined by the Society of Leather Technologists and Chemists for T_s analysis (Haines, 1987).

For each sample, the initial T_s, final T_s, and T_s at birefringence change was recorded. The initial T_s was recorded when the hydrated collagen fibers made an obvious independent movement. The final T_s was recorded when there was no movement in the field of vision after about 10 seconds. The use of polarized film allowed observation of birefringence. Young (personal communication) points out that temperatures associated with the loss of the bright white coloration of collagen birefringence (observable under total polarization) correspond to the final T_s. By using slightly uncrossed polarized films, it is possible to create a more contrasting blue coloration on parts of the collagen fibers. The point of the T_s cycle when most of the blue coloration was lost provided another measurable temperature that preceded the final T_s. These three T_s values were recorded 5–14 times for comparative purposes. To evaluate the typicality of the observed T_s cycle, the T_s range (number of degrees between initial T_s to final T_s) was compared, as well as the point in the T_s cycle where birefringence changes were documented.

Mean, range, standard deviation, and coefficient of variation were determined for the series of T_s measurements and T_s ranges of each sample. Analysis of variance determined if there were significant differences attributed to stratification and soaking procedure. The procedures also were compared for each of the chemicals examined. If significant differences occurred between soaking procedures for a specific preservative, the two samples were treated independently, otherwise they were combined for the determination of nonsignificant subsets. The analysis of variance and the determination of nonsignificant subsets were used to compare the chemical treatments. The results of the univariate statistical analyses were used to evaluate the T_s procedure and to assist in interpreting collagen interactions that may result from different treatments.

Results

Variation between sample layers.—Variation in T_s measurements attributed to stratification is summarized in Table 1. Although the mean T_s was different for each layer, only the initial T_s of the outer layer was significantly different, thus indicating a need for a consistent sampling location of materials being tested. Subsequent analyses used the outer layer of the flesh side of the skin sample.

Variation attributed to soaking procedure.—For the control sample there were no significant differences found between soaking procedures used (Table 1). However, samples having potentially greater hydration as a result of the soaking process, tended to have a slightly lower mean for all T_s values. Similar results were obtained with the magnesium carbonate sample. Significant differences among the T_s values were obtained only with mercuric chloride, potassium nitrate, and formalin (Table 2). Regardless of whether samples showed significant differences between soaking procedures, it was noted that the mean T_s of birefringence change and final T_s were higher for all soaked samples (except the control and magnesium carbonate samples). These analyses demonstrate that the soaking procedure used with some chemicals may significantly affect some T_s values, thus there is a need to maintain uniformity in procedures. Furthermore, these procedures require that chemicals be removed from the collagen so that collagen stability can be accurately evaluated.

Analysis of pH provided a method of determining if any of the treatments in conjunction with procedures used, could affect the isoelectric point of the collagen, and the T_s analyses. The range of pH values for individual samples of each treatment during 24 hours of soaking was 6.4 to 7.1. The pH values of individual samples were reasonably stable and uniform; any observed pH changes were minor and could have been attributed to carbonic acid development (Williams, 1988). Because of the nearly neutral conditions and the mass ratio of the sample to the amount of distilled water was at least 1:200 (approximating that used for microscopic T_s observations), it was assumed that the sample treatments had been standardized for T_s analysis.

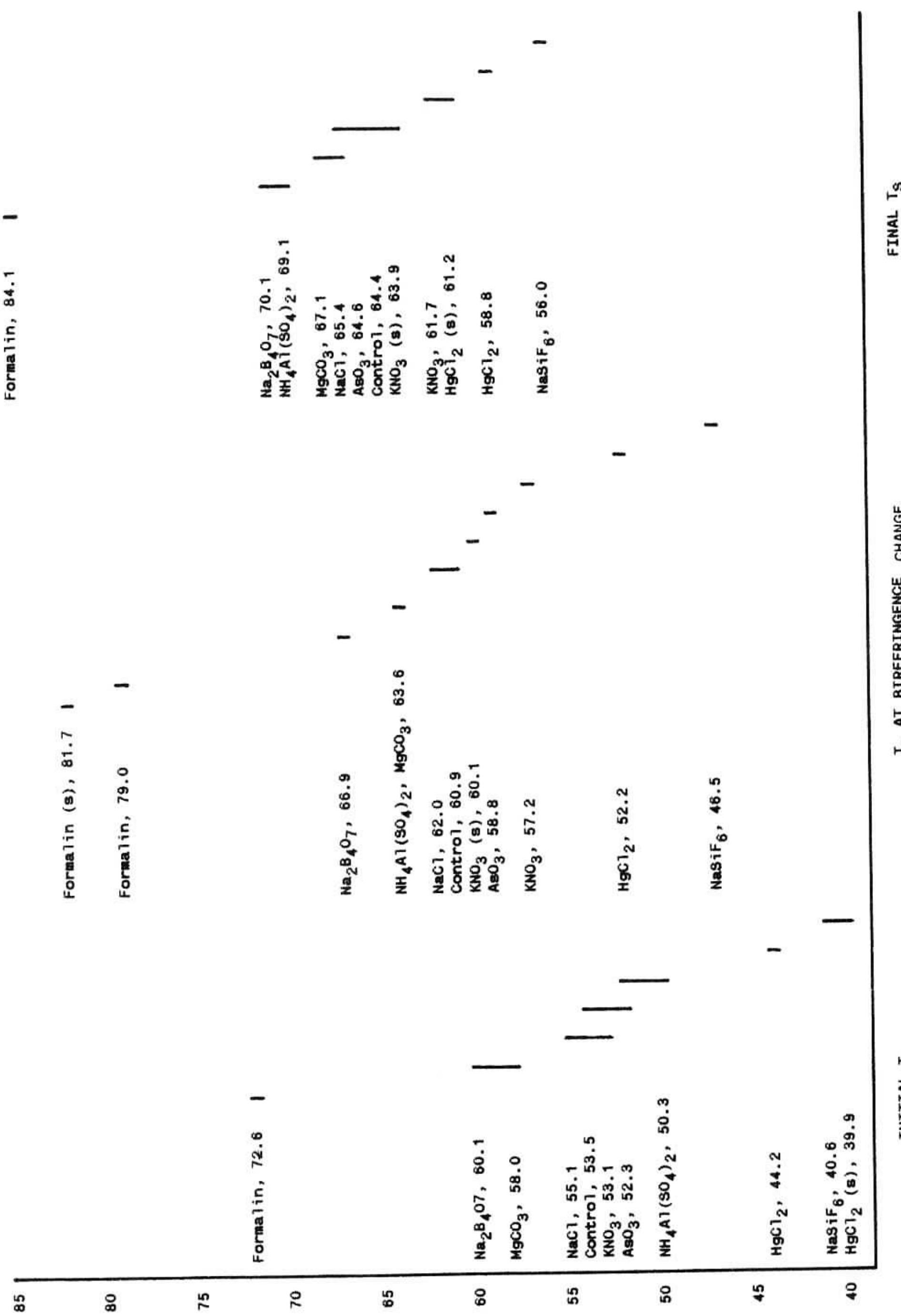
Variation attributed to chemical treatment.—The control sample served as a basis for comparing the amount of difference between various treatments. Untreated collagen was reasonably easy to evaluate and replicate, as indicated by low coefficients of variation. The average T_s values obtained for the control were as follows: initial T_s, 53.5°C; T_s at birefringence change, 60.9°C; and final T_s, 64.4°C. The difference between initial T_s and final T_s averaged 10.9 degrees, but fluctuated between 7.2 and 14.1. The birefringence change usually occurred about 68% through the cycle. The low coefficients of variation (<0.05) for the three recorded T_s values, indicate that these measurements are repeatable, and therefore useful in T_s analyses. The lowest coefficients of variation were acquired with final T_s, followed by T_s at birefringence change and then initial T_s. High coefficients of variation for the T_s range (10.9) and the point in the cycle where the blue coloration

Table 1. Summary of standard statistics of shrinkage-temperatures acquired from the control sample, using different collagen layers and soaking procedures. An asterisk (*) indicates significantly different groups. The examination of soaking procedure involved the outer layer of the flesh side of the skin sample. The control sample indicated with the letter "s" in parentheses was soaked prior to determining the T_s.

Sample	N	Initial T_s mean (min–max) ± SD, CV	T_s at birefringence change mean (min–max) ± SD, CV	Final T_s mean (min–max) ± SD, CV	T_s range mean (min–max) ± SD, CV
Stratification					
Outer layer	6	56.1 (54.1–57.9) ± 1.44, 2.6*	61.3 (59.6–62.8) ± 1.17, 2.2	65.4 (64.9–66.2) ± 0.50, 0.8	9.3 (7.4–12.1) ± 1.73, 18.6*
Central layer	5	53.2 (51.8–55.7) ± 1.65, 3.1	60.6 (59.7–62.6) ± 1.23, 2.0	64.6 (63.8–66.4) ± 1.32, 2.0	11.4 (10.7–12.1) ± 0.52, 4.6
Inner layer	6	52.9 (50.8–54.7) ± 1.54, 2.9	61.1 (59.2–61.9) ± 0.99, 1.6	65.2 (63.8–66.7) ± 0.96, 1.5	12.3 (10.1–14.1) ± 1.32, 10.7
Soaking procedure					
Control	14	54.0 (50.8–57.7) ± 1.91, 3.5	60.9 (59.2–63.0) ± 1.11, 1.8	64.7 (63.1–66.7) ± 0.98, 1.5	10.7 (7.2–14.1) ± 2.04, 19.0
Control (s)	8	52.6 (51.1–55.0) ± 1.45, 2.8	60.8 (59.8–62.1) ± 0.84, 1.4	63.9 (62.6–65.5) ± 0.81, 1.3	11.3 (9.4–12.3) ± 1.02, 9.0

Table 2. Summary of T_s statistics of the control sample and samples treated with different preservatives. Treatments are ranked according to the mean final T_s because that variable provided the lowest coefficients of variation (CV). Procedures involving presoaking are indicated with the letter "s" in parentheses. Where procedural variation was significant, statistics for both procedures are given with the level of significance indicated with asterisks (* = 0.05; *** = 0.001).

Sample	N	Initial T_s mean (min–max) ± SD, CV	T_s at Birefringence change mean (min–max) ± SD, CV	Final T_s mean (min–max) ± SD, CV	T_s Range mean (min–max) ± SD, CV
Na_2SiF_6	14	40.6 (38.0–43.4) ± 1.46, 3.6	46.5 (44.9–48.6) ± 0.95, 2.0	56.0 (50.5–58.5) ± 2.30, 4.1	15.4 (9.9–19.6) ± 3.18, 20.6
$HgCl_2$	8	44.2 (41.5–46.5) ± 1.51, 3.4		58.8 (54.4–61.0) ± 2.36, 4.0	21.3 (19.3–25.0) ± 1.97, 9.3
		***	52.2 (49.1–57.9) ± 2.41, 4.6	*	***
$HgCl_2$ (s)	8	39.9 (38.4–42.5) ± 1.29, 3.2		61.2 (59.0–63.4) ± 1.57, 2.5	14.6 (7.9–17.3) ± 2.91, 19.9
KNO_3	9		57.2 (54.8–60.5) ± 1.77, 3.1	61.7 (58.9–64.0) ± 1.45, 2.3	8.4 (7.7–9.7) ± 0.67, 7.9
		53.1 (50.5–56.8) ± 1.54, 2.9	***	***	***
KNO_3 (s)	10		60.1 (57.6–62.9) ± 1.78, 2.9	63.9 (62.2–65.5) ± 1.02, 1.6	11.0 (7.9–14.1) ± 1.79, 16.2
Control	22	53.5 (50.8–57.7) ± 1.81, 3.4	60.9 (59.2–63.0) ± 0.98, 1.6	64.4 (62.6–66.7) ± 0.96, 1.5	10.9 (7.2–14.1) ± 1.69, 15.5
AsO_3 (s)	6				13.7 (11.7–17.7) ± 2.48, 18.2
		52.3 (49.7–54.9) ± 1.35, 2.6	58.8 (54.0–62.5) ± 2.49, 4.2	64.6 (62.2–68.1) ± 1.76, 2.7	*
AsO_3	8				11.2 (8.8–13.3) ± 1.78, 15.9
NaCl (s)	8				11.5 (9.2–13.5) ± 1.48, 12.9
		55.1 (52.7–58.8) ± 2.04, 3.7	62.0 (59.7–63.4) ± 1.00, 1.6	65.4 (63.3–68.0) ± 1.20, 1.8	***
NaCl	8				9.1 (7.1–10.9) ± 1.11, 12.3
$MgCO_3$	14	58.0 (54.2–61.1) ± 2.17, 3.7	63.6 (62.1–65.3) ± 0.99, 1.5	67.1 (64.6–68.2) ± 1.06, 1.6	9.1 (6.6–11.8) ± 1.57, 17.3
$AlNH_4(SO_4)_2$	15	50.3 (41.7–57.6) ± 5.3, 10.5	63.6 (56.7–67.4) ± 2.81, 4.4	69.1 (61.7–72.8) ± 3.13, 4.5	18.7 (10.6–27.0) ± 4.36, 23.3
$Na_2B_4O_7$	16	60.1 (57.8–62.0) ± 1.19, 2.0	66.9 (65.4–67.8) ± 0.66, 1.0	70.1 (69.2–71.5) ± 0.71, 1.0	10.0 (7.3–12.7) ± 1.45, 14.5
Formalin (s)	7		81.7 (80.7–82.5) ± 0.54, 0.7		
		72.6 (68.1–77.1) ± 2.75, 3.8	***	84.1 (82.4–86.0) ± 1.05, 1.2	11.4 (7.9–15.6) ± 2.84, 24.8
Formalin	5		79.0 (78.2–80.0) ± 0.69, 0.9		


85
80
75
70
65
60
55
50
45
40
INITIAL T_s
T_s AT BIREFRINGENCE CHANGE
FINAL T_s
Formalin, 72.6
$Na_2B_4O_7$, 60.1
$MgCO_3$, 58.0
NaCl, 55.1
Control, 53.5
KNO_3, 53.1
AsO_3, 52.3
$NH_4Al(SO_4)_2$, 50.3
$HgCl_2$, 44.2
$NaSiF_6$, 40.6
$HgCl_2$ (s), 39.9
Formalin (s), 81.7
Formalin, 79.0
$Na_2B_4O_7$, 66.9
$NH_4Al(SO_4)_2$, $MgCO_3$, 63.6
NaCl, 62.0
Control, 60.9
KNO_3 (s), 60.1
AsO_3, 58.8
KNO_3, 57.2
$HgCl_2$, 52.2
$NaSiF_6$, 46.5
Formalin, 84.1
$Na_2B_4O_7$, 70.1
$NH_4Al(SO_4)_2$, 69.1
$MgCO_3$, 67.1
NaCl, 65.4
AsO_3, 64.6
Control, 64.4
KNO_3 (s), 63.9
KNO_3, 61.7
$HgCl_2$ (s), 61.2
$HgCl_2$, 58.8
$NaSiF_6$, 56.0

was lost (11.4) indicate that this information is more useful for evaluating the typicality of individual observations than for statistical analyses; greater reliance was given to temperature range.

Table 2 summarizes the analyses made for the respective chemical treatments. For sodium fluosilicate, mercuric chloride, and potassium nitrate, all mean T_s values were lower than the control, whereas for sodium chloride, magnesium carbonate, sodium borate, and formalin, all mean T_s values were higher. Arsenic trioxide and alum were the only chemicals that had mean T_s values that were higher and lower than the control.

Although low coefficients of variation for T_s values indicate the usefulness of these measurements, it was noted that sodium fluosilicate, mercuric chloride, arsenic trioxide, and alum had the highest coefficients of variation (4.0–5.0) for one or more of the T_s values. A particularly high coefficient of variation (10.5) was acquired with the initial T_s of alum.

Calculations of T_s range and the point in the cycle where birefringence changed resulted in coefficients of variation ranging from 7.9 to 24.8 and 10.4 to 32.6, respectively. Lower values indicate that the observed T_s cycles were similar to one another and that the analyses of the treatment were consistent; treatments involving sodium chloride and sodium borate had comparatively lower values and were as easy to document as the control sample. In contrast, high values (>20.0) indicate other factors are possibly contributing to the variability of T_s cycles. Treatments with high coefficients of variation and greater temperature changes for T_s cycles (for example, sodium fluosilicate, mercuric chloride, arsenic trioxide, and alum) tended to be the most difficult to document. With regard to the point in the cycle where birefringence change occurred, the only treatments with coefficients of variation below 20.0 were sodium chloride (14.5), sodium borate (10.4), and formalin (12.1).

The results obtained from the determination of nonsignificant subsets are summarized in Figure 1. Analysis of T_s values resulted in the formation of 7 to 10 groups that were significantly different from one another. In most cases there was little or no overlap between groups. For the three T_s values examined, there was very little consistency in the samples that grouped to form nonsignificant subsets.

Discusssion

One of the difficulties of conducting T_s analyses with a hot-stage and microscope is quantifying observations that tend to be somewhat qualitative. In this study three different temperatures were examined and sources of variation for each were recognized. For instance, initial T_s can be mistaken by movement of air bubbles (inside or outside of the field of vision), water absorption by collagen fibers, optical illusion involving different depths of field, settlement of tissues in the water, or simply missing movements because they were out of the field of vision or the observer was distracted at the critical moment. Such subtleties could have contributed to the comparatively higher coefficients of variation for initial T_s. Sim-

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Figure 1. Graphic representation showing nonsignificant subsets and their relationships, for each of the T_s values documented in the study. Values following chemical formulae are means for the respective samples.

ilarly, judgments for deciding the final temperatures of birefringence change or completion of collagen shrinkage can be influenced by factors as subtle as the quantity of collagen being observed in the field of vision. Furthermore, the amount and quality of blue coloration associated with collagen strands is related to the amount of fiber swelling, which in turn is influenced by chemical interaction.

Regardless of the source, factors contributing to variation do exist. Therefore, it is very important to standardize procedures as much as possible. Even under the best conditions there is the potential for inadvertently obtaining misleading T_s values. This possibility can be reduced by documenting several T_s cycles and statistically evaluating the results. With regard to conducting T_s analyses it was demonstrated that standardization of procedure and replication of observations can provide meaningful information of collagen stability.

Haines (1987) stated that untreated collagen "... shrinks at about 65°C and there is little variation in the shrinkage temperatures of skin collagen from different mammalian species or between different regions of the same skin." The current study found that among the T_s values used with the otter skin, the final T_s (mean = 64.4) most closely approximated reported values. The slightly lower value would be expected as the difference between free collagen fibers and strips of collagenous tissues under stress (Borasky and Nutting, 1949).

Although it is recognized that there are several variables that may affect T_s analysis, the influence of chemicals was the greatest concern. It is acknowledged that the differences noted in the current study involve a variety of chemical reactions. However, it was not the scope of the current study to determine or compare the reversible or irreversible perturbative effects of different chemical preservatives.

Although the procedural consistencies and the nearly neutral conditions suggest that external influences (for example, pH, presence of salts, and heating rate) had been minimized, the T_s values of this study differed somewhat from those of previous reports. Theis and Steinhardt (1942) demonstrated that pH levels outside the range of 4 to 10 deviate from the isoelectric point of collagen and will cause a lower T_s. They further demonstrated with sodium chloride solutions that the effect of pH on T_s can be chemically influenced. However, the differences in mean final T_s (65.4) for sodium chloride in the current study and values from 68 to 70 reported by Theis and Steinhardt (1942), suggest that there is a chance that the salt concentrations might have affected the T_s. The significance of these differences is not fully understood at this point.

Gustavson (1956) commented on inconsistencies in T_s values between different labs, as well as minor variations being attributed to sampling location on the animal, sampling of individuals of the same species, and sampling between different species. If T_s values reported by the leather industry are based on material originating from cattle (genus *Bos*), then the T_s differences noted by Gustavson (1956) between artiodactyles (63–67°C) and carnivores (60–62°C) might explain some of the differences observed in the current study with the otter skin. Gustavson (1956) also points out that free standing collagen will have a T_s that is 1–2 degrees lower than collagen in a skin sample attached and under stress from two sides. Based on this information, there is a need for further studies of intra- and interspecific variation. There is also a need for careful interpretation of data reported elsewhere, particularly with regard to methods and materials used.

The T_s values obtained for all of the preservatives were extremely variable, ranging from 38.0°C to 86.0°C. Although the reliability of values varied with preservative, the results for any particular chemical treatment were often significantly different from that of other treatments (Fig. 1). Because of these differences it is possible that T_s values could help focus non-destructive chemical identifications of unknown preservatives used in natural history collections. However, this possibility is predicated on knowing about the full range of possible preservatives, as well as standardizing important variables that may affect collagen stability (for example, degradation attributed to age, light, climatic conditions, and fumigants).

Except for differences in T_s values, some preservatives (for example, sodium chloride and sodium borate) behaved similarly to the control with respect to the temperature changes during the T_s cycle and perhaps the point in the cycle where birefringence was lost. In contrast, other preservatives (for example, mercuric chloride, sodium fluosilicate, and alum) exhibited greater temperature changes and different points where birefringence changed. This study concurs with Borasky and Nutting (1949) in suggesting the temperature range of the T_s cycle may be used to detect differentially treated collagen. These differences might be due to the nature of the preservative and/or the method of application.

When all of the collagen is in contact with equal amounts of the preservative, the reaction should be uniform throughout. As a result, it might be expected that coefficients of variation, temperature change during the cycle, and the point of birefringence change would be similar to the control. In this study, sodium chloride and formalin were applied in solution and both provided well-defined T_s cycles, thus suggesting collagen below the surface was being equally affected as the surface collagen. In contrast, greater coefficients of variation, greater mean temperature range, and major deviations in the point of birefringence change suggest that collagen is differentially affected by the treatment. Mixed reactions would be expected between exposed, partially exposed, and unexposed collagen. The potential for affecting collagen below the surface of the skin is dependent on the water solubility of the preservative as well as the amount of moisture in the fresh skin at the time of treatment. Chemicals that demonstrated high levels of variability and prolonged cycles were alum and mercuric chloride. The lack of overlap in T_s values between mercuric chloride and the control would indicate that there was little or no collagen present that had not reacted with the preservative. In contrast, the greater coefficients of variation and broad overlap of T_s values of alum and the control suggest the presence of collagen fibers in all stages of reaction. It may be possible to reduce the amount of variation if conditions were such that all of the collagen molecules were able to react to the treatment.

Recent electrophoretic work, using the collagenase-SDS-PAGE technique (unpublished data) provides a means of assessing T_s methods for analyzing collagen stability. Both studies used the same control and preserved samples of *Lutra* skin for analysis. Although there are some differences, both studies suggest mercuric chloride, sodium fluosilicate, and potassium nitrate contribute to collagen degradation, and that formalin interacts with collagen to protect it from factors that would normally cause degradation. However, differences between the two studies are apparent. The level of stability for sodium fluosilicate and alum were particularly different. Assuming both analytical techniques provide reliable information, any variation in results would suggest that the respective techniques are evaluating degradation of different structural levels of the collagen molecule. Because T_s analysis is associated with the breakage of hydrogen bonds between the three chains of the molecule, it might be assumed that the collagenase-SDS-PAGE analysis would account for degradation involving the individual chains. These different perspectives potentially provide a complementarity between the two techniques which can result in a better understanding of collagen stability.

Conclusions

This study reiterated several problems associated with T_s analyses, but it also demonstrated that the hot-stage with a microscope can be useful for detailed comparisons of different treatments used for preserving collagenous tissues of natural history specimens. If analyses are to have any validity, it is essential that all details of the procedure be standardized, that neutralized samples be used for analysis, and that extrinsic influences be controlled.

This study found that the methods used resulted in T_s values that can easily withstand statistical testing. The presence of significant variability might be useful in understanding the level of chemical reactions taking place with the sample. Furthermore, the characteristics of the T_s (values and levels of variability) are often unique enough that they could be used to help identify unknown chemicals used for preserving specimens. The ability to restrict the number of possible preservatives with this procedure can simplify and expedite subsequent analyses that involve more refined techniques.

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USING PARIS DOCUMENTATION AS A RESEARCH TOOL IN PALYNOLOGY

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Abstract.—Through cooperation with the Canadian Heritage Information Network, Communications Canada, a database with supporting entry and retrieval programs was developed for the Canadian Museum of Nature to accommodate our palynological research requirements. The PARIS program allows specific questions to be answered through a series of simple searches, thereby serving as an identification tool. Appropriate standards for accuracy, cross-referenced fields, and the ability to search for "unknown" pollen or spore taxa via morphological characters are all accomplished using PARIS.

Part of the conservation of natural history specimens concerns the supporting documentation and the quality and use of the recorded data. Today, many, indeed most, collections are documented and managed through the use of one or more computer-assisted programs. One such system is PARIS (Pictorial and Artifact Retrieval and Information System) based on the software system BASIS (trade name for the information, storage, retrieval, and analysis system developed by Battelle Laboratories, Columbus, Ohio). BASIS has been modified by system programmers at the Canadian Heritage Information Network, Communications Canada (CHIN), to suit the particular needs and demands of individual clients and the collections they curate (Cox, 1986).

Palynology at the Canadian Museum of Nature (CMN) is a discipline within the Earth Sciences Division that studies plant microfossils (primarily fossil pollen and spores) in order to provide information on the nature, diversity, and evolution of plant life on this planet in the geological past. Of special interest is the plant life at the Cretaceous-Tertiary boundary, the time of the extinction of dinosaurs, especially within the Western Interior of North America, and Australasian regions.

The palynology collections of the CMN are 100% catalogued, and the supporting data are managed via the PARIS system. The system is used to catalogue and document relevant taxonomic, collection, preparation and locality data, and also as a research tool, supporting other research techniques, in elucidating the identity, affinities and stratigraphic significance of fossil pollen and spores.

Pollen and spores are easily fossilized and can be extracted from rocks by chemical and physical processes. They often have unique shape, aperture structure and position, and surface sculpture, so that they may frequently be identified to the parent plant family or genus which produced them (Jarzen and Dettmann, 1989). Most pollen and spores are produced in great abundance—hay fever sufferers can attest to this fact. Most spores and the pollen of wind pollinated plants annually fall down from the atmosphere and become incorporated into the ongoing sedimentation process as potential fossils. This abundance in rock sediments makes them valuable as fossils, more so than the leaves, stems or flowers, which are fewer in number and more rarely fossilized.

Collection Forum, 7(2), 1991, pp. 64–71

Identification Process

The diversity in morphological features of pollen and spores can be illustrated through a few examples. The spores of ferns are either triangular in outline with a characteristic "Y"-shaped mark on one face, or bean-shaped with a single slit-like mark on one face. These features coupled with various surface ornamentation types are used to identify fossil fern spores.

Pollen of some conifers such as spruce, pine, and fir have a central body with two air bladders attached, presumably to provide buoyancy for long-distance dispersal. Other conifers such as bald cypress have less distinctive pollen, yet may be easily recognized by other features.

The pollen of flowering plants or angiosperms are more diverse, from the simple single aperture of palm pollen to the unique and bizarre pollen tetrads of the Sarcolaenaceae (Erdtman, 1969). The morphological variation in angiosperm pollen includes shape, size, apertural structure, wall architecture, and surface sculpture (Fig. 1). Even so, the variation observed within angiosperm pollen is not randomly distributed, but rather similarities within major groups are quickly recognized.

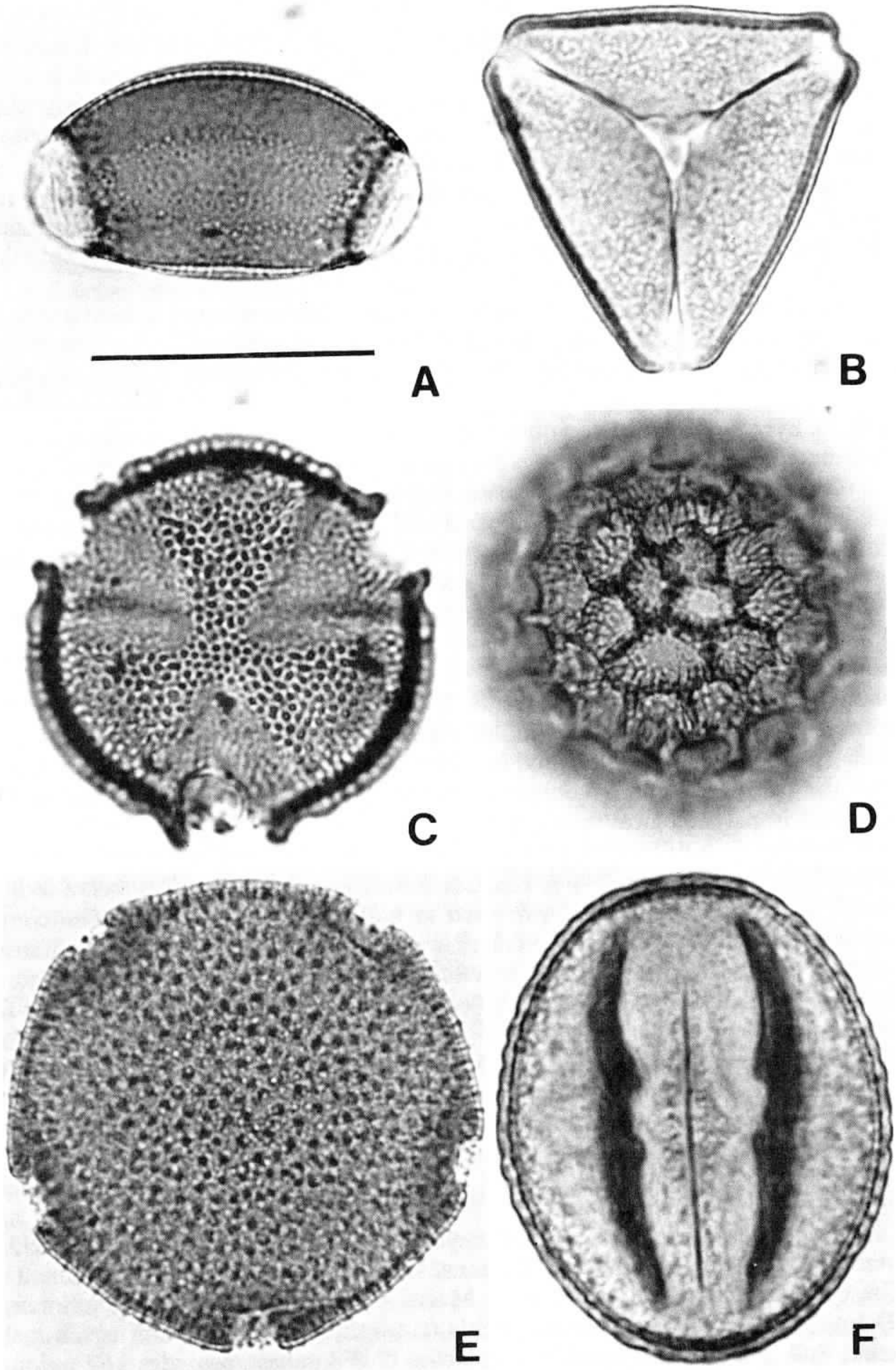
Paleopalynology, the study of fossil pollen and spores, is used to reconstruct the kinds of plants which lived on earth at the time the rock layers, in which we find these microfossils, were being formed. This depends of course upon the proper, accurate identification of the fossil pollen grains and spores.

The identification process, that is comparing the features of a recovered fossil pollen grain or spore with those of a living plant species, is an ominous task. There are more than 375,000 extant plant species, including 270,000 flowering plants (Hawksworth, in press). Hence, for every fossil specimen identified, the comparison with extant species could be a lengthy process. Although not all fossil pollen or spores may be compared to that of extant species, it is becoming evident that the computer, and a complete, useable documentation system are useful elements in palynological research.

Before the days of PARIS, pollen and spore identification and comparisons at the CMN were on a one-on-one basis. A collection of pollen and spores of living plants (a reference collection) was used to make these comparisons. The comparison process was slow, and depended in part upon the palynologist's familiarity with the reference collection and previous success or failure in the identification process. Published keys and pictorial catalogues and card files were also used to supplement the comparison process. Although the reference collection and literature sources are today still the primary identification and comparison basis, the PARIS system database serves as a catalogue and research tool which can decrease the sometimes random search process.

Canadian Museum of Nature Database

Working with CHIN's Museum consultant, Barbara Rottenberg, the data fields were selected based upon the cataloguing, searching, and retrieval requirements. The database was developed from a Master Natural Sciences Data Dictionary (Delroy *et al.*, 1988) of over 600 fields (categories) compiled from seven task forces and museum information standards. This database provides 167 unique fields, many specific to palynology, which accommodate the data associated with fossil or extant pollen and spores. The fields provide indexed categories for spec-


A
B
C
D
E
F

imen data including taxonomic, collection, geographic, description, preparation, cataloguing, dating, geological, habitat, publication, photographic, loan, and exhibition information. The fields and commands used in the database are available in either English or French. Figure 2 illustrates the information from a single specimen.

Indexing of Fields

The indexing of fields is an important feature which determines how a field may be searched. Although the indexing type is established by CHIN, the system is, in most cases, flexible enough to allow a change in indexing as required by the users.

Free-text indexing allows searching on each word in a field. Thus, in the field "HABITAT" (mnemonic HAB), the entry might be "moist forest, elevation 300 metres." Each key word is indexed and therefore searchable.

Full-field indexing groups the field mnemonic (a two- or more letter representation of the field name) and the data (up to 30 characters) as one term. In the field "ORIGIN-CONTINENT" (mnemonic ORCT) the entry "North America" is indexed as "North America" *not* "North" and "America." The same is true for the field "ORIGIN OCEAN/BASIN" (mnemonic OROC) as "South Pacific Ocean."

Phrase indexing allows separate indexing of multiple entries within a field when each entry is separated by a semicolon. The field "SYNONYM" (mnemonic SYN) is an example where phrase indexing is necessary. A particular taxon (genus, species, etc.) may have several names placed in synonymy. As the names in synonymy are placed into the field separated by a semicolon, they are indexed in alphabetical order. Any of the synonyms may be searched separately.

Phrase-linked indexing links each occurrence within a field (or series of fields) with a corresponding occurrence in another field. This linking of fields is especially important when linking an object (specimen) with an authority (name) where several different objects are associated with several different names within the same record.

Subfield indexing groups numeric data into "range buckets" or sets within a numeric range. This index form is of special value in lumping equivalent entries into a range, such as processing dates or collection dates.

←

Figure 1. A. *Dryandra kippistiana* Meissner (Proteaceae): a diporate grain (DE4 = P2; Diporate); with barrel shape (doliiform) outline; incomplete tectum (DE5 = Tectate-perforate); and foveolate surface (DE6 = Foveolate); see also Fig. 2. B. *Psittacanthus auriculatus* Eichl. (Loranthaceae): a tricolpate (DE4 = C3; Tricolpate) grain with the colpi fused at their polar junction; the ambit (outline in polar view) is triangular. C. *Stahlia monosperma* (Tul.) Urb. (Leguminosae): a tricolporate (DE4 = C3P3; Tricolporate) grain with a lace-like (DE6 = Reticulate) surface sculpture; and incomplete tectum (DE5 = Tectate-perforate). D. *Persicaria acre* (HBK) Gomez de la Maza (Polygonaceae): a spherical pollen grain with one pore each within several of the net-like sculpture elements (DE4 = Pperi; periporate); (DE6 = Reticulate). E. *Waltheria glomerata* Presl (Sterculiaceae): a spherical pollen grain with five apertures (colpi) distributed around the circumference of the grain (DE4 = Cstp; Stephanocolpate); and a finely spinate sculpture (DE6 = Echinate). F. *Mabea occidentalis* Benth. (Euphorbiaceae): an elongated "football"-shaped grain with three colpi, each with a pore (DE4 = C3P3; Tricolporate); the surface of fine pits (DE6 = Foveolate) is obscured by the focal level; the tectum is perforated (DE5 = Tectate-perforate). (Scale bar for A = 25 μm; for all others = 50 μm.)

PARIS NUMBER	446
SECURITY CODE	5
USER ID	NMPS1
DATE OF BIRTH	830530
DATE OF CHANGE	910429
NATIONAL PARIS NO	9000446
DESTINATION DB	SNDB
DEST. CONTROL FIELD	0
INSTITUTION	CMN; MCN
DEAP-ID	DLX100100019
DEPARTMENT	Paleobiology
DISCIPLINE	Palynology
HERBARIUM CODE	US 650352
KINGDOM	Plantae
DIVISION	Anthophyta
CLASS	Magnoliatae
SUBCLASS	Rosidae
ORDER	Proteales
FAMILY	Proteaceae
FAMILY AUTHORITY	Juss.
SUBFAMILY	Grevilleoideae
GENUS	Dryandra
SPECIES	kippistiana
SPECIES AUTHORITY	Meissner
OTHER TAXA	Tribe Banksieae; Subtribe Banksiinae
SPECIMEN NATURE	SLIDE
EXCHANGE	NO
COLLECTOR	Pritzel
PREPARATOR	Jarzen, D. M.
DATE PREPARED	19750806
PREPARATION	KOH, Saf, G
ACCESSION NUMBER	01257
MUSEUM COLLECTION	Australian Pollen/Spore Collection
PREVIOUS NUMBERS	00552
CATALOGUER	Jarzen, S. A.
CATALOGUER REMARKS	This sample was collected from US by Dr. D. M. Jarzen on 19740425
WILLIS GEN/SP	62/1050
DTH FAM	66
RESIDUE	YES
STAGE CO-ORD/EFS	35.4 × 93.5 (M20)
DESCRIPTION	Pollen free (monad), bilateral, doliiform, elongate; diporate, pores more or less circular, 11–12 μm diameter, surrounded by thin collar; surface foveolate; exine 1.5–3.5 μm thick, thickening slightly at apertures, sexine thinner than nexine
POLLEN TYPE	Monad
APERTURE	P2; Diporate
TECTUM	Tectate-perforate
SURFACE	Foveolate
UNIT-LINEAR	micrometre; μm
DIAMETER-UM	34
DIMENSION REMARKS	Measurements are on largest dimensions of palynomorph
ORIGIN-CONTINENT	Australia
ORIGIN-COUNTRY	Australia
PHOTO TYPE	Kodak Panatomic-X
PHOTO NEG NUMBER	059
PHOTO DATES	19760421
PHOTOGRAPHER	Jarzen, D. M.
PUBLICATIONS	Memon, H. R. 1984. Pak. J. Bot. 16(2):205–229.

Figure 2. Data fields associated with a single extant pollen specimen collected from *Dryandra kippistiana.*

Multi-indexing, as the name implies, allows a field to be indexed in more than one way. In numeric fields (e.g., dates) it is often desirable to use the word UNKNOWN instead of a strictly numerical date. Data are accepted even though they may be numeric, alphabetic, or a combination of both.

Application

Since 1983, the pollen and spore reference collection and the fossil pollen and spore locality collection have been totally documented into the PARIS system. The data entered include the required or mandatory fields for the Natural Sciences National Database (CHIN, 1989), but also include many other fields for specific retrieval requests. The 167 fields that have been established provide several directions for searching, cross-referencing and providing complete taxonomic, morphologic, and descriptive information which allow access to the myriad of fossil pollen and spore names and thus information on their parent plants.

The description of pollen and spore morphology is guided by principles established over the last 80 or so years and is now generally accepted. The terms and their definitions are clearly established (Kremp, 1965) and internationally applied. In the CMN database, each pollen and spore species is first described using predetermined, one-word descriptors (for simplicity and uniformity) entered into fields DE2 to DE6. The DE2 through DE6 fields are:

DE2—POLLEN TYPE: monad (single), dyad (pair), tetrad (in fours), etc.
DE3—SPORE TYPE: monolete, trilete, etc.
DE4—APERTURE: number, form, arrangement, etc.
DE5—TECTUM: nature of the pollen wall, whether complete, perforated, etc.
DE6—SURFACE: kind and structure of the pollen wall ornamentation.

A complete written description of the species is then entered into the description (DE) field (see Fig. 2). By searching any one or more of the DE2 through DE6 fields, only pollen or spore data which "fit" the requested set of search terms are selected (e.g., a simple series of FIND X and Y, AND NOT Z). A simple search for extant plant families whose pollen occur singly (DE2), have three pores (DE4), and a reticulate (net-like) surface pattern (DE6) is performed using the following commands:

```
FIND DE2=MONAD AND DE4=P3 AND DE6=RET*

* 5823   7/  DE2=MONAD
*  562   8/  DE4=P3
*  548   9/  DE6=RET*
*   93  10/  DE2=MONAD AND DE4=P3 AND DE6=RET*
```

Ninety-three records share the features requested. The EXPAND command itemizes the FAMILY (mnemonic FAM) and the number of records in each family:

```
EXPAND FAM, TALLY

THE UNIQUE VALUES ARE:

81 Leguminosae
12 Proteaceae
```

Once a document set is located, several commands may be used to SORT, EXPAND, or simply DISPLAY the required information. Normally an EXPAND of the taxa recovered at the plant family level provides the best selection since related taxa at the familial level often share similar morphologic features.

The practical use of such a basic computer request has decreased tremendously the initial search time, providing only those families (or genera) whose pollen or spores are described to fit the search request. Obviously, the system can find only the data supplied; thus, it is important that the original description and descriptors are accurate and allow flexibility to account for natural variation and aberrant forms. For some specimens, more than one descriptor (separated by semicolons) may be entered for a given field. Multiple descriptors are useful when a particular feature occurs in two or more ways; for example, some plants produce pollen both singly (monad) or in groups of four (tetrad). In this example, the terms may be searched individually. Using this simple model, a fossil pollen grain or spore can be described using the same DE2 through DE6 descriptors. A search through the database will effectively locate the extant plant families whose pollen or spores share similar morphological features.

Discussion

This simple morphologic key provides the first step in accurate fossil pollen or spore identifications. Once the extant taxa that share gross morphological features with the fossil pollen or spore in question are determined, affinity may be made through careful and detailed microscopic examination. The new data set obtained can now be used to generate other data. Comparisons (through another EXPAND command) of locality data, collection data, availability of associated specimens, etc., are made in order to obtain a total picture of the extant and/or fossil taxa. The 15,000 slides of extant pollen and spore preparations and the 127 fossil pollen and spore localities (each containing up to 200 species and several hundred thousand individual specimens) may now be compared and frequently cross-referenced to each other via several fields and the data they each contain.

The PARIS system provides a basic search tool, albeit only as refined as are the data, that can provide the first major step in the identification of fossil pollen and spore taxa. As more data are entered into PARIS, and as existing data are refined and made more exacting, the system likewise will become more efficient and exacting. The future possibilities are nearly endless. The use of video-discs to display images of the pollen or spore species is being examined.

The research necessary to reconstruct the composition and structure of the plant life on earth during the geologic past is a rewarding but always time-consuming endeavour. PARIS has partly reduced the time factor, leaving the rewards intact.

Acknowledgments

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SUMMARY OF A STUDY TO EVALUATE COLLECTION MANAGER-TYPE POSITIONS

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Abstract.—An exploratory project was initiated to develop a profile of professionals who directly care for natural science collections as well as a profile of the positions held by these individuals. The primary emphasis was on those positions involving collection management regardless of the formal institutional title of the position. Surveys were sent to 130 individuals working with natural science collections in the United States and Canada; 82.3% of the individuals responded. Analysis of the responses provided brief descriptions of the institutions represented; the collections with which the individuals were affiliated; the individual's job, background and training; professional development opportunities; and a more detailed description of the tasks involved with the individual's job. Seventy-two percent reported that collection manager best described their job function, but only 40% formally held a title of "collection manager." The majority reported a broad range of responsibilities under the following categories: specimen preparation; management of specimens, data, and records; personnel management; service; and general collection support and administration. About one-third also reported tasks in the areas of research and publications, teaching, and grant-writing.

During the past ten years there has been an increased awareness of the need to improve the level of care and management of museum collections. Education and training of museum personnel is a critical component of the priorities and strategies recommended by various studies concerning collection needs including the 1983 AAM Collections Needs Project (summarized by Brandes, 1984; American Association of Museums, 1984); a study by the American Association of Museums in cooperation with the National Institute for Conservation of Cultural Property and the American Institute for Conservation (American Association of Museums, 1985); and the ASC Workshop on Collection Resources for the 1990's (Hoagland and Mabee, 1988). This emphasis reflects the profession-wide interest in improving education and training opportunities for museum personnel (Matelic, 1990).

Although the need for training has been emphasized, there has not been an extensive effort to define and clarify the positions held by individuals responsible for collection care. Collection care positions defined by the AAM Museum Studies Committee in 1980 included curator, registrar, conservator and collections manager (Glaser, 1980). The definitions provided included a number of overlapping responsibilities among these four positions. More recently, the positions of registrar and collections manager were defined as a single position (Canham, 1987), suggesting no differences between the two. Although this may be the case in some institutions, it is definitely not in many natural science institutions.

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Intuitively, one would suspect that the responsibilities for collection care positions will vary with the size of the institution as well as the discipline. Yet, there have been few efforts to systematically identify the tasks and responsibilities of each position relative to institutional size and discipline. One exception to this is a recent study on the museum labor force in Canada (Ekos Research Associates, 1989). As part of this study, profiles were developed of the typical tasks performed by 17 occupational categories in museums permitting, among other analyses, a comparison of generalists and specialists. The most specialized position performed only one task whereas the most generalized performed eight. Collection care positions ranged from three (curators) and four tasks (conservators, curatorial assistants) to six (registrars). The summary of this study did not describe the tasks nor present data reflecting the effect of institutional size or discipline, however.

There have also been several efforts to document, analyze and refine the curricula of training programs, for example, the ICOM Basic Syllabus for Professional Museum Training under the auspices of the International Committee for the Training of Personnel (ICTOP, 1988), the " Curriculum for Museum Studies Training Programs" approved in 1988 by the Canadian Museums Association, and projects by the Committee on Museum Professional Training of the American Association of Museums (Museum Studies Committee, AAM, 1987). Relative to collections management, a summary of academic museum studies programs was prepared by Genoways (1989). NIC has recently initiated a project to develop a curriculum for a graduate course of study in preservation of natural history materials (National Institute for the Conservation of Cultural Property, 1990, in press). This project is also examining ways to provide continuing education for practicing collection care professionals.

"The nature of museum jobs is changing—in scope, technical complexity and degree of specialization, increasing demands on museum staffs and the need for training" (Matelic, 1990). This is certainly the case for collection care positions in natural history museums and collections (Humphrey, 1989). Before one can devise training programs to educate museum collection care professionals, it is important to have accurate information relative to the tasks these individuals are currently performing. There needs to be an assessment of actual activities, not merely of formal job descriptions. Job descriptions frequently reflect the job as it was five or ten years ago or as it should be. Do natural science collection managers perform the same kinds of tasks that art or history collection managers do? Are registrars and collection managers interchangeable or do they have unique functions? Do curators and collection managers differ relative to actual tasks performed? To what extent does the size, discipline or governance structure of an institution affect the tasks performed by individual collection care professionals? This information is essential to adequately assess current training opportunities and future training needs.

Information such as that provided by the study on the museum labor force in Canada (Ekos Research Associate, 1989) provides one level of information, but does not provide sufficient detail on collections care positions. The Cooperstown Conference on Professional Training (Matelic and Brick, 1990) also addressed in part the needs of collections professionals, but the emphasis was from the perspective of history museums. The Society for the Preservation of Natural History Collections (SPNHC) recognized a need to address specifically collection care professionals in the natural science community. As an initial step, a 1989 workshop co-sponsored by SPNHC and the Association of Systematics Collections focused on the current state of collection management and preservation, addressing the definition and purpose of collection management from the perspective of directors, curators and collection managers (Cato, 1990a). Needless to say, opinions varied.

Collection managers in the natural sciences generally have had a major "hands-on" responsibility for the care and management of the collections. Collection manager-type positions have evolved rapidly over the last ten to fifteen years, resulting in confusion over the true nature of the responsibility for this type of job. Ask five curators, five directors and five collection managers what it is that a collection manager does or should do, and the result will be at least ten different answers. Therefore, SPNHC initiated a project to develop (1) a profile of professionals who function as collection managers in the natural sciences, and (2) a profile of existing collection manager-type positions in Canada and the United States. These profiles must take into consideration the kind of institution, its governance structure, its size, and its disciplinary emphasis.

Research Design

A well-defined population of collection care professionals does not exist. The emphasis for this study centered on individuals who care directly for one or more types of natural science collections and who might serve in a capacity of "collection manager" regardless of institutional title.

The sampling frame for this study consisted of 245 individuals from Canada and the United States involved with collections care for one or more of the following collection types: anthropology, archaeology, botany, entomology, geology, herpetology, ichthyology, mammalogy, and paleontology. An effort was made to insure representation of all disciplines. The majority (55.9%) of individuals in the sampling frame were involved with life sciences; 20% represented the earth sciences and 7.8% anthropology and archaeology. The remaining 16.3% dealt with at least two major types of collections (for example, earth and life sciences).

Samples for a mail survey were drawn using probability sampling procedures as described in Babbie (1973) and Schaeffer *et al.* (1979). The 245 individuals were stratified according to the disciplinary emphasis of their collections into four groups: life sciences, earth sciences, anthropology/archaeology, and multiple disciplines. The sample size for the final mail survey was limited to approximately half of the individuals in the sampling frame. One hundred thirty individuals were randomly selected using proportional allocation from the four strata for the final survey.

The survey instrument was developed according to procedures recommended by Dillman (1978) and Labaw (1980). A draft of the survey was developed by two of us (Cato and Simmons), then reviewed by committee members to confirm the content validity of the questions. The draft subsequently underwent several revisions before it was mailed to ten individuals from the sampling frame to confirm the reliability of the instrument. The survey was accompanied by a letter describing the project. This pilot test resulted in further revisions of the survey instrument and accompanying letter. The final version of the questionnaire and the letter were reviewed by SPNHC Council. Copies of these are available from the author.

Surveys were mailed 20 December 1989, accompanied by a letter requesting participation and explaining the project. Approximately 50% of the surveys were returned by 1 March 1990, and by 12 March, a second letter and questionnaire were sent to non-respondents. By May 1990, 82.3% (107) questionnaires had been returned.

Five of the questionnaires were eliminated before analysis; either the questionnaire was returned with less than half of the questions answered or the respondent held a job that did not directly relate to collections care (for example, a librarian). Responses to the questions for the remaining 102 questionnaires were analyzed by the most appropriate of the following methods: frequency distribution; descriptive statistics including median, range, minimum, maximum, and skewness; and content analysis. Responses were summarized in tables and histograms to facilitate analysis.

The analysis was subdivided into six categories: description of the institutions represented, description of the collections, description of the individual's job, description of the individual's background and training, description of the individual's professional development, and a more detailed description of the tasks involved with the individual's job. Due to the exploratory nature of this project, a series of analyses was completed for most questions to identify trends in the data. Data concerning the institutions and collections were analyzed according to the kind of institution, the governance structure, and the level of operating revenue. Kind of institution refers to whether the institution was best described by the respondent as a museum, a center, a free-standing collection, or a collection within an institution other than a museum (e.g., a collection in a academic department of a university). The governance structure followed definitions used by Cato (1990b), resulting in four categories: federal, university (both universities and colleges, private and public institutions), public (under a public authority, excluding federal, university and college institutions), and private. The level of operating revenue reflected the institution's most recent fiscal year figure for income from all sources, a figure comparable to the figure used by the Institute of Museum Services General Operating Support grant applications for "total revenue and support—operating." Some questions were also analyzed according to the country (United States vs Canada) and the discipline of the collections. The latter were grouped into four categories: life sciences, earth sciences, anthropology/archaeology, and multiple disciplines.

Data for the individual's job titles and job functions were also analyzed according to kind of institution, governance structure, levels of institutional operating revenue, and country. Most of the remaining questions concerning the individual's job, background and training, and professional development were analyzed only according to the job function as determined by the respondent.

Results

Description of Institutions Represented

Sixty-four institutions were represented by the 102 respondents; 15 of these institutions were represented by more than one individual. The majority of the institutions were museums (77%), and 22% were collections. The latter included collections that were either free-standing, or were part of an institution that was not a museum (for example, a university academic department). None of the respondents represented a center (science center, nature center, etc.). Thirty-nine percent of the museums were privately-governed whereas the majority of the collections (79%) were governed by universities.

Institutions from the United States comprised 86% ($n = 55$) of the returns, and of these, 38% were privately-governed, 38% university-governed and 22% publicly-governed. In contrast, the Canadian institutions ($n = 9$) were 56% publicly-governed and 33% university-governed; no private institutions were reported from Canada.

Almost half (48%) of the 64 institutions reported operating revenues of more than $2 million and 13% reported operating revenues of less than $100,000. Of the former category, 52% are privately-governed and 29% publicly-governed, whereas all of the institutions with revenues under $100,000 were university-governed.

Individuals were requested to note the presence or absence of four collection care positions (as evident by formal institutional titles) in their institutions. The responses varied with respect to (a) whether the institution was a museum or a collection, (b) the country, and (c) the operating revenue (Fig. 1). Museums were more likely to have one or more of these positions than were collections; only one registrar and two conservators were reported by the latter institutional category.

Institutions in both countries reported high frequencies of curator positions. With only one exception, less than half of the institutions reported the other three positions; two-thirds of the Canadian institutions had conservators. These data reflected only positions that have been formally designated by the institution and should not be used to imply that there were not individuals serving in these capacities.

As might be expected, the presence of some collection care positions varied with respect to the level of the institution's operating revenue. Whereas curator positions were present in at least 75% of all institutions, collection managers, registrars and conservators were more frequently found in the higher operating revenue categories.

Two institutions from the lowest revenue category (<$100,000) did not have any of these four positions; two had both a curator and collection manager. None of the eight institutions in this category had a registrar or conservator. All eight of the institutions with revenues more than $100,000 but less than $750,000 had curators and no collection managers. Only one had the combination of curator, conservator and registrar.

Institutions in the two larger revenue categories reported a range from only one to all four of the four positions (Table 1). The most common were two or three positions, Only six of the 46 institutions with revenues of more than $750,000 had all four positions.

Description of Collections

Respondents were requested to describe the collection(s) for which they were responsible as part of their job. These questions were analyzed based on 102 responses.

Forty-four percent of the respondents were responsible for only one kind of

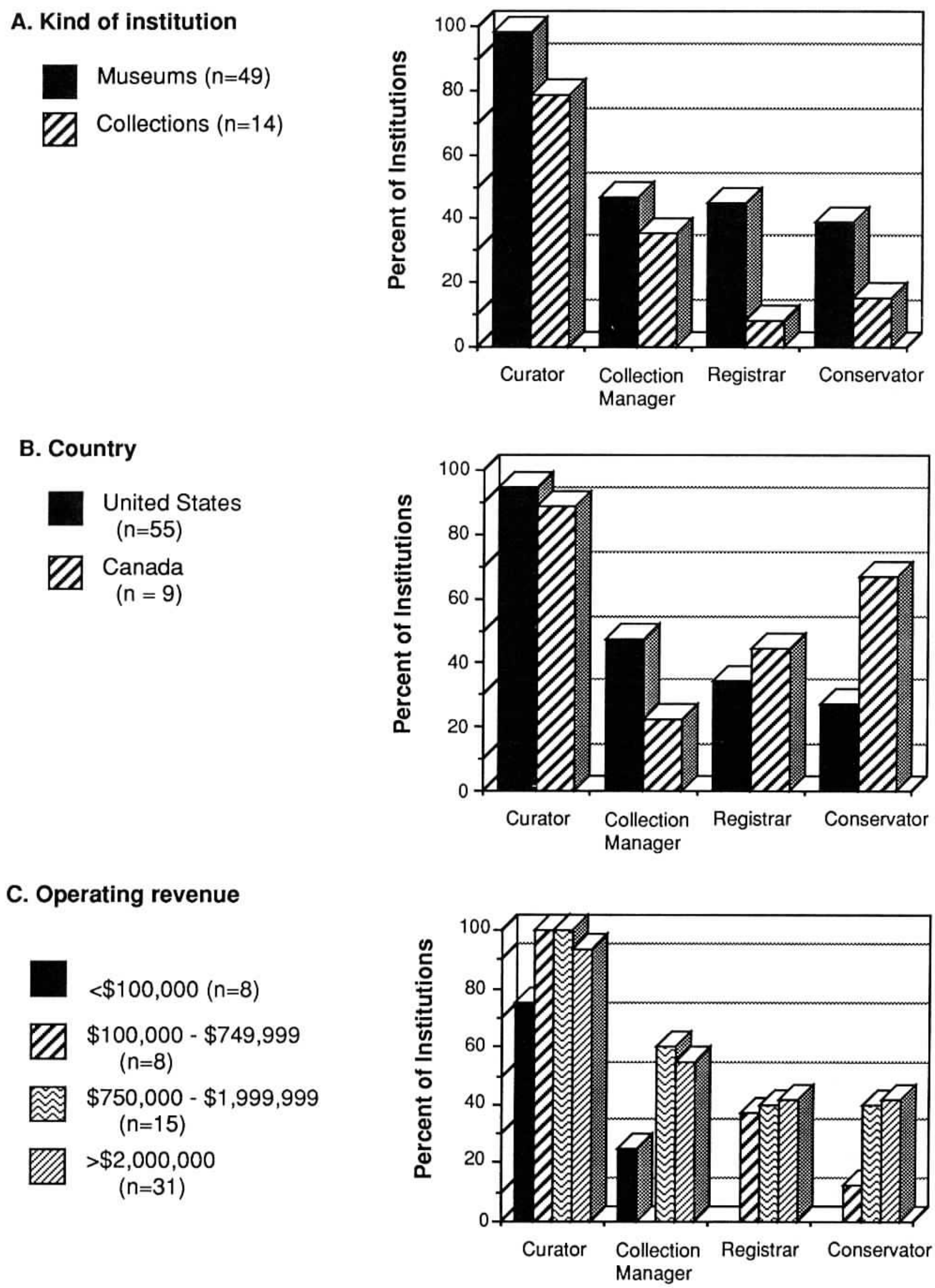


Figure 1. Variation in the presence of collection care positions as evidenced by the formal institutional titles relative to A) kind of institution; B) country; and C) operating revenue.

Table 1. Number of collection care positions within an institution according to formal institution titles.

Number of positions	Number of institutions	Curator	Collection manager	Registrar	Conservator
A. Operating revenue ≥$750,000 and <$2,000,000 (N = 15 institutions).					
1	3	X	–	–	–
2	4	X	X	–	–
	2	X	–	X	–
3	2	X	X	–	X
	1	X	–	X	X
4	3	X	X	X	X
B. Operating revenue ≥$2,000,000 ($N$ = 31 institutions).					
0	1	–	–	–	–
1	5	X	–	–	–
2	6	X	X	–	–
	2	X	–	X	–
	3	X	–	–	X
3	4	X	X	X	–
	3	X	–	X	X
	3	X	X	–	X
	1	–	X	X	X
4	3	X	X	X	X

collection (for example, mammals, birds, vertebrate paleontology, etc.), whereas 21% were responsible for three to six kinds of collections, and 23% for seven or more kinds of collections. The majority of respondents from institutions with the smallest (<$100,000) and largest (>$2,000,000) operating revenues were responsible for only 1 or 2 kinds of collections (75% and 65% respectively). In contrast, only 36% or respondents from institutions in the two categories for midrange operating revenues ($100,000–$2,000,000) cared for only 1 or 2 kinds of collections. The majority (52%, 54%) of these individuals were responsible for three to ten kinds of collections. The kinds of collections were reported in proportions similar to those in the sampling frame and sample (Table 2).

Two-thirds of the collections have both manual and electronic data systems, whereas 24% have only a manual system and 12% only an electronic system. Respondents from the privately-governed institutions reported the highest level of manual only (37%) while those from the federal institutions noted the highest level of computer only (33%).

Table 2. Frequency of collection disciplines represented.

	Sampling frame		Sample		Responses	
Discipline	N	%	N	%	N	%
Earth Sciences	49	20.0	25	19.2	19	18.6
Life Sciences	137	55.9	69	53.1	57	55.9
Anthropology/Archaeology	19	7.8	15	11.5	10	9.8
Multiple	40	16.3	21	16.2	16	15.7
Total	245	100.0	130	100.0	102	100.0

Table 3. Frequency of responses indicating written policies and/or procedures.

Policy or procedure	All collections		Life Sciences		Earth Sciences		Anthropology/Archaeology		Multiple disciplines	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%
Acquisitions policy	65	63.7	34	59.6	11	57.9	8	80.0	12	75.0
Field preparation/ preservation procedures	26	25.5	21	36.8	1	5.3	2	20.0	2	12.5
General management policies, procedures	56	54.9	32	56.1	8	42.1	8	80.0	8	50.0
Guidelines for visiting researchers, users	35	34.3	25	43.9	2	10.5	4	40.0	4	25.0
Loan policies, procedures	76	74.5	45	78.9	10	52.6	8	80.0	13	81.2
Conservation treatment	22	21.6	12	21.1	3	15.8	4	40.0	3	18.8
Totals	102	100.0	57	100.0	19	100.0	10	100.0	16	100.0

Respondents also recorded the number of paid staff members who worked with or were affiliated with the collection described in the questionnaire. The total FTE (full-time equivalent) ranged from zero to 78 with a median of four for the 102 responses. When the responses were analyzed according to governance structure, only the federally-governed institutions differed from this median; the latter had a median of nine FTEs per collection. All of the responses were heavily skewed, indicating a large proportion of collections with small numbers of paid staff. As would be expected, the median FTE increased with an increase in the operating revenue (1.4 for institutional revenues of less than $100,000; 5 for revenues of more than $2,000,000).

Respondents were requested to indicate whether written policies and procedures had been completed, only drafted or did not exist for acquisition policies, field preparation/preservation procedures, general management policies and procedures, guidelines for visiting researchers/users, loan policies and procedures, and conservation treatment of specimens. The responses to these questions are partially summarized in Table 3. More than half of the collections have written statements describing acquisitions policies, general management policies and procedures, and loan policies and procedures, whereas less than one-third have written statements for field preparations, visitor guidelines and conservation treatment. For all six categories, however, approximately 11–19% indicated that something had been drafted. Some differences in written policies and procedures were evident according to the discipline of the collection.

The majority of the collections did not have written long-range plans addressing

Table 4. Frequency of written long-range plans for the collections.

	Yes		No		No answer		Totals	
	N	%	*N*	%	*N*	%	*N*	%
Growth and development	43	42.2	54	52.9	5	4.9	102	100.0
Improving collection management	30	29.4	65	63.7	7	6.9	102	100.0
Conservation of collections	32	31.4	64	62.7	6	5.9	102	100.0

Table 5. Frequency of job titles.

Title	*N*	%
Collection Manager	41	40.2
Curator	17	16.7
Curatorial assistant	11	10.8
Assistant curator	4	3.9
Registrar	4	3.9
Technician	4	3.9
Chief	3	2.9
Museum specialist	3	2.9
Associate curator	2	2.0
Preparator	2	2.0
Assistant collections manager	1	1.0
Associate collections registrar	1	1.0
Collection manager, department	1	1.0
Collections coordinator	1	1.0
Conservator/cur. assist./coll. mgr.	1	1.0
Conservator	1	1.0
Curatorial specialist II	1	1.0
Curatorial/research associate	1	1.0
Research associate	1	1.0
Other	2	2.0
Total	102	100.2

the growth and development of the collection, improving the management of the collection, or the conservation of the collection (Table 4).

Description of Job

Job title vs job function.—A comparison was made between the individual's formal job title and the one term of four provided (curator, collection manager, registrar, conservator) that the respondent felt best described the job function. Forty percent of the respondents held the title of collection manager, whereas only 16.7% and 10.8% had titles of curator and curatorial assistant respectively (Table 5). All of those with titles of collection manager, 88.2% of the curators and 54.5% of the curatorial assistants were in the United States.

Responses relative to their job function showed very different percentages. The majority (72.2%, $n = 73$) of respondents reported that collection manager best described their job function, whereas only 19.8% ($n = 20$) selected curator as the best descriptor. Only 5.0% ($n = 5$) and 3.0% ($n = 3$) selected registrar and conservator respectively.

Almost 93% of those with the job title of collection manager reported their job function as collection manager. In contrast, only 58.8% of the respondents with a title of curator noted their function as a curator; instead, 35.3% reported they functioned as a collection manager. Ninety-one percent of individuals with the title of curatorial assistant reported they functioned as collection manager. Due to the small responses for registrar and conservator, these categories were not further analyzed.

Job tasks.—Results from the survey provided an indication of tasks that were part of the individual's formal job responsibilities as well as time actually spent doing some of these tasks. It was possible to identify those tasks that were most commonly performed, as well as those that were most time consuming. Respondents completed a checklist to better identify the tasks that their positions formally included (Table 6). They then provided an estimate of the percentage of their time actually spent completing various groups of tasks (Table 7). Tasks were grouped into eight categories: specimen preparation, management of specimens, management of data and records, management of personnel, service, research and publications, teaching, and general collection support and administration; these were defined as listed in Table 6.

There was substantial overlap in the tasks indicated by those who functioned as collection manager and those who functioned as curator. Differences between the two functional groups appeared to be a matter of the amount of time that was spent rather than absolute differences in the tasks themselves. For example, collection managers and curators both reported formal responsibilities for management of data and records, but a higher percent of collection managers reported involvement with data input into computerized systems and maintenance of cross-reference or database systems. This is supported by the percent of time actually spent at these tasks reported by individuals (Table 7). Ninety percent of the curators and 95.9% of the collection managers spend at least 1% of their time managing data and records; however, the median time spent was 20% for collection managers, and only 10% for curators.

The data also permit comparisons between formal job responsibilities and tasks actually performed. For example, approximately 20% of the collection managers indicated formal job responsibilities for research, writing grant proposals and writing for professional publications (Table 6). However, 60% noted that they actually spent time doing research and writing, even though the amount of time was relatively small (median = 3% of an individual's total time). In contrast, approximately 50% of the curators indicated formal job responsibilities in this area, but 75% reported actually spending time for research and publications. The median for curators (10%) was also low, however. Teaching responsibilities were very low for both collection managers and curators. Trends noted relative to the institution's budget size, number of kinds of collections managed by the respondent, and the discipline of the collections are discussed under "Profile of Collection Management Positions" below.

The majority of the respondents (72.5%) had written job descriptions, but only 41.2% felt they adequately described the actual job responsibilities. Thirty-four percent felt the written description did not adequately describe their responsibilities and 22.5% did not have an opinion.

A number of other job similarities existed between those who function as collection managers and those who function as curators. The majority of respondents spent more than 40 hours per week on professional and job-related activities: 71.2% (n = 52) and 60% (n = 12) for collection managers and curators respectively. The amount of additional time ranged from one to more than 15 hours per week in addition to the basic work week; of the respondents for this question, 11 of the 52 collection managers and 4 of the 12 curators reported spending an additional 15 hours or more per week.

Supervision.—Respondents indicated the number of individuals they super-

Table 6. Frequency of tasks that are part of the formal job responsibility.

Task	Collection manager (N = 73)		Curator (N = 20)	
	N	%	N	%
Specimen preparation				
Field collecting; salvaging	42	57.5	16	80.0
Specimen preparation; initial preservation	41	56.2	16	80.0
Specimen processing (dermestid colony, mounting, etc.)	44	60.3	14	70.0
Other	6	8.2	1	5.0
Management of specimens				
Accessioning	63	86.3	16	80.0
Identification of specimens	55	75.3	18	90.0
Cataloging	64	87.7	17	85.0
Loan approvals	41	56.2	16	80.0
Loan processing	65	89.0	14	70.0
Pest control program	43	58.9	11	55.0
Maintaining physical organization of specimens	65	89.0	17	85.0
Monitoring/maintaining fluid levels	45	61.6	8	40.0
Managing specimen conservation program	38	52.1	13	65.0
Other	4	5.5	2	10.0
Management of data and records				
Record keeping (permits, field notes, conservation treatment records, etc.)	67	91.8	19	95.0
Data input into manual system	56	76.7	15	75.0
Data input into computerized data system	48	65.8	6	30.0
Maintaining manual cross-reference systems	38	52.1	9	45.0
Maintaining computerized database system	40	54.8	8	40.0
Other	8	11.0	1	5.0
Management of personnel				
Hiring new employees	26	35.6	10	50.0
Training new employees	53	72.6	12	60.0
Supervising employees	56	76.7	14	70.0
Training volunteers	50	68.5	15	75.0
Supervising volunteers	54	74.0	15	75.0
Evaluating (formally) employees and/or volunteers	34	46.6	10	50.0
Firing employees	23	31.5	5	25.0
Other	2	2.7	1	5.0
Service				
Assist visitors	61	83.6	13	65.0
Tours	39	53.4	6	30.0
Educational programs	26	35.6	7	35.0
Lectures	18	24.7	10	50.0
Exhibit development—planning/research	22	30.1	13	65.0
Exhibit development—production (labels . . .)	15	20.5	5	5.0
Respond to questions from researcher/public	65	89.0	15	75.0
Professional societies/organizations	32	43.8	11	55.0
Other	2	2.7	0	0.0
Research and publications				
In traditional discipline (mammalogy, systematics, ecology, etc.)	20	27.4	12	60.0
On collection care, conservation	23	31.5	7	35.0

Table 6. Continued

Task	Collection manager (N = 73) N	%	Curator (N = 20) N	%
Writing grant proposals	17	23.3	9	45.0
Writing for professional publications	17	23.3	12	60.0
Writing for popular publications	10	13.7	8	40.0
Other	3	4.1	0	0.0
Teaching				
Formal classroom; elem.–college level	6	8.2	6	30.0
General collection support and administration				
Budget planning and/or management	37	50.7	11	55.0
Ordering supplies and equipment	56	76.7	16	80.0
Inventory of supplies and equipment	53	72.6	12	60.0
Maintain library	22	30.1	7	35.0
Maintain archival material	24	32.9	8	40.0
Write grants—collection/project support	25	34.2	8	40.0
Long range planning for collection and/or institution	29	39.7	13	65.0
Institutional committee assignments	30	41.1	13	65.0
General maintenance of collection area	57	78.1	11	55.0
Other	5	6.8	1	5.0

vised relative to full-time paid support staff, half-time paid support staff, part-time (hourly) paid workers, volunteers and students. Approximately half of the collection managers supervised full-time, half-time and part-time paid employees, ranging in quantity from one to 50 individuals. In contrast, 40% of the curators supervised full-time staff, 20% supervised half-time staff, and 50% supervised part-time staff; the quantity of staff ranged from one to 12 individuals. At least 70% of the collection managers and curators reported supervising volunteers, ranging in quantity from one to 30, and slightly less than half of both groups supervised students who worked as paid employees (range = 1–32).

Table 7. Percent of the respondent's time actually spent on tasks.

Task category	Collection manager (N = 73) % time Range	Median	% spending at least 1% time	Curator (N = 20) % time Range	Median	% spending at least 1% time
Specimen preparation	0–75	5	72.6	0–40	4.5	75.0
Management of specimens	0–80	20	95.9	0–50	10.0	90.0
Management of data and records	0–70	20	95.9	0–40	10.0	90.0
Management of personnel	0–65	10	83.6	0–50	5.0	75.0
Service	0–40	5	84.9	0–25	7.5	75.0
Research & publications	0–70	3	60.3	0–80	10.0	75.0
Teaching	0–15	0	30.1	0–60	0.5	50.0
General collection support/ administration	0–80	10	84.9	0–50	10.0	90.0

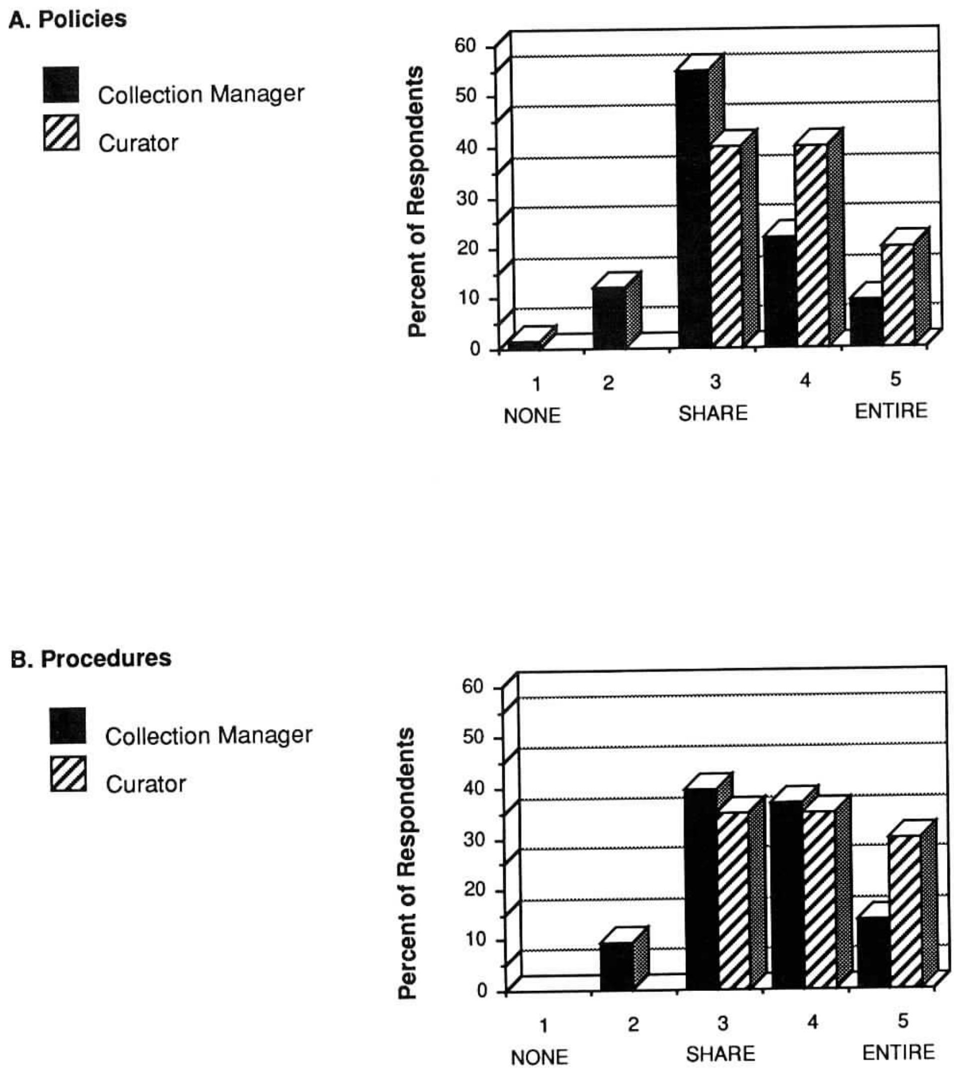
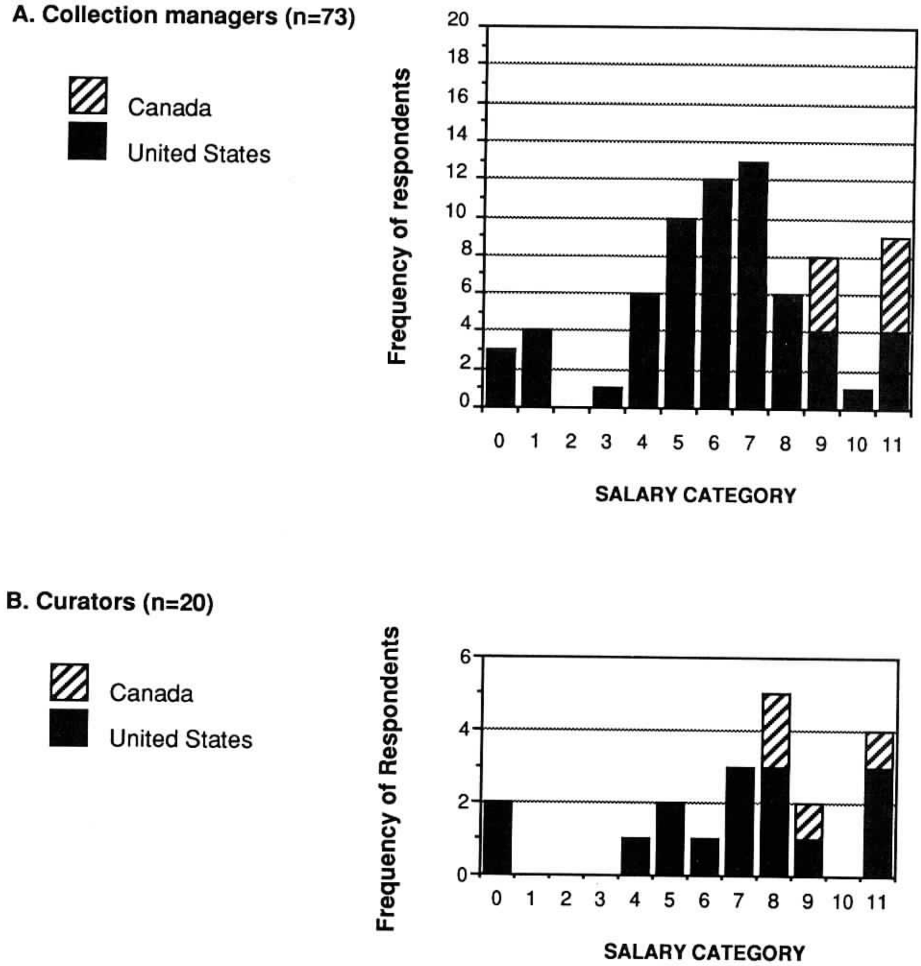


Figure 2. Degree of responsibility for establishing policies and procedures for collection care according to job function.

Supervisors.—Thirty-seven job titles were reported by respondents as their immediate supervisor, but the most frequently reported were curator (29%) and director (13.7%). Thirty-five percent of the collection managers were supervised by a curator, and 13.7% by a director or assistant director. In contrast 25% of the curators were supervised by a curator or chief curator and 25% by a director. When questioned with regard to how much time the supervisor spent in caring for the collection during the previous 12 months, the median response by collection managers and curators was 5% and 0% respectively. Seventy-five percent of the collection managers responded that their immediate supervisors spent no more than 10% of their time caring for the collection.

Responsibility for policies and procedures.—Collection managers and curators



Salary Categories

0	no response	6	$22,000 - 24,999
1	< $10,000	7	$25,000 - 27,999
2	$10,000 - 12,999	8	$28,000 - 30,999
3	$13,000 - 15,999	9	$31,000 - 33,999
4	$16,000 - 18,999	10	$34,000 - 36,999
5	$19,000 - 21,999	11	>$37,000

Figure 3. Histograms summarizing salary levels as reported by the respondents according to job function.

responded similarly to questions concerning their responsibility with regard to establishing policies and procedures for collection care and use (Fig. 2). The majority responded that they share the responsibility, although more curators noted that they had the entire responsibility than did collection managers. Fifty-four percent of all respondents reported they had the level of authority needed to

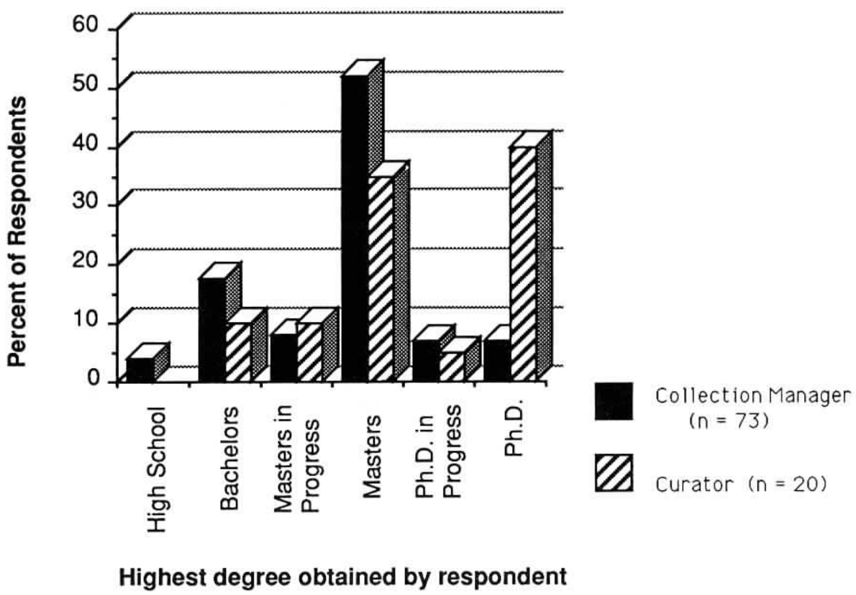


Figure 4. Histogram indicating the highest degree obtained by the respondent according to job function.

carry out the responsibilities of their job; only 18% reported that they did not have sufficient authority. With respect to this question, however, more curators than collection managers (25% vs 16.4%) responded that they did not have sufficient authority. Approximately 54% of all respondents were satisfied with their current level of authority, 30% were more or less satisfied and 15% were not satisfied.

Salaries.—Salaries for all functional groups ranged from less than $10,000 per year to more than $37,000 per year (Fig. 3). Salaries for curators were only slightly higher than for collection managers. Fifty-five percent of the curators had salaries of at least $28,000, whereas 51% of the collection managers had salaries of at least $25,000. It should be noted that results from Canadian respondents were used as reported and not converted to US dollars. Assuming that respondents from Canada reported salary figures in Canadian dollars, the resulting graphs would be skewed slightly high.

Background and Training

The majority (78%) of all respondents had completed a master's or Ph.D., or had one of these degrees in progress (Fig. 4). Fifty-two percent of the collection managers reported a master's as their highest degree obtained, 7% a Ph.D., and 15% were working on one of these. By comparison, curators reported Ph.D. degrees most frequently (40%), followed by 35% with master's degrees. An additional 15% of the curators were working on a degree as well.

The median for number of years employed as paid employees in collection support positions was similar for collection managers (11) and curators (10). However, curators had been in their current positions longer (median = 8.25 years) than collection managers (median = 5 years). The former were also born

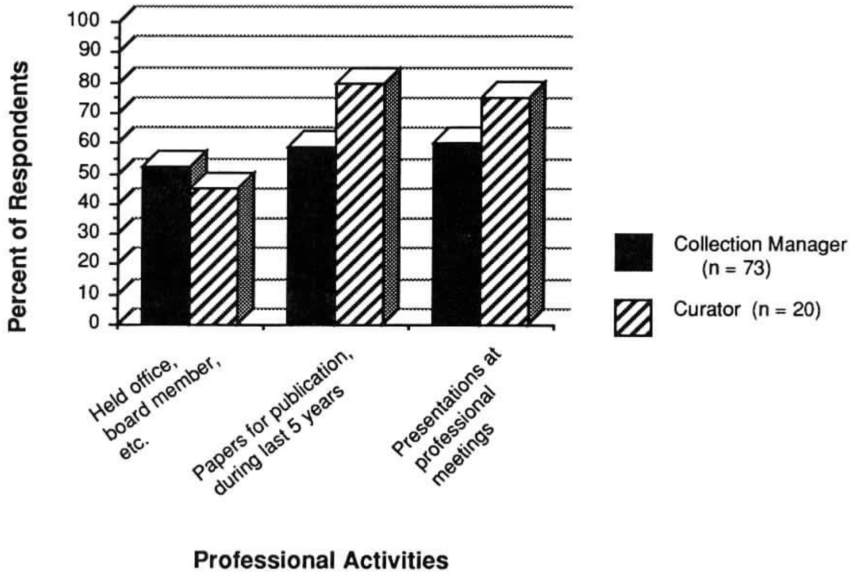


Figure 5. Level of professional activities according to job function.

earlier than the collection managers; the median for the year born was 1947 for curators and 1952 for collection managers.

Curators and collection managers reported similar levels of participation in professional activities as noted by membership in professional societies; involvement in a society as an officer, board member or committee member; writing papers and/or reviews for publication; presenting oral or poster presentations at professional meetings; and grants received as principal or co-principal investigator (Fig. 5, Table 8). At least half of the collection managers and curators were involved in professional societies. The median values for the numbers of papers written was low for both groups but the percent responding positively ranged from 38% to 80%. Twenty percent of the curators and 30% of the collection managers indicated their papers and presentations dealt with collection care topics. Slightly more than half of both groups reported having received at least one grant.

Table 8. Frequency of publications, presentations and grants.

	Collection managers (N = 73)			Curators (N = 20)		
Activity	% response	Range	Median	% response	Range	Median
Papers						
Refereed journals	64.4	1–31	2	80.0	1–50	5
Books, proceedings	38.4	1–11	0	35.0	1–22	0
Popular	38.4	1–80	0	65.0	1–10	3
Collection care						
Presentations	30.1	1–7	0	20.0	1	0
Papers	23.3	1–5	0	20.0	1–2	0
Grants	52.1	1–7	1	55.0	1–4	1

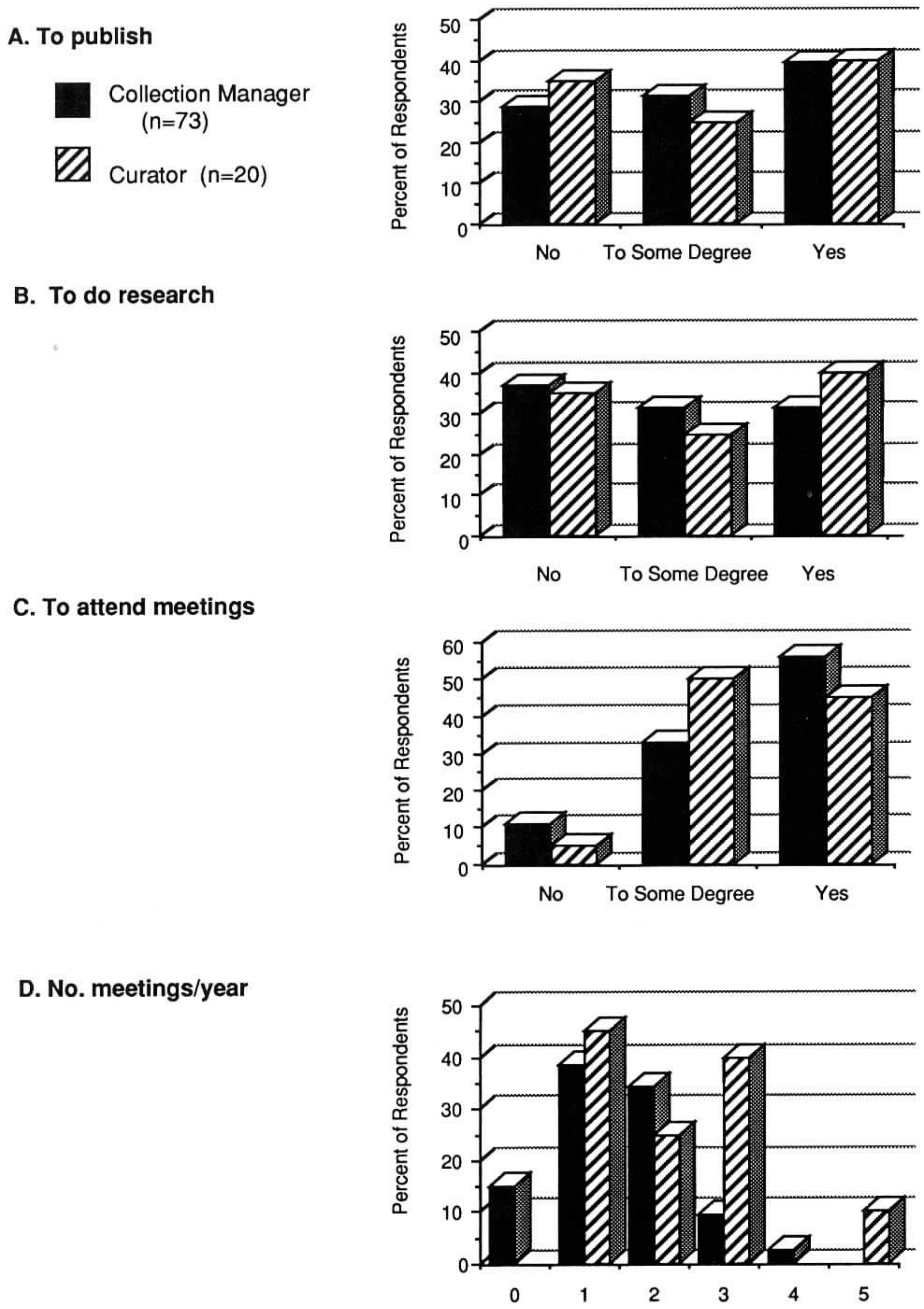


Figure 6. Histograms summarizing degree of encouragement to respondent provided by his/her institution: A) encouragement to publish; B) encouragement to do research; C) encouragement to attend meetings; and D) number of meetings attended per year.

Table 9. Summary of amount of time spent on tasks by collection managers ($N = 72$) relative to institutional operating revenue (medians are enclosed in parentheses).

Operating revenue	N	Median times for task categories		
		Most		Least
<$100,000	5	Mgmt. specimens (20) Mgmt. data/records (20)	Mgmt. pesonnel (10) Research/publications (1)	Service (5) Specimen preparation (2) Teaching (1) General support/admin. (1)
$100,000–$749,999	6	Mgmt. specimens (36.5) Mgmt. data/records (22.5)		Mgmt. personnel (5.5) Spec. preparation (3.5) Service (2) Gen. support/admin. (2) Research/publications (0) Teaching (0)
$750,000–$1,999,999	12	Mgmt. specimens (27.5) Mgmt. data/records (20)	Spec. preparation (10) Mgmt. personnel (10) Service (10) Gen. support/admin. (9)	Research/publications (5) Teaching (0)
≥$2,000,000	49	Mgmt. specimens (20) Mgmt. data/records (20)	Mgmt. personnel (10) Gen. support/admin. (10)	Spec. preparation (5) Service (5) Research/publications (3) Teaching (0)

Professional Development

Eighty-five percent of all respondents considered their jobs to be a professional as opposed to a technical position. However, only 58% of their institutions classified the jobs as professional. This ranged from 53% for the collection managers to 80% for the curators. Twenty-three percent of the institutions classified the jobs as technical.

Sixty percent of the respondents reported they could advance professionally within their institutions through steps in salary; only 46% reported advancement through steps in title. These frequencies were similar for collection managers and curators. In addition, 56.9% responded that they had reached the highest staff position open to a collection manager within the current structure of their institutions.

As one indication of the degree to which institutions encouraged certain kinds of professional development, respondents were asked whether they were encouraged to publish, to do research and to attend meetings. The responses were divided evenly between "no," "to some degree" and "yes" for both publishing and research activities, but almost 90% received at least some degree of encouragement to attend meetings (Fig. 6). The majority attended one or two meetings annually in an average year, and 55% reported receiving nearly complete or complete reimbursement for meeting costs. Thirty-one percent received partial reimbursement and 11% did not receive any at all.

Profile of Collection Manager Positions

Respondents who functioned as collection managers indicated a broad range of responsibilities, both with respect to the formal job responsibilities (Table 6) and time actually spent on job-related activities (Table 7). Management of spec-

Table 10. Summary of amount of time spent on tasks by collection managers ($N = 72$) relative to the number of kinds of collections (medians are enclosed in parentheses).

Number of kinds	N	Median times for task categories: Most		Least
1	35	Mgmt. specimens (20) Mgmt. data/records (20)	Mgmt. personnel (10) Service (10) Gen. support/admin. (8)	Spec. preparation (5) Research/publications (5) Teaching (0)
2	11	Mgmt. specimens (15) Mgmt. data/records (15) Mgmt. personnel (15) Gen. support/admin. (15)		Spec. preparation (5) Service (5) Research/publications (3) Teaching (0)
≥3	26	Mgmt. specimens (20) Mgmt. data/records (20)	Mgmt. personnel (10) Gen. support/admin. (9)	Service (5) Spec. preparation (4.5) Research/publications (2) Teaching (0)

imens and management of data and records were the two categories that were most commonly cited by respondents (95.9%) and were the most time consuming (median = 20%). These categories were followed by management of personnel, and general collection support and administration. Tasks in the categories for service and specimen preparation were also commonly cited, 84.9% and 72.6% respectively, but were less time consuming (median = 5%). Research and publication-related tasks and teaching were cited by 60.3% and 30.1% of the respondents respectively, but at relatively low time allotments (medians of 3% and less).

Responses for the time actually spent on tasks were analyzed for the collection managers relative to the institution's operating revenue (Table 9), the number of kinds of collections for which the individual was responsible (Table 10), and the disciplines for those collections (Table 11). Collection managers in the smallest revenue category spend more time on research and publications than in the other

Table 11. Summary of amount of time spent on tasks by collection managers ($N = 72$) relative to the disciplines of the collections (medians are enclosed in parentheses).

Collection discipline	N	Median times for task categories: Most		Least
Anthropology/ Archaeology	5	Mgmt. specimens (20) Mgmt. data/records (20) Mgmt. personnel (15)	Service (10) Gen. support/admin. (10)	Research/publications (5) Spec. preparation (2) Teaching (1)
Earth Sciences	10	Mgmt. specimens (27.5) Mgmt. data/records (20)	Research/publications (10) Mgmt. personnel (7.5) Service (7.5) Gen. support/admin. (6.5)	Spec. preparation (3.5) Teaching (0)
Life Sciences	47	Mgmt. specimens (20) Mgmt. data/records (20)	Mgmt. personnel (10) Gen. support/admin. (8)	Spec. preparation (5) Service (5) Research/publications (3) Teaching (0)
Multiple	10	Mgmt. specimens (22.5)	Mgmt. data/records (12.5) Gen. support/admin. (12.5) Mgmt. personnel (10) Service (7.5)	Spec. preparation (2.5) Research/publications (0) Teaching (0)

three categories (Table 9). This is not unexpected as all of the institutions in this group are university-affiliated. Respondents from the second category ($100,000–$749,999) indicated the highest level of time spent on managing specimens and managing data and records, with correspondingly lower levels of the other task categories.

Individuals responsible for only one kind of collection spent more time on service-related tasks than those dealing with more collections (Table 10). Individuals responsible for two kinds of collections spent as much time managing personnel and working with general support as they did with managing the specimens, data and records.

Trends were evident relative to the discipline of the collections (Table 11). Collection managers responsible for collections from two or more broad discipline groups (e.g., life science and earth science, or archaeology and life science) spent less time managing data and records than did individuals responsible for collections from only one discipline. Earth science collection managers spent more time than the other groups managing specimens, and working on research and publications.

Discussion

The results reported above summarize the major findings from the survey, but are only a portion of the total amount of detail gathered. It was not the intention of the study to provide a definition of collection care positions (curator, collection manager, registrar, and conservator), but to develop a profile of collection manager-type positions. The sample was biased in the sense that the basis for the sampling frame came from the SPNHC membership lists; thus it was comprised of individuals who recognize a need to remain current with the state of the collection care profession.

The results of this study document the status of the collection manager-type positions. Comparative historical data do not exist, yet those who are familiar with the recent history of curator and collection manager-type positions certainly will recognize that both have evolved substantially. In particular, collection manager-type positions now encompass a broad variety of responsibilities, many of which were historically those assigned only to curators.

Not only is there an obvious overlap with curators, but one exists with registrars as well. A formal description of the position of registrar is included in the "Code of Ethics for Registrars":

> an individual with broad responsibilities in the development and enforcement of policies and procedures pertaining to the acquisition, management and disposition of collections. Records pertaining to the objects for which the institution has assumed responsibility are maintained by the registrar. Usually, the registrar also handles arrangements for accessions, loans, packing, shipping, storage, customs and insurance as it relates to museum material.
>
> Registrars are usually specialists in the areas of information management, risk management, and logistics. The primary concerns of registrars are creating and maintaining accurate records pertaining to objects, including those documents that provide legal protection for their museum; ensuring the safety of objects;

arranging insurance coverage for objects; and handling, transporting, and control of objects." (Case, 1988)

Out of the 46 institutions in this survey with operating revenues of more than $750,000, 19 had registrars, 26 had collection managers, but only 11 had both. As in the case of collection managers, registrar positions have evolved rapidly over the last 15 years. However, the emphasis has been in history and art museums rather than natural science museums. Due to the small representation of registrars and conservators in this sample, it was not possible to directly compare the three positions. Additional study is needed to further clarify the responsibilities of the various collection care positions, relative to the profession at large as well as individual institutional needs to fulfill collection care objectives.

The results of this survey emphasize the importance of collection manager-type positions to overall collection care goals in an institution., Individuals in these positions are involved with the development of policy and procedures related to collections, as well as every aspect of the specimens from collection and preparation through identification, organization and storage, maintenance, use transactions, research and dissemination of information. If these individuals are not directly involved with the specimens, a large percent are supervising those who are directly involved.

This study also reinforces the importance of analyzing the actual responsibilities, tasks, and abilities of individuals rather than of formal position titles. Standard descriptions or definitions of collection care positions in natural science institutions do not exist, and differences in institutional size, discipline and so on affect the actual tasks for which a position might in fact be responsible. It is important that this variability be recognized not only within an institution but across the museum profession as well.

Conclusions

The majority of those who function as collection managers have degrees at the master's or Ph.D. level. They have been in their current job about five years, and in collection care positions for 11 years. These individuals participate in professional activities by presenting papers at annual meetings, writing papers for publication and handling committee assignments and elected offices in professional societies. Approximately 71% spend more than 40 hours per week completing professional and job-related activities. More than half supervise paid personnel and 70% supervise volunteers. Collection managers are directly responsible to directors, assistant directors and curators, and 75% reported that these supervisors spent no more than 10% of their time caring for the collection. Seventy-three percent had written job descriptions, but only 41% felt these were adequate to describe their jobs accurately. Collection managers shared the responsibility for establishing policies and procedures, but only half felt they had sufficient authority to carry out the responsibilities of their jobs. Opportunities to develop professionally with respect to research and publishing activities and to advance in salary or title within an institution were not consistently available. The median salary for collection managers was $25,000.

Individuals who function as collection managers reported a broad range of responsibilities, both with respect to their formal job responsibilities and time actually spent on job-related activities. Management of specimens and management of data and records were the two categories that were most commonly cited by respondents and were the most time consuming. These categories were followed by management of personnel, general collection support and administration, service and specimen preparation. Research and publication-related tasks and teaching were cited by 60.3% and 30.1% of the respondents respectively, but at relatively low time allotments. Responses for the time actually spent on tasks varied with respect to the institution's operating revenue, the number of kinds of collections for which the individual was responsible, and the disciplines for those collections.

The importance of collection manager-type positions to overall collection care goals in an institution is supported by data from this survey. It is necessary to analyze the actual responsibilities, tasks, and abilities rather than rely on formal position titles to obtain an accurate description of an individual's role in collection care for a particular institution. This study provides a basis for clarifying training needs and developing professional standards for individuals in collection manager-type positions.

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MUSEUM COLLECTIONS: FUNDAMENTAL VALUES AND MODERN PROBLEMS

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Abstract.—Collections support scientific enquiries about the natural world and enhance education. These fundamental values notwithstanding, resources for collections remain limited despite recent increases in material stemming from biodiversity itself, from the development of mass collecting techniques, and from the need to house endangered collections, voucher specimens, collections preserving genetic diversity, and regional collections. The pressure on resources can best be met by obtaining more resources. Knowing biodiversity (and thus understanding the world we inhabit and living there sensibly) requires the steady accumulation of information supported by collections, which in turn require essential infrastructure resources. The support to other branches of science provided by collections (and by the systematics work they facilitate) must be explained to those who use this support but do not appreciate its true cost. Initial project costs should include the means to identify material and preserve voucher specimens. In addition, existing resources can be used more efficiently by setting priorities to optimize scientific quality and resource use. Increasing operational efficiency (collections management and improved preservation) and division of labour (regional participation, networks, and data standards) also converse resources. Modern problems can be solved by emphasizing the fundamental scientific value of collections in building knowledge for current and future use.

This paper discusses various current problems and concepts related to natural history collections. Most of the specific examples given are drawn from the insects, mites, spiders and their relatives. This is not inappropriate because three quarters of all living animal species are terrestrial arthropods. Indeed, the very large numbers of specimens and of undescribed species increase the problems associated with arthropod collections. Nevertheless, the central theme of this paper is a general one: the basic values of collections, and how to get the most out of them under current circumstances.

FUNDAMENTAL VALUES OF COLLECTIONS

Collections have value both in practical ways and in supporting theoretical advances in scientific knowledge. The basic roles and importance of collections have been recognized for a long time (e.g., Holland, 1965), and were recently elucidated by Wiggins *et al.* (1991).

Collections support many kinds of scientific enquiries (Table 1). Research collections underlie the study of organisms because they record natural diversity, and carefully preserved specimens assembled in permanent institutions are the foundation for scientific study. Without this long-term process of accumulation of adequate material for study, many species would never be defined and identified, and their distributions and ecological significance would never be known. This is the basic function of a research collection.

Based on well-curated collections, systematics research distinguishes and establishes a taxonomic classification of named species. In turn, authoritatively identified specimens and the data associated with them are the basis for further

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Table 1. Basic roles and values of collections.

Basis for Research
Accumulation of data
Material for study
Reference material for identification
Voucher specimens
Especially for taxonomy
Increasingly for ecological and other work
Means for understanding diversity and evolutionary relationships
Means for understanding extinct species diversity
Reference material on historical diversity and biogeography
Means for understanding ecosystems and the environment
Basis for Education
Public awareness
Extension
Undergraduate teaching
Graduate training

research. The specimens also become references for naming other specimens submitted for identification, and for educational purposes.

Specific identification, facilitated by comparison with named specimens in collections, is the key by which the information available on each species can be organized and retrieved. Through identification, the results of previous studies become accessible. Successive studies thus build up an increasingly broad knowledge of the ranges and systematic and biological relationships of species.

Collections also document previous work directly. Type specimens document the scientific names, and so serve as references for the species. Such type specimens must be maintained in collections that guarantee their permanent security. Moreover, voucher specimens for many other kinds of research are deposited in permanent collections. If there is future doubt about the identity of the specimens on which published work is based, voucher specimens can be examined to ascertain what species was studied (e.g., Knutson, 1984).

Beyond the recognition of species, and the provision of keys to identify them, studies in systematics that are based on material in collections provide the means for understanding evolutionary relationships, which can be reflected in classifications. In this way, large amounts of comparative data are synthesized into generalizations and predictions about organisms, resulting in important theoretical contributions and insights into the nature of diversity. On a shorter time scale, collections include considerable historical documentation, providing the means to assess recent extinctions and changes in occurrence and distribution.

Furthermore, collections and their associated data provide the means to understand ecosystems, because it is species, each with their particular properties, that interact to determine environmental relationships and ecosystem function. The great abundance of terrestrial arthropods (in numbers of both species and individuals) makes them especially significant in this respect.

Perturbations in ecosystems can be detected by changes in their component species (Lehmkuhl *et al.*, 1984; Rosenberg *et al.*, 1986). Many studies of environmental disturbance rely on the documentation provided by collections, for both initial identification and subsequent establishment of voucher specimens. These vouchers represent particular ecological communities and give baseline information for comparison with later samples.

The second major role of collections is in support of education. Providing information to the public at large, as well as to special-interest groups such as farmers and foresters, is greatly assisted by well-curated collections. Moreover, actual specimens lend reality and emphasis to exhibitions and other programmes for the public, although most collections for public exhibition consist of specially prepared material rather than research specimens. Collections are invaluable teaching aids to introduce younger children to the study of nature. They assist undergraduate teaching because the diversity of organisms can be learned most effectively by study of actual specimens. And collections aid graduate training because comparative materials are necessary for more detailed study and for research. In all of these roles, collections serve to document and to reveal to others the enormous and fascinating diversity of organisms.

Modern Problems

Although the fundamental values of collections are clear to taxonomists and curators, such basic values have not been widely recognized. Therefore, a long-standing problem has been that resources to develop, maintain and use collections are limited or even reduced. At the same time, however, new demands are being made of collections, resulting from the additional elements shown in Figure 1. These six elements create collections of a different scale, nature, or purpose than hitherto.

Biodiversity

The concept of biodiversity, and the need to know the diversity of the world's species, is being recognized increasingly beyond the scientific community. Wilson (1985) and others have pointed out the values of diversity, including the roles of the many species in ecological networks, the direct benefits from some species, and the potential for products of value from still unknown or unexplored species. However, the scale of diversity is not fully appreciated. Current estimates of the numbers of species in the world range from 10 to 80 million species, most of them arthropods (e.g., May, 1988; Stork, 1988). The wide range of estimates confirms that the vast majority of species are unknown and unnamed.

Even in Canada, over 66,000 species of terrestrial arthropods are estimated to occur, half of them undescribed (Danks, 1979). Most of these species occur also in the U.S.A.; in some groups many of them occur also in Eurasia. In New Zealand, only about 20,000 species are estimated to occur, again with only about half the species yet described; but 90% are endemic (Crosby, 1990).

The implications for systematists, and for collections, of housing and documenting this diversity and its regional variations are, like diversity itself, not fully appreciated. The Natural History Museum in London, for example, houses 25 million insect specimens from all over the world in 6,000 m^2 of a six-floor building (Mound, 1988, 1990). But although this enormous collection was built up over many years and contains about 800,000 species (currently maintained by less than 100 people), it probably represents only a small percentage of global biodiversity.

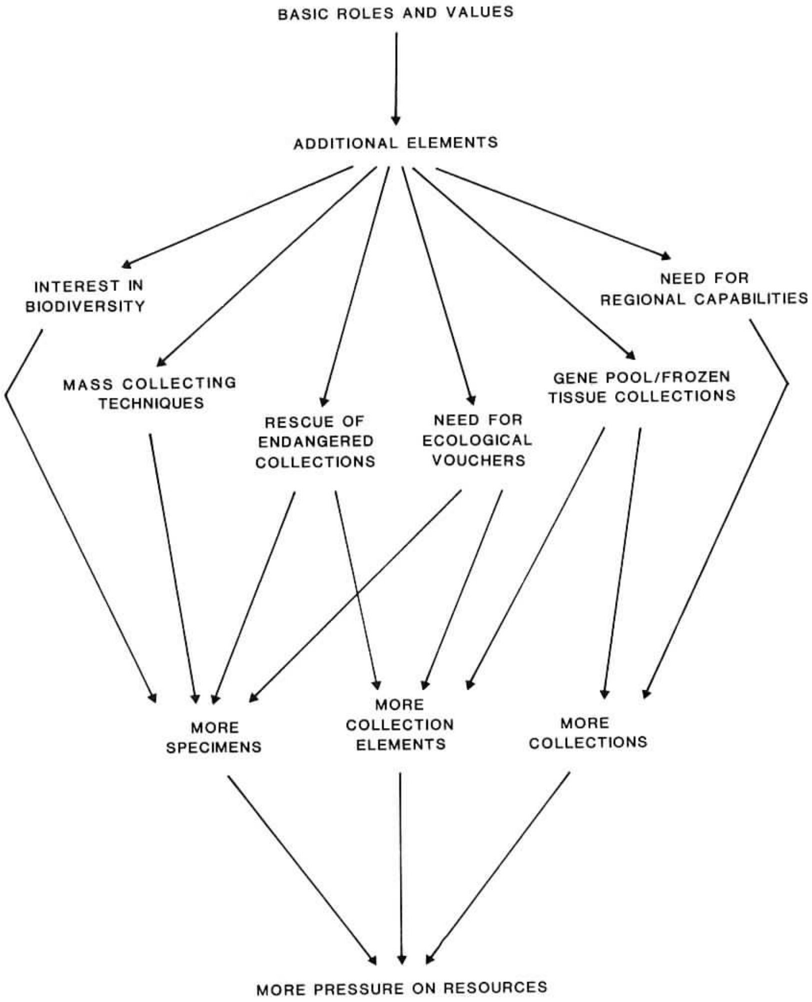

Figure 1. Sources of recent pressure on collections resources.

Mass Collecting

The desire to understand the full extent of biodiversity has been assisted by some remarkably effective tools to collect specimens, especially of arthropods. Light traps to attract flying insects, Malaise traps to intercept them, suction traps to filter air, and Berlese funnels to extract organisms from soil have been available for some time (e.g., Martin, 1977). More recently, insecticides used to knock down insects from the high canopy of tropical forests on to collecting sheets (Erwin, 1983), and a variety of inexpensive but very effective pan traps (cf. Masner and Huggert, 1989), have allowed enormous numbers of specimens of a range of species to be accumulated with relatively little effort. For example, routine sampling of several sites in southern Alberta for one season, 1990, using chiefly pan traps, resulted in the acquisition of about 3.5 million specimens belonging to hundreds of species (A. T. Finnamore, personal communication).

Mass collecting brings enormous numbers of initially unsorted samples and specimens into the collection. The bulk samples, as well as the large number of specimens that can be extracted and organized subsequently, may overwhelm the space and personnel available.

Endangered Collections

Collections that are not properly curated deteriorate; collections for which no local curatorial mandate exists are in danger of being discarded. Endangered and "orphaned" or abandoned collections (West, 1987, 1988) arise for two main reasons. Some are built up locally by one individual, and when that individual retires or moves on, no one has responsibility for the material. This form of abandonment happens especially to smaller college and university collections. Other collections are neglected because institutional priorities change, or because collections are regarded as a low priority and are the first items to lose support when funds are scarce. Collections of low priority are found especially in some local branches of government agencies as the agency follows recent trends to pursue a narrower mission.

Some of these endangered collections are rescued by larger institutions. Indeed, some institutions encourage acquisition, whether or not a specific policy has been articulated, but others do not. The rescue of collections is limited primarily by funds. According to West (1987, appendix 3; 1988, table 2), the cost of accession varies from $0.25 to $16.00 per zoological specimen, depending on the group, the size of specimens, etc. Whether such costs are deemed worthwhile by a given institution depends on factors such as the scientific value of the collection, its geographic origin, the level to which it has been curated, and current institutional priorities. As resources diminish, the loss of material—even very valuable material—becomes more likely.

Voucher Specimens

Voucher specimens document findings for subsequent reference. Taxonomic vouchers (type specimens) are well known, but vouchers for ecological assessments, physiological work, biochemical analyses, and other studies have a legitimate place in collections. Because taxonomic work advances through time, taxonomic entities become increasingly well-defined, and an earlier "species" may prove to have been misidentified, or to comprise more than one species. Data associated with that "species" are lost unless the true taxon can be determined, but this is only possible if voucher material exists for subsequent study. For example, Wilkinson (1981) stated that on occasion he had been asked to assist physiologists who had been unable to repeat earlier experiments. In every instance either their animals or the original animals had been identified incorrectly.

Therefore, voucher specimens should be maintained and made accessible because of their scientific value, but large numbers of specimens may then have to be housed, especially when extensive ecological appraisals have been carried out. Moreover, the logical grouping for such vouchers usually is an ecologically or habitat-based one. In the few well known groups of organisms it may be feasible to track the ecological or habitat information by means of a database (though many collection databases are not designed to include all of the relevant detail). In most groups of invertebrates, taxonomic uncertainties and the volume of material make it impossible to record information on each specimen, so that the specimens cannot simply be dispersed into a taxonomically arranged collection. Consequently, a parallel system for arranging material may have to be devised, adding new collection elements that are difficult to accommodate.

New Types of Collections

In recent years, new types of collections have been established to house samples of the genetic information associated with various kinds of organisms. Most of these collections are aimed at the conservation of diversity, both for future research (e.g., frozen tissues), and to allow future culture of living organisms (e.g., seed banks and culture collections). Tissue samples provide a particular kind of voucher specimen, and they allow for work that is impossible on dried or pickled material. Seed banks and other collections of gene pool resources usually have been set up to conserve diversity deemed to be of present and future value, and consequently emphasize material of potential agricultural (cf. crop breeding), medical (cf. pharmaceuticals) and similar importance, including both artificial variants (cultivars) and natural stocks (wild strains). It is worth noting that these living collections, like more traditional collections of preserved specimens, form a parallel with the natural stocks preserved in parks, conservation areas, and similarly protected sites, which in effect are living museums. Such living museums conserve natural diversity and can play an important role in association with the various types of museum collections.

Regional Capabilities

Regional collections are necessary in addition to a strong national collection, because usually it is better to study or manage regional situations and associated problems locally than from a less accessible central facility. Therefore, like universities, libraries, research stations, ecological preserves, and other widely distributed facilities, regional collections are essential foci for research, education, curation, identification and reference (Danks, 1983).

In particular, regional collections are best placed to house baseline information about local biotic communities. Recent environmental concerns have highlighted the importance of regional collections as ecological as well as taxonomic data bases, in addition to their "heritage" value previously emphasized (compare Biological Council of Canada, 1977; Danks, 1983; Wiggins *et al.*, 1991).

The need to augment a somewhat patchy network of regional collections increases the pressure on resources available to support biological collections.

Summary

Modern developments can all be justified: collections are the only way to maintain the reference material required to assess real biodiversity; in some groups, mass collecting is the only way to acquire the necessary material rapidly; valuable material that is endangered must be rescued; ecological vouchers are essential for building a base of ecological knowledge and as a reference for environmental work; living collections can preserve threatened genetic diversity; and regional collections play important local roles. However, the fact that all of these recent demands can be justified places enormous pressure on collections resources (Fig. 1).

Coping with the Problems

As shown in Figure 2, there are four ways to cope with increased pressure on the resources available to support collections: (1) obtain more resources, so that more work is possible; (2) set priorities, so that the facets regarded as most important are done first; (3) increase operational efficiency, so that any institution makes the best possible use of its funds and personnel devoted to the priorities decided upon; and (4) arrange for division of labour, to permit economies of scale and prevent duplication of effort.

Obtaining Resources

Resources can be sought for several different facets of the work of collections; Figure 3 emphasizes that modern collections contribute, and can seek resources, in three separate arenas, relating to fundamental, supporting, and new roles.

The fundamental roles of the collection can be fulfilled only if resources are available to maintain relevant infrastructures in the form of museums. Wiggins *et al.* (1991) pointed out that current levels of such essential support are unworkable and unacceptable. The need for basic equipment for scientific study is readily appreciated, but one of the most indispensible bases for study, scientific collections, has not received comparable recognition.

The only way to obtain the basic resources for collections is to demonstrate to society the validity and importance of studies of diversity, which are supported by permanent collections. The resulting knowledge facilitates ecosystem preservation and management, and avoids costly mistakes in resource use. Moreover, it is the only way of coping with the pressures humans have brought to bear on the biosphere.

One particular deficiency in arranging for the support of collection infrastructures is the absence in Canada of a national agency with a responsibility for collections (Wiggins *et al.,* 1991). In the United States, for example, the National Science Foundation provides specific support not only for maintenance but also for the improvement of collections. A central role in Canada could be played by the Canadian Museum of Nature, with its mandate for the acquisition and dissemination of knowledge on the biota, but would require new resources (Wiggins *et al.,* 1991). Any such agency would need to consider both national and regional collections.

Resources can also be sought for the support that collections and associated work provide to other branches of science. For example, identifications have traditionally been provided by systematists associated with collections. Indeed, except in the few well known groups, identification is an expert contribution of systematics data rather than a simple technical operation. Such support roles are pervasive (e.g., Danks, 1988).

Theoretically, such support could be provided by cost recovery, augmenting the resources available to collections. However, the true value and cost of services such as identification (like the fundamental values of systematics itself) are undervalued. Especially in diverse taxa, considerable time (equals costly manpower) and expertise (equals costly training) are required to identify species, yet hundreds of identifications may be required by a typical ecological project. Furthermore, the real cost of an identification is not just the cost of labelling the specimen with

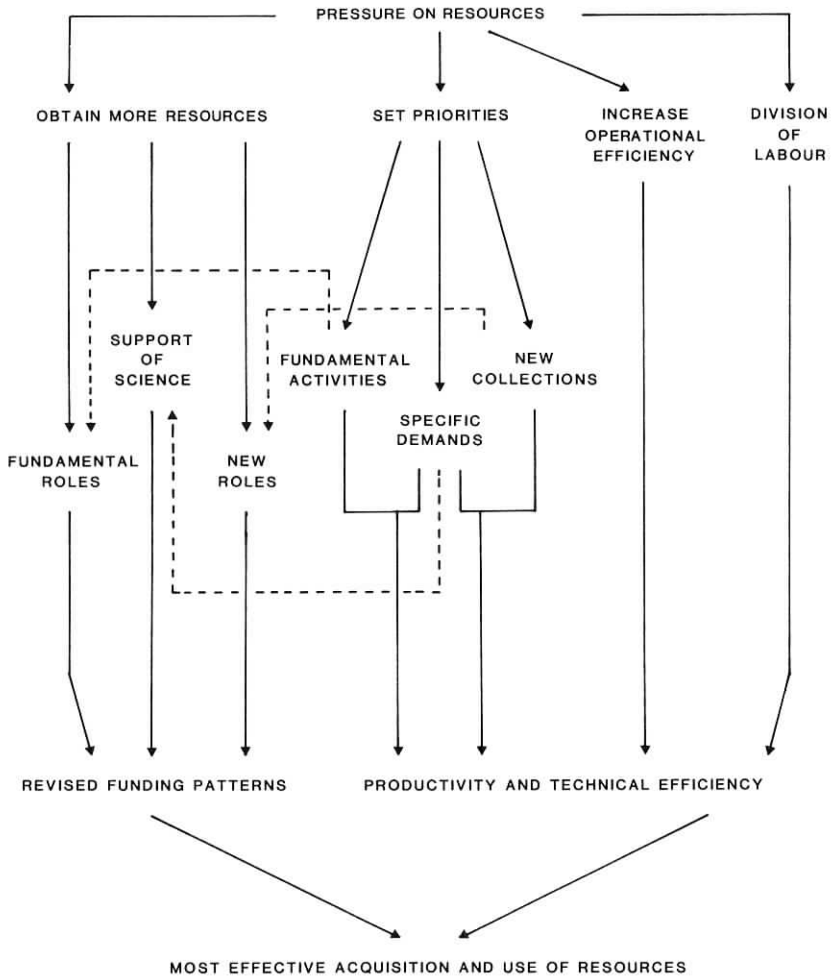

Figure 2. Ways to offset pressure on collections resources.

its taxon, but the cost of establishing the reality and significance of the taxon in the first place. The discovery, definition, analysis and testing of taxa by observation and use over the long-term is basic research, the continuing work of systematics.

People are willing to pay costs only when they understand and appreciate the value of services that they buy. Potential users of identifications and other collection-based services therefore have to be educated about the real value of the work. Eventually, society must realize that access to knowledge of the organic world on which we depend has considerable value. Consequently, services provided by the special expertise of those familiar with collections should be paid for, in the same way as any other expert service that interprets specialized information (law, medicine, accounting, etc.; society pays for a substantial legal, medical and audit infrastructure, and additional services can be purchased). Telling the real cost of a response to those who ask for identifications or collection-based information (currently being done by the Systematic Entomology Laboratory of

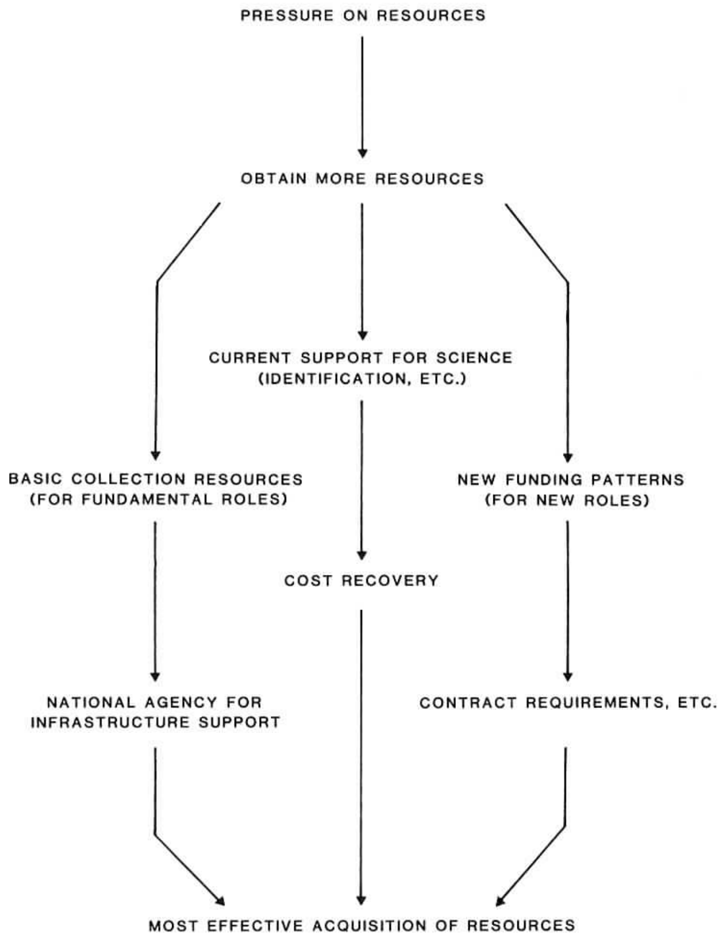

Figure 3. Means to obtain more collections resources.

the United States Department of Agriculture) might help the educational process. Cost recovery would then be viable, but it cannot be implemented unilaterally.

A third arena in which support for collections can be augmented pertains to new collections. New enterprises, such as gene pool banks, are feasible only if new resources for them are forthcoming. Projects that generate collections (often held subsequently as vouchers) should explicitly include a cost projection for the collections component during planning and resource allocation. Thus, grants for taxonomic work require resources to maintain the necessary research collections; some systematists have not made this argument forcefully enough in their applications for funds. Environmental appraisals require resources not only for sampling, sorting, identification and publication, but also for preparing specimens and housing voucher materials in a recognized repository able to provide long-term care. Proper planning of biological studies could be enhanced by specifying funds for the deposition of voucher specimens, and in contract work by requiring such deposition under the terms of the contract.

Setting Priorities

As just introduced in the context of resources, collections contribute in three arenas: basic roles, support or service roles (including traditional and recent elements), and new roles (compare Fig. 2). Priorities, from a broad perspective, should be ranked in that order. Thus, the fundamental and unassailable values of collections relate to the basic understanding of diversity. Research-driven fundamental activities are the foundation for other activities, so that collections and the systematics research on them cannot be separated. Just as preserving the collections is an operational priority (and therefore preventing the destruction of specimens is funded before other demands), so should conducting basic scientific research on the taxonomic collections take priority over exhibition uses, for example. This does not mean that exhibition uses are invalid, but rather that they should be funded from different, service-related, elements of support.

The second priority is accorded to specific demands related to identification, exhibition and other services. These roles often are highly visible. However, because most of the services require independent funding over and above the basic level, priorities here might be set by resources derived from the particular services.

A final priority would be elements new to the existing collection. Some separate or special-purpose collections (notably of ecological voucher specimens) have been accepted by many museums informally, but with increased demand require more formal treatment (see below). Nevertheless, such collections should be carefully selected. For example, the unbridled growth of collections can be prevented and the quality of material maintained if vouchers are accepted only from habitats and sites that were carefully chosen as part of a planned scientific study. Ecological collections are intended as references, not as routine dumping grounds for unsorted collections of varying provenance (Danks *et al.,* 1987).

The establishment of more detailed priorities is difficult. Mound (1990) pointed out that "priorities are a function of current knowledge, expertise, equipment, funding, external demand and feasibility—and they change with time."

Two main principles should determine priorities: the optimization of scientific quality, and the optimization of resource use. For example, a network of regional collections might be rationalized by studying the origin, nature and local scientific value of the existing collections. Some local institutional collections are large and scientifically important, and hence are potential regional foci. Others are small, specialized, or do not match current interests; some might even be combined effectively. Establishing a geographical network focussed on collections of high scientific value, while optimizing resource use by sharing regional curation among adjacent centres (cf. Danks, 1983), would be a logical aim.

On the other hand, establishing priorities based on the principles of current relevance and direction has to be done with great caution, as exemplified by attempts at the internal management of priorities. One extreme is that every societal or managerial whim is followed ("flavour of the month research"). The other extreme is to share out resources equally among qualified workers, and leave them alone to become authorities, on the assumption that they will know best what needs to be done. The first option is often falsely justified as "taxpayer-driven." It fails because the taxpayer in fact prefers wise investment to political behaviour, and wants the long-term understanding that comes from well-planned science, not the short-term frittering of resources on changing trends. The second option fails because unproductive individuals pass unchallenged for many years, and in effect may work in isolation. The best system therefore is a version of the latter constrained by monitoring productivity. Certainly, qualified people are more likely to know what is necessary. But scientific productivity should be evident as long-term goals are pursued. Any properly designed piece of work allows interim (visible or publishable) results subject to peer scrutiny. In this view, managerial (including financial, personnel, and materiel) expertise is used in a positive way to encourage and provide resources for productive specialists, rather than in a negative way to control activities toward specific projects imposed from above.

The overall aim for collections and systematics research is simply put: to understand the nature of diversity and put it into context. Within this framework, directions are influenced by the choice of personnel employed, and by scientific priorities and cooperation determined by mutual consent, which is of course influenced over the long term by societal trends. In the case of the Biological Survey of Canada, for example, steered on behalf of the Canadian Museum of Nature by the scientific community working chiefly through the Entomological Society of Canada, experience has shown that important social questions, such as climate change and environmental appraisal, are addressed in this way, but within a scientific framework based on broad consideration of how best to characterize the fauna. Experience elsewhere has shown that exaggerated forms of internal control chiefly act as a brake.

Increasing Operational Efficiency

Operational efficiency can be enhanced by collections management, used here in a narrow sense to mean the organization, documentation and tracking of collection materials, and by improved techniques for handling and preserving specimens.

Collections management.—The key to effective collections management is the recognition that it is the data associated with the specimens, as well as the specimens themselves, that make the collection valuable. Indeed, a collection has even been described as "an interesting and legible set of data labels, illustrated by specimens." Collections management therefore is facilitated by automatic data-handling, which allows information to be recorded and analysed more efficiently. Because the basic purpose of the collection is to underpin research, systems for collections management should be developed in a context that favours research activity, for example by allowing access to information on the status of the collection, type specimens, and ecological voucher collections, and by supporting external access to the materials, such as provision of specimens for study (including loans). Therefore relevant specimens must be easily located.

These roles also must be fulfilled as far as possible without duplication of effort. Therefore, the recovery system or label for specimen(s)-plus-data must be standardized, and contain information useful for many purposes. It is inefficient, for example, to generate new code numbers to identify loaned material, rather than using existing accession numbers. The following three examples illustrate the principle that the planning and operation of effective collections management schemes require a good deal of thought.

Example 1. Electronic Data Systems. Computers allow a variety of information associated with collections to be handled efficiently. Indeed, both in-house tracking and external management of material can be incorporated into the specimen databases. Standardization favours the exchange of information. However, computer systems can be implemented effectively only under certain conditions (Chenhall, 1987). First, the objectives of the exercise must be clearly understood (is the system intended to serve for research, inventory control, comprehensive collections management, or all three) and the leadership of the institution must be committed to seeing the exercise through. Expertise to guide the process must then be available within the institution to ensure that the precisely controlled structure needed by computers is achieved, but that at the same time the original objectives of implementation remain clear and feasible. Otherwise, delay and waste, rather than greater operational efficiency, are likely to result. The development of the data system itself, and the acquisition of hardware and software to support it, though very significant, actually are less important than these other conditions for success.

Example 2. Status of Specimens. The level of curation provides useful information on the health of collections. As explained by McGinley (1989) for insect collections, accessioned specimens belong to one of nine levels: 1) conservation problem (e.g., insect pins on which the specimens are mounted have rusted); 2) unidentified material, unsorted (hence inaccessible to the research community); 3) unidentified material, sorted (accessible); 4) identified, not in general collection (studied but not yet put away; inaccessible); 5) inadequately curated (poor physical status); 6) curation complete, data not extracted; 7) curation complete, species level inventory extracted; 8) curation complete, individual specimen label data extracted (primary types, research material, etc.); and 9) curation complete, individual specimen research data (measurements, etc.) captured. Healthy collections have peaks at level 3 and at level 6 or beyond, with ongoing work reflected by levels 2 and 4. Such inventory allows for future planning, and detailed priorities can be established. For example, a typical order of priority (McGinley, 1989) would be: first, solve preservation problems (level 1); then make material accessible (level 2); incorporate identified material (level 4); complete curation (upgrade level 5 to 6); extract data (from level 6 material); and capture more specialized data. Of course, plans for the whole collection, to increase status of lower levels, may differ from selected work associated with research studies, to capture all possible data at higher levels.

Example 3. Maintenance of Voucher Collections. Ecological and other voucher specimens create particular difficulties for collections because their roles differ considerably from the purpose of taxonomic types. Moreover, the material is likely to be extensive. Briefly, some guidelines have to be put into place before such material arrives. These guidelines must consider what items will be allowed (e.g., properly documented, properly prepared, and for specific studies); what limits will be placed on the number of samples; to what level sorting will be taken; how specimens will be accessioned (e.g., by lot); how taxonomic elements of the data will be handled to make them recoverable independently of the grouping of the ecological samples; and who will judge whether the guidelines have been met.

These questions can be answered properly only if resources are available to finish the job started by the original ecological or other work—to add to the store of knowledge in a way useful to future scientists, and so to both publish results and deposit reference collections. Thus resources for vouchers should stem from the original project, but in fact many collections are guided by a policy that balances the acquisition of unfunded vouchers against the numbers and quality of specimens in relation to the resources required to house and document them. Few collections have addressed this problem except in a general way. Particular difficulties arise because the value of specimens for the taxonomic collection differs from their value as ecological vouchers. Culling and rearranging specimens of taxonomic interest from voucher samples, as has been done in the past, may increase their accessibility to taxonomists and reduce the costs of keeping them, but in most cases it greatly reduces their value as vouchers. Such possibilities confirm that vouchers should normally be supported by resources from the original ecological project.

Improved techniques.—Improved techniques also allow more effective use of resources. For example, data labels or loan forms can be generated automatically, and linked to the collection databases; procedures for sorting, storing and preserving materials are constantly being improved. The great diversity of terrestrial arthropods causes particular difficulties, especially dealing with vast amounts of material, and many examples of helpful techniques come from this arena.

Example 4. Extraction of Specimens. Sorting of some groups is most effective on living material: behavioural responses can be used to recover specimens from substrates in Berlese funnel extractions (e.g., Martin, 1977) and wet temperature-gradient extraction (Fairchild *et al.,* 1987), and to separate small insects through their responses to light (e.g., Masner and Gibson, 1979). Hand-sorting of preserved bulk material is very time consuming, but several methods to facilitate sorting are available, as exemplified by Rosenberg's (1978) review.

Example 5. Bulk-stored Collections. It is not feasible to sort all represented taxa from every bulk sample, yet many such samples contain specimens of great present or future value. As knowledge improves it becomes feasible to recover immature stages and currently unrecognized taxa. The bulk samples can be preserved more or less indefinitely by replacing the fluid with fresh ethanol and keeping the samples under very cold conditions, which slows the rate at which material deteriorates (as is done currently at the University of California at Riverside, the Biosystematics Research Centre, and elsewhere, especially for small Hymenoptera). Hand extractions of valuable material by a series of specialists (working individually or in teams), each concentrating on the group of interest to them, may be feasible later as time permits. However, large numbers of ethanol-preserved samples housed in freezers occupy considerable space, so that despite the potential value of such samples, not all institutions can or are willing to house them. Without cold preservation, however, the bulk material now being assembled as a record of biodiversity becomes useless for taxonomic work in a number of arthropod groups after several years.

Division of Labour

Resources are limited. Therefore, institutions should cooperate to avoid duplication and enhance each other's work. Not all collections serve the same purpose. Indeed, the Association of Systematics Collections (1991), in drafting a framework to rationalize requests for funding from the National Science Foundation's Biological Research Resources Program, recognized National Systematics Research Resource Centres (large institutions with several major collections with national and international coverage), Regional Systematics Research Resource Centres (with strong and/or historically important local and regional collections), National Systematics Research Collections (major collections in institutions whose major mission is not necessarily systematics), Centres for Education in Systematics (universities or consortia with Ph.D. degree-granting programs in systematics in association with a research resource centre), and Systematics Research Facilitation/Sorting Centres (acting as clearing houses for collections in a particular region, typically funded from a parent institution). Wharton (1989) extended ideas about sorting centres in view of the numbers of insect specimens in bulk collections already accumulated in various museums. Whatever the merits of formal recognition of different types of institutions, the objectives of a given institution must be refined not only within its own mandates, but also in the context of other institutions in order to maximize the use of resources. Therefore, collections with regional responsibilities need not duplicate national or international objectives. If major collections of a given order or family are held at an institution (along with appropriate systematics expertise), nearby institutions need not develop comparable holdings. For example, the Canadian National Collection of insects and arachnids in Ottawa has relatively few Orthopteroids, because of the extensive Orthopteroid holdings of the Lyman Museum of Macdonald College of McGill University at Ste-Anne-de-Bellevue, located less than two hundred kilometres away.

Cooperation among institutions increases efficiency. Networks of institutions and coordinated activities can be established informally, for example through newsletters such as *Insect Collection News*. More formal avenues include agreements for long-term loan of selected collection elements, as arranged by the Smithsonian Institution with other museums (McGinley and Evenhuis, 1990; Leighty *et al.*, 1990), and attempts to define management networks for cooperating collections (e.g., Kim, 1989). Finally, museums can endeavour to adopt similar standards so that material and information are more readily transferable. Because scientific data are potentially so complex, there have been great difficulties in establishing standards. Difficulties stem from two sorts of differences. First, different specimen data elements may be included, or aspects of the same data may be subdivided differently or use different terminology (e.g., for habitats). These differences occur among individuals working on one taxonomic group, and among those working on different groups of organisms. Second, differences in database structures, vocabularies, and field sizes and names, as well as hardware configurations, limit the feasibility or accuracy of data transfer. Hellenthal *et al.* (1990) provide an introduction to some of these problems with respect to insect data. Many organizations are working on the problems, and progress in standardization is certain to make resource use more efficient.

Conclusions

Despite their fundamental values, less is being provided to collections but more is being demanded of them. These problems can be partly offset by improvements in general operations such as cooperation among institutions, and modern methods of preservation and collections management. Administrators, curators and conservators should actively pursue mutually beneficial links with other institutions, and keep abreast of advanced methods for handling specimen data and preserving specimens. However, the long-term solution to the shortfall in resources for collections lies in the acquisition of additional resources, justified as follows.

As amply demonstrated in many biological and other fields, scientific knowledge and our ability to put it to use grows by the accumulation of information, rather than by magical quick fixes. Nowhere is this more evident than in biology, with its remarkable and little known diversity, yet its enormous potential to help us understand the world we inhabit, and so to live here in a sensible way.

Collections underpin the accumulation of biological knowledge, providing not only references for the natural units (as labelled by specific names) without which information could not be organized and retrieved, but also acting as an ecological database through the data associated with specimens collected in both taxonomic and ecological studies. Maintenance of the collections that underpin knowledge requires guaranteed support, not funding based on crises or on short-term trends. For example, if systematics studies and collections had been based only on supposed pest species, there would have been very little taxonomic progress. In turn, biological information would not have been available for use in many valuable ways, in forestry, agriculture, biocontrol, health of wildlife, assessment of water quality, and environmental studies. Resources for the support of regional collections, which serve as local foci for research and identification, and which house essential ecological and taxonomic databases, are also necessary. From such a perspective, infrastructure support of broadly based collections is a responsible investment of resources by society, requiring national agencies to assume overall responsibility for the upkeep of collections.

By the same token, the priorities in collections themselves should reflect their basic long-term value, and thus emphasize preservation and research. Basic collection priorities are driven by research that helps us to understand diversity, while other priorities depend on demands made from elsewhere. Consequently, other solutions to the limitation of resources lie outside the fundamental role of the collections, and with the users of scientific support (in the form of identifications, information on ranges and ecology, etc.) furnished by the specimens and their curators. The costs of these contributions of scientific data to other endeavours should be borne more equitably by those requiring it. Therefore, some sort of user-fee is necessary (see Obtaining Resources, above), but is not feasible until the true cost of the services, and the fundamental value of the collections, are more widely appreciated. A better alternative, of course, would be very substantial increases in infrastructure support, preferably with some direct support and participation by the users. However, funding for service elements in specific projects, and for new collections components such as seed banks, would offset the dilution of existing resources.

In the last analysis, decisions about collections always depend on certain fundamental truths related to their scientific value. Therefore, those who are in a position to justify new resources, those able to enhance inter-institutional cooperation, those planning systematics research effectively and those maintaining the collections efficiently can all help to solve the modern problems of collections by appreciating the fundamental context in which collections exist.

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REVIEWERS

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BOOK REVIEWS

INDEX HERBARIORUM, PART I. THE HERBARIA OF THE WORLD 8th edition (REGNUM VEGETABILE v. 120), 1990, Patricia K. Holmgren, Noel H. Holmgren, and Lisa C. Barnett, eds. (Published and distributed for the International Association for Plant Taxonomy by New York Botanical Garden, Bronx, New York 10458-5126, 693 pp.) *Index Herbariorum, Part I,* is a detailed directory of the public herbaria of the world. Each herbarium entry includes (when the information was supplied) the name and address of the institution, correspondent, telephone and FAX numbers, status, foundation date, number of specimens, geographical areas represented by the collections, important collections, incorporated herbaria, exchange available and wanted, list of staff and associated staff (including position, date of birth, and expertise), associated universities or gardens, periodicals and serial works published by the institution, and other remarks.

The most notable change in the format of *Index Herbariorum* since the last edition, published in 1981, is that the main index is arranged alphabetically by country, and within the country, alphabetically by city. The main index of the previous edition was arranged solely alphabetically by cities of the world. The old arrangement would allow the herbarium at Miami University in Oxford, Ohio (which is confusing enough) to wind up between the separate herbaria of the Dept. of Forestry and the Dept. of Botany, both of the University of Oxford, England. This new arrangement is a vast improvement, enabling a user who may be unfamiliar with city names in some countries, to quickly scan the pertinent entries.

Data was gathered by means of questionnaires mailed to herbarium curators. For the first time, the data was entered into a database, making it possible to analyze and compare data using a computer. Appendix I includes comparative data, such as the 329 herbaria listed for the first time in *Index Herbariorum,* the 71 herbaria with more than one million specimens, the 51 oldest herbaria, and some interesting figures arranged by country compiling the number of herbaria, total specimens, total types, and specimens accessioned and loaned from 1982–86.

Other appendices include an index to important collections which lists the herbaria of deposit, an index by city, a succinct country index, an index to herbarium codes and an index to staff. It would be logical that current indices to specialists and specialties be in the offing.

This publication is not just a list of names and addresses, but fascinating reading. The effort that the New York Botanical Garden, especially the editors and assistants, put into this publication is truly appreciated by the botanical community.—*Deborah Bell, U.S. National Herbarium, Dept. of Botany, National Museum of Natural History, Smithsonian Institution, Washington, D.C. 20560.*

THE HERBARIUM HANDBOOK, 1989, Leonard Forman and Diane Bridson, eds. (Royal Botanic Garden, Kew, Great Britain, 214 pp.) *The Herbarium Handbook* with its imprimatur of the Kew Botanic Gardens is fast becoming a regular on herbarium reference shelves.

It would be beneficial for users to be cognizant of the Handbook's origin. Kew Gardens, recognizing the world-wide need of herbarium workers for training in

Collection Forum, 7(2), 1991, pp. 112–114

herbarium curation and management, started a program of yearly training in 1987. One result of this course is 1989's *The Herbarium Handbook* which was intended for instruction and reference. However, it seems caught between its dual roles of a training manual for multi-nationals of varied educational backgrounds employed by recognized herbaria and a reference manual which could (perhaps should) provide information to fine-tune the skills and knowledge of the experienced who also need and want help. This review is examining the Handbook's value to the experienced herbarium manager as opposed to the novice technician.

An obligatory explanation of taxonomy and discussion of the nature of herbaria start off the text. The next two sections, the Herbarium Building, Collections and Materials along with Herbarium Techniques and Management, provide the most substance. While individual readers may not agree with all the directives, (generally influenced by Kew procedures but left flexible enough to meet the economic situations and local supply quirks of the course participants), a thorough reading should produce at least a few alternatives/improvements to extant methods. Several of the units could help one produce in-house instructions/guides and/or manuals. The unit on mounting herbarium specimens is particularly rich in illustrations which say much more than the few accompanying words; also amply illustrated are possible forms and label formats. Much of what is written is on the human scale, that is, with the realization that perfection is unattainable.

Although the next three and final sections are of less probable value, one can still find informative portions depending on one's interest and activities. The computer unit of two pages is very general. The Herbarium in a Wider Context section (consisting of economic botany, ecology and conservation units) is overly broad and might be appropriate when instructing novices from developing countries. However for the wider audience, the space might have been better utilized to provide more in-depth coverage of other relevant topics.

The Handbook's approach to literature citations is user friendly. At the end of each unit, there is a reference list of authors, and a final listing of references. While not exhaustive, its selectivity includes the "classics" (as exemplified by Fosberg's Manual for Tropical Herbaria) and intensive entries (such as the various taxon specific readings). Recent works have not been ignored either (as evidenced by A. V. Hall's article on pest control).

While the final bibliography is most helpful, a final glossary would also be of benefit for quick consultation. It could start with the present paper glossary (currently located in the text's Materials unit), continue on through other items covered in Materials and also include other terms used in the Handbook, such as their accessions terms.

There may be instances of inappropriate inclusions such as the Archer method to attach plants (despite the mention of various drawbacks and health hazards). There are also some gaps, which might be expected considering the scope of this book.

In summary, *The Herbarium Handbook* aims for the practical and yet its coverage may be too broad. When it does treat specifics, these range from the elementary (for most readers: its explanation of Roman numerals) to the very useful. It would seem that the dual purpose of introductory class text and reference has reduced its value as the latter.—*Ann Pinzl, Nevada State Museum, Capitol Complex, Carson City, Nevada 89710.*

A RHINO IN HIGH STREET, IPSWICH MUSEUM—THE EARLY YEARS, 1990, R. A. D. Markham (Ipswich Borough Council, Ipswich, Great Britain, 59 pp.) Museums are anxious to present themselves to the public as dynamic, vital, and entertaining. In that process, they replace old exhibits with newer, slicker, and improved versions, often until no trace of the past remains. The Ipswich Museum, according to author Markham, also renovated its exhibits after a 1976 plan was adopted "to redisplay the entire High Street Museum. . . . By 1989 only the Natural History Gallery showed its Victorian origins." It had undergone "piecemeal case modifications, deterioration," and removal of some exhibits, and no longer retained its earlier ambiance. Instead of discarding the antique, however, the Museum chose to honor its own past. It recreated the Victorian Natural History Gallery "to capture the atmosphere of the Gallery at the time when the exhibits were new and their arrangement reflected Darwin's then controversial Theory of Evolution."

Written to commemorate the opening of the refurbished gallery on April 26, 1990, "A Rhino in High Street" tells the story of the Museum's Victorian and Edwardian years. Intending this book for a popular audience, the author, a Geologist at the Ipswich Museum since 1965, interspersed the more serious facts and dates with humor and fascinating anecdotes.

Markham recounts remarks delivered at the Museum's opening on December 15, 1847. The Right Rev. Dr. Edward Stanley, Bishop of Norwich, conveyed the following message to the Museum President, Rev. William Kirby, then 88 years old: "you are sinking in the Vale of Years, and may God grant that as your life has been useful to those around you, so may you sink to the grave, happy in having done your duty." In the end, Kirby outlived Stanley by a year!

The narrative is brief, but teases one's curiosity. For example, an early President of the Ipswich Museum, the Reverend Professor John Stevens Henslow, taught Charles Darwin at Cambridge University. It's a story that begs to be told, but the relationship receives only a mention in this book.

Still missing is the story of the Museum between 1920 and 1990. Hopefully, a sequel will be forthcoming.

With 30 black-and-white, generously-captioned illustrations, and a color photo of the refurbished Victorian Gallery on the cover, the book is attractively designed and tempts the reader.

Museums are often reticent to recognize the importance of their own histories—to themselves, to the scholarly and scientific worlds, to the communities they serve, and to the world as a whole. By publishing their histories, museums not only acknowledge the importance of their influence, they also make their stories accessible. In addition, written histories result in an increased awareness and appreciation of archival records, without which there would be no story to tell.

The Ipswich Museum should be praised for preserving its exhibits and records from the past, and for allowing the public to share in these resources.

Anyone who works in a natural history collection setting will want to read "A Rhino in High Street," which is available for £3.95, plus postage and packing, from the Ipswich Museum, High Street, Ipswich, Suffolk, IP3 8HB, England, UK.—*Kristine A. Haglund, CA, Denver Museum of Natural History, 2001 Colorado Boulevard, Denver, Colorado 80205.*

Preparation of Manuscripts

General.—It is strongly recommended that, before submitting a paper, the author ask qualified persons to appraise it. The author should submit three copies of the manuscript either typewritten or printed on letter quality printers. **All parts of the manuscript must be double spaced** with pica or elite type on 8½ × 11 inch (21.6 by 27.9 cm) or A4 paper and at least one inch (2.5 cm) margins on all sides. Manuscripts should not be right justified, and manuscripts produced on low-quality dot matrix printers are not acceptable.

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

The first page includes the title of the article, names of authors, affiliations and addresses of authors, and the abstract if present. In the top left-hand corner of the first page, indicate the name and mailing address for the author to whom correspondence and proofs should be addressed. All subsequent pages should have the last names of the authors in the upper left-hand corner.

The preferred language for manuscripts is English, but a summary in another language can precede the literature cited, if appropriate. Manuscripts written in other languages will be considered if the language uses the Roman alphabet, an English summary is provided, and reviewers are available for the language in question.

Abstract.—An abstract summarizing in concrete terms the methods, findings and implications discussed in the paper must accompany a feature article. The abstract should be completely self-explanatory and should not exceed 200 words in length.

Style and abbreviations.—Symbols, units, and nomenclature should conform to international usage. Cite all references in the text by the author and date, in parentheses. Footnotes should be avoided. For general matters of style authors should consult the "Chicago Manual of Style," 13th ed., University of Chicago Press, 1982.

Literature cited.—This section includes only references cited in the manuscript and should be typed double spaced. References are listed alphabetically by authors' names and take these forms:

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

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

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

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

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CONTENTS

Articles

Reviews