Collection Forum

Fall 1990
Volume 6
Number 2

Society for the Preservation of Natural History Collections

Collection Forum, the official journal of the Society for the Preservation of Natural History Collections (SPNHC), is published twice a year to disseminate substantive information concerning the development and preservation of natural history collections. The journal is available by subscription ($20US per year) and as a benefit of membership in SPNHC ($15US per year for individuals; $40US per year for associate members). Address all communications involving membership dues and subscriptions to the SPNHC Treasurer.

Collection Forum (ISSN 0831-4985) is published by SPNHC, 5800 Baum Blvd., Pittsburgh, Pennsylvania 15206. POSTMASTER: Send address changes to *SPNHC* % Suzanne B. McLaren, Treasurer, 5800 Baum Blvd., Pittsburgh, PA 15206.

THIS PUBLICATION IS PRINTED ON ACID-FREE PAPER.

THE EFFECTS OF FREEZING AND FREEZE-DRYING ON NATURAL HISTORY SPECIMENS

MARY-LOU FLORIAN

Conservation Services Section, Royal British Columbia Museum, 675 Belleville Street, Victoria, British Columbia V8V 1X4, Canada

Abstract.—Fresh specimens may be frozen to prevent deterioration or to prepare them for preservation by freeze-drying. However, even at 0°, very little water in most biological materials is actually frozen. Specimens held at freezing temperatures are still subject to protein and lipid changes and damage from the growth of microorganisms. Tissues may be severely damaged by ice formation. Freezing for specimen storage and freeze-drying for specimen preparation have only limited application, depending on the intended use of the specimens.

Sometimes it is necessary to freeze fresh specimens until preservation treatments can be carried out. The purpose of freezing under these circumstances is to prevent biological and chemical deterioration. In some situations the deterioration is reduced, but unfortunately, in others, it is enhanced.

There is a great deal of information in the food processing literature on frozen stored food. Poulsen and Lindelv (1981) summarized the deleterious effects of storing frozen food. They showed that at temperatures below 0°C, oxidation, autooxidation, and enzymatic reactions occur. Fungi and bacterial activity may take place at these temperatures as well.

Biological materials are also frozen as a step in preparation for freeze-drying. In this procedure it is essential that the water in the specimen be frozen, but this may not always occur even at below zero temperatures.

Fresh organic materials have a high moisture content, usually around 90%. They are naturally swollen by their inherent moisture, which is a complex solution of biological fluids. Most of the fluids are intercellular or held in tissues between fibers.

THE FREEZING PROCESS, ICE FORMATION AND DAMAGE

It is surprising to realize that at 0°C very little water in materials actually freezes. At −30°C, only 85% of the water in frozen beef is frozen, and with bread crumbs (which have a larger surface area to volume ratio and a lower moisture content) only 65% of the water is frozen (Poulsen and Lindelv, 1981). The unfrozen water is in a supercooled state. In fresh collagen samples, 45–60% of the water does not freeze at temperatures as low as −50°C (Dehl, 1970). This is because free water in fine capillaries below 30 μ in diameter does not freeze (Horne, 1969). The water in the capillaries is physically altered and is similar to molecular bound water. At least 20% of the intramolecular water and all of the bound water does not freeze in proteins.

When ice does form under frozen storage or freeze-drying conditions, large hexagonal crystals are formed. These crystals can pierce cell membranes and organelles (Karow and Webb, 1965). Even if small crystals are formed they will, over time, change to large hexagonal forms. Crystallization is a time-dependent phenomena (Luyet, 1960, 1970). The size of ice crystals is dependent on the rate of freezing. In the freezing of free water, large crystals are formed down to −60°C.

Ice is extremely strong due to the double hydrogen bonds in the ice crystal structure. The same forces that cause freezing water to break a glass bottle, or a frost front to lift cement and split trees are present during the freezing of wet organic materials.

The expansion of freezing water is approximately 8.5%. In freeze-dried foods, damage may result from this expansion. At the developing fronts ice spears often make holes up to 30 μ in diameter which cause leaking on thawing of frozen meats. The reason rapid freezing is used in the food processing industry and cryobiology is to prevent concentration effects and the formation of intracellular ice. It has also been suggested that rapid freezing forms smaller crystals, which reduces expansion damage.

Freezing waterlogged materials or whole specimens containing cell fluids results in expansion and physical damage due to ice formation. Materials frozen this way may not be useful for histological analysis.

If sublimation is to be used as a method of drying, it is important to know if ice formation has occurred in the tissues during freezing.

Freezing to Control Microorganism Growth

Even at temperatures below 0°C microorganisms will grow. Experimentation on frozen food shows that growth of some bacteria occurs at −5°C on unfrozen medium, but took several months to show visible increases. Some fungi were reported to grow at −7°C as long as the substrate was not frozen (Haines, 1934).

The limiting factor for microorganism growth is water activity (Aw). Aw is calculated as the ratio of the vapor pressure of the water in the material to that of pure water under the same conditions. The decimal value can be converted to percent and considered as equilibrium relative humidity. Vapor pressure is influenced by temperature, solute concentration, and the physical state of the water as described below.

Water in cells and tissues will be either molecularly bound, bound to other water layers, or free water. Molecularly bound water is bonded to polar sites of molecules and does not freeze at −20°C (Meryman, 1966; Sinanoglu and Abdulnor, 1965; Zachariassen, 1985). Water in the multi-layer region is bound to other water layers. Although easily lost and regained with changes of humidity, it rarely freezes. Free water may be located inside large capillaries, inside and between cells, in vacuoles and between large fibers. It readily freezes, is quickly lost on drying, and is active in osmosis. The water activity of the three states of water varies.

Wolf *et al.* (1972) reported the following: monomolecular site, Aw 0.3; multilayer region, Aw 0.3–0.7; and free water, Aw above 0.7. Aw is important in that it governs moisture hysteresis (adsorption and desorption rate and amount), chemical activity and also microorganism growth.

Water will support the growth of microorganisms only in a free or condensed state at an Aw above approximately 0.75, which is comparable to 75% RH (Poulsen and Lindelv, 1981). Lowering the temperature lowers Aw and thus limits growth. Also, ice formation, withdrawing free water and increasing the solute concentration will lower the Aw and limit growth.

Free water in materials at temperatures just below 0°C may not be frozen because it may be held in small capillaries in the condensed state, or because the solutes present will lower the freezing point of the solution. The significance of this is

that if wet materials are stored at below 0°C for a prolonged period the storage temperature must be low enough to limit microorganism growth. The rate of growth and metabolic activity of microorganisms is reduced by low temperature, but the goal should be to limit microorganism growth. Growth can be stopped in storage at −20°C (which is a common storage temperature for frozen foods).

A review of the effects of freezing on bacteria, yeasts and molds in frozen food shows that their numbers decrease with an increase in freezing time, but a few will survive for several years (Wallace and Tanner, 1933).

Calcott (1978) reviewed the literature on the survival of microorganisms at low temperature and found that there are species differences in survival; the lethal aspects of low temperature are time and temperature dependent; the media is an important factor (e.g., water alone was moderately lethal whereas saline or a nutrient medium was more lethal); the age and density of the population is significant (the older and denser the better the survival); storage death and thawing death are different.

The rates of cooling and thawing are significant. For yeast cells and *E. coli,* cooling at 7°C per min allows optimum survival. As the rate of cooling is increased or decreased the survival rate is reduced. The rates of 1°C per min and 100°C per min yielded maximum kills (Mazur, 1965). In general, organisms tend to succumb to freezing temperatures, and slow thawing is more lethal than fast thawing. Hydrated spores are more vulnerable to freezing than dry sprores. Mazur (1956) reported that frozen hydrated spores had low survival and that dry fungi spores frozen in air were hyper-resistant to freezing because of their low water content (6–25%). It has been reported that vegetative yeast cells and fungi hyphae are vulnerable to the freezing of water (Mazur, 1960). Spores are more resistant but few survive −40°C, and survival is time dependent—the longer at the minimum temperature the fewer survive. In all organisms and stages the rate of freezing and thawing is critical for survival. The slower the rate of freezing and thawing, the fewer survive.

Some cells which escape death on the first freezing will not survive a second freezing. The resistance to the first freezing is not due to an individual selective advantage, but to some physiological state that may be altered on the second freezing. The initial freezing of the microorganisms can reduce the viable population size dramatically if the rate of freezing and the low temperature reached are controlled. If microorganisms are a major threat, repeated freezing can almost eliminate the population.

Freezing to Reduce Chemical Activity

The information available on temporary frozen storage of fresh specimens shows the importance of the temperature of storage, the variable response to storage of different tissues and tissues from different types of animals, and the alteration of chemicals during storage that may influence the research potential of a specimen.

Rate of reaction.—Some chemical reaction rates are reduced by lowering the temperature, but freezing may increase others. Due to the removal of water during freezing, the increase in concentration of solutes and possible shift in pH may increase some reactions (Poulsen and Lindelv, 1981).

Lipid oxidation:—Lipid oxidation occurs when materials are frozen and increases with a decrease in temperature and activity of water (Goldblith *et al.,* 1975; Karel, 1975, 1979). Poulsen and Lindelv (1981) reported that the rate of

reaction was greater at −20°C than at 0°C and almost equal to that at +20°C. Even at extremely low temperatures (around −130°C) autooxidation of lipids occurred which releases high energy radicals that deteriorate proteins (Karel and Young, 1981).

Karel (1975) described the reactions which may be initiated by lipid oxidation. Free radicals formed by the oxidation of polyunsaturated fatty acids may react with pigments, cause protein denaturation, and polymer formation. For example, malonaldehyde reacts with myosin amino acid end groups to cause fluorescent aging pigments in meat. Shenouda and Pigott (1977) described methods of determining myofibrillar protein and lipid interaction.

Enzymatic activity.—Enzymatic reactions may increase due to pH shift or an increase in substrate and enzyme concentration as long as water is available. Enzymes are not usually destroyed by freezing (Sizer, 1943).

Protein changes.—Fish protein deterioration is most rapid at temperatures from 0°C to −3°C and then decreases as the temperature is lowered (Connell, 1964). In this temperature range, morphological changes, such as shrinkage, color change related to oxidation/reduction of haemproteins, stiffness, and loss of water-binding ability may occur. The biochemical changes may include protein denaturation and linkage, increase in acidity, or solubility changes.

Buttkus (1970) showed that under reduced temperatures, trout myosin formed more insolubility polymers and formed them more rapidly than rabbit myosin. He also showed that extracted myosin and the protein in the whole muscle showed similar solubility responses to decreasing temperatures. The amount of insoluble (denatured) protein increased to −11°C. Below the eutectic point it decreased to the same level as that observed at 0°C.

Brown and Dolev (1963) showed that there is a decrease in autooxidation of oxymyoglobin solutions with a decrease in temperature until it freezes, then there is an increase. This explains why color change is more pronounced in frozen than in refrigerated meat and fish.

Lewis and Wills (1962) reported that protein sulphhydryl groups are destroyed by peroxides formed from the oxidation of unsaturated fatty acids. The reaction rate increases with a decrease in temperature, an increase in oxygen and with a metal catalyst.

Fluctuations of storage temperature have a severe effect on protein deterioration. The deterioration of the protein comes about by the structural disruption of the polypeptide chain which may occur through polypeptide (or smaller) unit cross-linkage and changes in amino acids, called denaturation (Buttkus, 1970).

If fish are frozen before rigor mortis sets in, less protein damage occurs during frozen storage. The pH of fish protein drops after death, and autolysis and microbial activity may deteriorate the protein (Connell, 1964).

Freeze-Drying Procedures

Freeze-drying procedures may vary, but the following basic steps are always involved. The initial step is the freezing of the specimen. It is then placed in a chamber at a temperature appropriate to retain it in a frozen state, usually with a heat source for sublimation. Somewhere in the system is a condensing surface held at a lower temperature than the frozen material. The vapor pressure of the ice in the material is greater than that on the condensing surface, thus, the sublimed water vapor will move from the material to the condensor surface. The ice is

removed from the condensing surface by means of thawing. This diffusion process is slow but can be increased in speed by using a vacuum, which allows freer molecular movement. Fry (1984), Smith (1984), and Schmidt (1985) describe equipment used for freeze drying of artifact materials.

The State of the Ice

In preparation for freeze-drying, simply placing the specimen in a freezer will not prevent the damaging hexagonal ice crystals from forming (though it is possible that in some cases solute concentration may influence the ice form). For direct sublimation drying, ice crystals which connect with each other on the free surface of the material are required.

Sublimation

The loss of bound water cannot be prevented during sublimation of frozen materials. This loss of bound water causes brittleness in some materials.

The sublimation front moves from the outside of the material inward. This means that the outer layer of the material is continually being dried. The main disadvantage of this is that bound water will be lost in the outer layers. Even if a specimen is removed from the procedure before it is completely dry the outer surface may still have lost bound water while the inner material will still have its original water content.

Examination of drying charts for exhibit specimens (Hower, 1979) shows that weight loss, which reflects ice loss, is rapid initially, and then slows to a greatly reduced rate. The reduction in rate is due to the difficulty the internal vapor encounters in penetrating the dry outer region. For exhibit specimens where the form of the frozen specimen must be retained, all ice must be sublimed, because the last remaining amount of water is present at the original 90% moisture content (MC) in the internal tissue.

In thick materials, sometimes the outer layers become impermeable, or case hardened, and the center does not dry.

The Effect of Vacuum During Freeze Drying

A vacuum is used to speed up the rate of sublimation. Vacuum or reduced pressure will not damage specimens. The rapid removal of water (and possibly gases and other volatile materials) from tissue during a rapid decrease in pressure can cause mechanical damage such as the loss of loose particulate matter. In histological preparation of tissues to preserve delicate organelle structure, the tissue, after critical point or solvent drying, is placed under vacuum several times without deleterious effects as long as free water is not present. This suggests that there will be no damage to materials subjected to vacuum as long as they are completely frozen, and evacuation is not done too rapidly.

Physical Changes in Material Due to Freeze-Drying

Porosity.—Materials have a more porous nature after freeze-drying, the pores being the spaces which were occupied by ice crystals (Meryman, 1960). There is also an increase in surface area, the wetting ability of the material is altered and it is generally more soluble. These changes are reflected in a change in regain ability of the materials.

Colloids.—Colloidal materials (adhesives, gelatin films) may be disrupted be-

cause of loss of bound water (Blanchard, 1940; Lea and Hawke, 1952). Tests showed that the best method of drying wet photographic films was air drying without freezing (Hendriks and Lesser, 1983). Wet films that had been freeze-dried showed loss of density and loss of gloss which can be explained by the loss of bound water and colloidal disruption. On the other hand, freeze-thaw cycling of dry motion picture film did not cause any changes (Kopperi and Bard, 1985).

In testing adhesives for low-temperature durability, casein based colloidal adhesives were most vulnerable. There are many possible colloidal materials associated with biological specimens. If they are to be used in future research this physical change may be significant.

Chemical changes.—Regier and Tappel (1956) considered carbonylamine browning of meat as the major deterioration reaction. The rate of this reaction increases with moisture content, but even with complete removal of water the reaction still continues. The result is denaturation of proteins. Potthast *et al.* (1975) reported that enzymatic breakdown of lipids occurred in freeze-dried meat at water contents as low as 2.2%.

Physical characteristics.—In assessment of physical characteristics of freeze-dried food products (Kapsalis *et al.,* 1970), archaeological wood, and biological specimens, brittleness is always mentioned. Freeze-dried meat, besides being porus, is light in weight and brittle, similar to balsawood. These changes are a result of freezing as well as freeze-drying which causes the loss of bound water and water bonding sites. It is bound water which gives the plasticity to organic polymers (i.e., cellulose, collagen, myosin, etc.).

Regain ability.—The loss of water bonding sites influences the regain ability or hysteresis. Wolf *et al.* (1972) showed that the hysteresis curve (the difference between adsorption and desorption) is altered after freeze-drying to different degrees for specific food types (apple, pork, rice). They also showed that with an increase in storage time there is a decrease in sorption ability. Kapsalis (1981) showed a decrease in moisture content of freeze-dried foods after storage.

Oxidation and biodeterioration.—Freeze-dried foods in storage are vulnerable to oxidation and biodeterioration. In the food industry, such foods are vacuum packed after flushing with nitrogen in an impermeable container. In some cases, dessicants are used to prevent moisture adsorption. There is nothing in the literature about the vulnerability of freeze-dried food to insect attack. In my experience, psocids have been observed to live on the legs of freeze-dried bird specimens on exhibit. Also, several cases of insect attack of freeze-dried taxidermy specimens have been reported to me.

Microorganisms.—It has been reported (Mazur, 1968) that freeze-drying is more injurious to fungi than freeze-thawing mainly because of the loss of bound water. In addition, the fluctuation of temperature during the heating of the material while freeze-drying increases its lethal aspect. Vegetative yeast cells and fungi hyphae are both vulnerable to the freezing of water and few survive freeze-drying. The relevance of this is that while freeze-drying will greatly reduce population size, some cells may survive.

SUMMARY

Frozen storage of biological specimens or water damaged materials should be undertaken only after considering the effects of freezing on the materials and the

parameters that affect chemical and biological deterioration. If the specimens are to be used for biochemical research, it is important to know that protein and lipid changes occur during frozen storage. Often very little water is frozen in biological tissues at temperatures just below 0°C. If frozen water is a prerequisite for freeze-drying, a temperature low enough to produce continuous ice is essential.

Frozen storage is convenient for specimens which will end up as skin and skeletal collections, but it is important to realize that freezers at −4°C will support microorganism growth if the water in the materials is not frozen. When the water is frozen, the growth of microorganisms is limited. Temperatures close to −20°C will kill the actively growing hypha and some hydrated spores. This will reduce the microorganism population but will not eradicate it completely. Dry spores are resistant to freezing.

The advantage of using freeze-drying for the preparation of museum specimens must be assessed in reference to use of the collections. Freeze-drying enhances the deterioration of tissues, and deterioration continues during storage. The process may have value in preparation for educational or exhibit specimens, but is inappropriate for long term preservation.

Literature Cited

Blanchard, K. C. 1940. Water, free and bound. Cold Spring Harbour Symposium on Quantitative Biology, 8:1–8.

Brown, W. D., and A. Dolev. 1963. Effect of freezing on autoxidation of oxymyoglobin. Journal of Food Science, 28:211–213.

Buttkus, H. 1970. Accelerated denaturation of myosin in frozen solution. Journal of Food Science, 35:558–562.

Calcott, P. H. 1978. *Freezing and Thawing Microbes.* Meadowfield Press, Ltd., Shildon, 68 pp.

Connell, J. J. 1964. Fish muscle proteins and some effects on them on processing. Pp. 255–293 in *Symposium On Foods: Proteins and their Reactions* (H. W. Schultz, ed.). The Avi Publishing Company, Inc., Westport, 472 pp.

Dehl, R. E. 1970. Collagen: Mobile water content on frozen fibers. Science, 179(3959):738–739.

Fry, M. F. 1984. An economy vacuum freeze-dryer for archaeological organic materials. Vacuum, 34(5):555–558.

Goldblith, S. A., L. Rey, and W. W. Rothmayr. 1975. *Freeze Drying and Advanced Food Technology.* Academic Press, New York, 730 pp.

Haines, R. B. 1934. The minimum temperature of growth of some bacteria. Biol. Appl. of Freeze-drying, 34:277–282.

Hendricks, K. B., and B. Lesser. 1983. Disaster preparedness and recovery: Photographic materials. American Archivist, 46:52–68.

Horne, R. A. 1969. *Marine Chemistry.* Wiley-Interscience, New York, 568 pp.

Hower, R. O. 1979. *Freeze-drying Biological Specimens.* Smithsonian Institution Press, Washington D.C., 196 pp.

Kapsalis, J. G. 1981. Moisture sorption hysteresis. Pp. 144–177 in *Water Activity: Influence on Food Quality* (L. B. Rockland and G. K. Stewart, eds.). Academic Press, New York, 921 pp.

Kapsalis, J. G., B. Drake, and B. Johansson. 1970. Textural properties of dehydrated foods. Relationships with the thermodynamics of water vapor sorption. Journal of Texture Studies, 1(3): 285–308.

Karel, M. 1975. Stability of low and intermediate moisture foods. Pp. 651–663 in *Freeze Drying and Advanced Food Technology* (S. A. Goldblith, L. Rey, and W. W. Rothmayr, eds.). Academic Press, New York, 730 pp.

———. 1979. Lipid oxidation, secondary reactions, and water activity of foods. Pp 191–193 in *Autoxidation in food and biological Systems* (M. G. Simic and M. Karel, eds.). Plenum Press, New York, 659 pp.

Karel, M., and S. Young. 1981. Autoxidation initiated reaction in food. Pp. 511–520 in *Water*

Activity Influences on Food Quality (L. B. Rockland and G. F. Stewart, eds.). Academic Press, New York, 921 pp.

Karow, A. M., and W. R. Webb. 1965. Tissue freezing. Cryobiology, 2(3):99–108

Kopperi, D. F., and C. C. Bard. 1985. Freeze/thaw cycling of motion-picture films. SMPTE Journal (Society of Motion Picture and Television Engineers), 94(8):826–827.

Lea, C. H., and J. C. Hawke. 1952. The influence of water on the stability of lipovitellin and the effects of freezing and of drying. Biochem. J., 52:105–114.

Lewis, S. E., and E. D. Wills. 1962. The destruction of -sh groups of proteins and amino acids by peroxides of unsaturated fatty acids. Biochemical Pharmacology, 2:901–912.

Luyet, B. J. 1960. Anatomy of the freezing process in physical systems. Annals of the New York Acadmemy of Sciences, 85(2):115–138.

———. 1970. Physical changes occurring in frozen solutions during rewarming and melting. Pp. 27–43 in *The Frozen Cell* (G. E. W. Wolstenholme and M. O'Conner, eds.). J. A. Churchill, London, 316 pp.

Mazur, P. 1956. Studies on the effects of subzero temperatures on the viability of spores of *Aspergillus flavus*. 1. The effect of rate of warming. J. Gen. Physiol., 39:869–888.

———. 1960. Physical factors implicated in the death of microorganisms at subzero temperatures. Annuals N.Y. Acad. Sci., 85:610–629.

———. 1965. Causes of injury in frozen and thawed cells. Fed. Amer. Soc. Exp. Biol. Cryobiology, 24(2) Part III Supl., 15:S175–182.

———. 1968. Survival of fungi after freezing and desiccation. Pp. 325–394 in *The Fungi an Advanced Treatise Vol. III. The Fungal Populations* (G. C. Ainsworth and A. S. Sussman, eds.). Academic Press, New York, 738 pp.

Meryman, H. T. 1960. The preparation of biological museum specimens by freeze-drying. Curator, 3(1):5–19.

———. 1966. Review of biological freezing. Pp. 2–114 in *Cryobiology* (H. T. Meryman, ed.). Academic Press, New York, 775 pp.

Potthast, K., R. Ham, and L. Acker. 1975. Enzyme reactions. In *Freeze Drying and Advanced Food Technology* (S. A. Goldblith, L. Rey, and W. W. Rathmayr, eds.). Academic Press, New York, 730 pp.

Poulsen, P. K., and F. Lindlev. 1981. Acceleration of chemical reactions due to freezing. Pp. 650–678 in *Water Activity: Influences on Food Quality* (L. B. Rockland and G. F. Stewart, eds.). Academic Press, New York, 921 pp.

Regier, L. W., and A. L. Tappel. 1956. Freeze-dried meat. IV. Factors affecting the rate of deterioration. Journal of Food Research, 21:640–649.

Schmidt, J. D. 1985. Freeze drying of historic cultural properties. Technology and Conservation, Spring:20–26.

Shenouda, S. Y. K., and G. M. Pigott. 1977. Fish myofibrillar protein and lipid interaction in aqueous media as detected by isotope labeling, sucrose gradient centrifugation, polyacrylamide electrophoresis and electron paramagnetic resonance. Pp. 657–686 in *Protein Crosslinking. Biochemical and Molecular Aspects* (M. Friedman, ed.). Plenum Press, New York, 760 pp.

Sinanoglu, O., and S. Abdulnor. 1965. Effect of water and other solvents on the structure of biopolymers. Federation Proceedings (Federation of American Societies for Experimental Biology), 24:512–523.

Sizer, I. W. 1943. The effects of temperature on enzyme kinetics. Advances in Enzymology and Related Subjects of Biochemistry, 3:35–62.

Smith, R. D. 1984. Fumigation dilemma: More overkill or common sense? The New Library Science, 3(6):1–3.

Wallace, G. I. and F. W. Tanner. 1933. Microbiology of frozen foods. Part III. Conclusion. Fruit Products Journal and Amer. Vinegar Indust., 13:109–113.

Wolf, M., J. E. Walker, and J. G. Kapsalis. 1972. Water vapor sorption hysteresis in dehydrated food. Journal of Agric. Food Chem., 20(5):1073–1077.

Zachariassen, K. E. 1985. Physiology of cold tolerance in insects. Physiological Reviews, 64 (Oct.): 799–832.

CHARACTERISTICS OF A COLLECTION OF FLUID-PRESERVED MAMMALS AND IMPLICATIONS FOR COLLECTION MANAGEMENT

PAISLEY S. CATO

Department of Wildlife & Fisheries Sciences, Texas A&M University, College Station, Texas 77843
Present address: Virginia Museum of Natural History, 1001 Douglas Ave., Martinsville, Virginia 24112

Abstract.—During a major recuration process, data were collected to document basic storage conditions for a collection of fluid-preserved Recent mammal specimens, then analyzed for trends. Parameters studied pertained to the type and size of jar, the ratio of specimens to fluid, the pH and alcohol content of the fluid, the number of specimens and the year the specimens were collected. Preparation and management procedures for fluid-preserved specimens were also considered. These data provide a profile for the collection at a point in time and document the result of a relatively typical pattern of care for fluid-preserved materials over a 50 year span. Implications for collection management are discussed.

Biological specimens have been preserved in various kinds of alcohol for over two hundred years. Yet it has only been during the last decade or so that there have been serious attempts to determine the long-term effects of such preservatives on the specimens. Documentation concerning preparation techniques has been minimal for most collections of specimens (Cato, 1986; Garrett, 1989). At best, there was an attempt to document the standard procedure, and variations in that procedure were rarely, if ever, noted. The same problem exists with management and maintenance procedures. Therefore, researchers are faced with discovering the actual composition of the preservatives, as well as the effect of the preservatives on the specimens.

Several recent publications concerning preparation and management techniques have focused on surveying existing literature to document materials and procedures traditionally used. Williams and Hawks (1987) documented the materials used for the preparation of mammals over the last two hundred years, citing numerous articles concerning fluid preservatives. Rogers *et al.* (1989) included a listing of the most pertinent references for fluid-preservation of birds and mammals. A few publications have dealt more specifically with summarizing the state of knowledge concerning fluid preservation providing little new data (Jones and Owen, 1987; Horie, 1989). The published proceedings from a course held at The University of Manchester in 1989 include several very useful papers, among them one on the nature of tissue, fixatives and preservatives, another on storage containers, and a third concerning possible remedies for common problems (Horie, 1989; reviewed by Suzumoto, 1989). Other authors, though few in number, have reported on techniques to identify the preservatives (Waller and McAllister, 1986) or on problems associated with fluid preservatives.

Based on these studies and reports, primary areas of concern relative to the effect of fluid preservatives on specimens are the identification of the fluid, presence of additives and dissolved or dispersed materials, acidity and alcohol concentration of the fluid, the storage container and conditions, the history of prep-

aration and maintenance, and the condition of the specimens. Very few data have been published, however, to document the storage condition parameters of any collection at a point in time.

This study was initiated as an exploratory project to determine the general characteristics of a collection of approximately 8,800 fluid-preserved mammal specimens. The recuration of the fluid-preserved material was the last phase of a three year (1984–87) project to recurate, reorganize, and computerize the data for 49,000 cataloged specimens in the mammal collection at Texas A&M University. The recuration project included verification and updating of nomenclature, the physical reorganization of the specimens to alleviate specimen crowding and to reorder jars according to the revised organizational scheme, and the verification of data that had been previously entered in the computerized data base system.

This recuration process, which necessitated handling every jar and every specimen, provided an excellent opportunity to document basic storage conditions for the specimens. The goals of the project were 1) to propose and test easily obtainable parameters, 2) to identify trends in collection storage parameters for a specific collection, and 3) make recommendations concerning the future storage conditions and maintenance of these specimens based on observations. No effort was made to document specimen conditions due to a lack of standards to compare with and lack of personnel time.

Methods and Materials

A history of the preparation and management procedures for fluid-preserved specimens was obtained. Due to the lack of detailed written documentation, most of this information was obtained through interviews with staff and collectors.

The collection parameters to be measured had to be ones that required minimal time and effort by staff and that used equipment that was either very inexpensive or already available. These factors eliminated the possibility of testing for the presence of additives or salts in the alcohol.

Each jar was numbered as data were recorded. Data recorded for each jar were:

1) type of jar—one of four basic types: glass with bakelite lid, glass with metal lid, glass with polyethylene lid, and glass with wire and gasket lid (including Ball and Le Parfait brands);
2) size of the jar—in ml;
3) quantity of fluid actually present—in ml;
4) ratio of specimens to fluid—a ratio comparing the volume taken up by the specimens and the volume of fluid above the specimens; observers were instructed to estimate the ratio using the following levels of definition: 0, 0.25, 0.33, 0.5, 0.66, 0.75, 1.0;
5) pH—using Fisher brand paper strips with a stated accuracy to 0.25;
6) alcohol concentration—in percent using a hydrometer;
7) number of specimens;
8) specimen catalog numbers;
9) taxonomic order for the specimens; and,
10) the year the specimens were collected—Many jars included specimens that were collected over a series of years. Therefore, to obtain a value per jar, it was necessary to assign a year to each of these jars based on the following order of priority: a) largest number of specimens collected in a given year; and b) oldest specimens. This priority ranking was based on two assumptions: 1) that new alcohol would generally be added to a jar if a large number of specimens were added to the jar at one time; and 2) that otherwise, the jar would be merely topped off or nothing added at all as new specimens were added.

A grid-like form was used for recording data to simplify and standardize the process.

Data were analyzed for statistical parameters using SAS. Medians, ranges, skewness, frequency

counts, scatter plots, and histograms were generated to explore trends for six parameters: jar size, number of specimens per jar, ratio of specimens to fluid, pH, alcohol content, and year collected.

Three approaches were then followed to see if it were possible to locate high risk situations for specimens: 1) analysis of pairwise combinations of the six parameters for Pearson's and Spearman rank correlation coefficients; 2) analysis of the tail regions of the distribution of values for five parameters; and 3) analysis of the conditions of the jars in which specimens were exposed to air. These high risk situations would presumably include fluids with low alcohol contents and/or low pH values.

RESULTS

Preparation and Management Techniques

Written protocols for the preparation of fluid-preserved mammals did not exist. Written procedural guidelines for the collection (Schmidly *et al.,* 1985) recommended, however, that fluid-preserved specimens be prepared according to Knudsen (1966), Wagstaffe and Fidler (1968), Quay (1974) and Williams *et al.* (1977). There was no written indication of how closely these recommendations were followed. Interviews with staff, however, indicated that specimens were routinely fixed in the field using injections and submersion in 10% formalin, then left in formalin for varying lengths of time until the field crew returned to the collection. The formalin was not routinely buffered. The length of time between death of the specimen and fixation varied but was not recorded. Specimens were rinsed in two to three tap water baths over 24 to 48 hours, then placed in 70–75% ethyl alcohol. Buffering agents were rarely, if ever, added to the alcohol.

Ninety-five percent ethyl alcohol was obtained in 55 gallon drums, then diluted, using tap water, to 70–75%. A hydrometer was used to verify the percentage of alcohol. The sources of 95% ethyl alcohol were not documented. The pH of tap water in 1987 was repeatedly measured at 6.5 using paper strips.

Written procedures (Schmidly *et al.,* 1985) for the maintenance of fluid-preserved specimens recommended spot checks to insure that fluid had not evaporated to the extent of exposing specimens. Alcohol should be replaced if the fluid were low, discolored or mold were found growing in the jar. In practice, however, maintenance of the fluid-preserved specimens was less stringent due to staff shortages and a lower priority for care. At most, fluid levels were topped off in the event of excessive evaporation.

Specimens have been consistently stored over the years in closed cabinets or covered steel shelving, minimizing exposure to light. The collection has been stored in at least three different buildings since the 1940's, moving to its present location in 1982. The present location, as part of the university library building, has the best environmental controls of any of the locations. Between 1982 and 1989, the temperature of the storage room was maintained within a five degree range (67°–73°F) with only two exceptions due to mechanical failures of the heating and cooling system. Relative humidity was not actively controlled in the storage rooms, but readings from humidity indicator cards during 1985–86 indicated a range from 45% to 75% during the year. Ambient humidity in the community fluctuated between 35% and 100% during the year.

Mammalian specimens were stored in glass jars, both straight-sided and shouldered. Lids varied depending on availability, expense, and perceived ability to prevent evaporation. New jars are fitted with polyethylene lids; lids of old jars were replaced with polyethylene lids during the recuration process.

Table 1. Descriptive statistics for six parameters measuring characteristics of collection storage conditions.

Parameter	*N*	Median	Skewness	Minimum value	Maximum value
Jar size (ml)	559	1,000	0.867	150	4,000
Number of specimens	560	6	2.508	1	129
Ratio (volume of specimens : volume of visible fluid)	562	1:1.2	1.733	1:0	1:6
pH	562	6.5	−2.337	5.0	7.0
Alcohol content (%)	400	64	−1.434	40	71
Year collected	558	1972	−0.593	1934	1984

Table 2. Frequency of jar sizes.

Size of jar (ml)	Percent of total (*N* = 559)
150–300	21.7%
450–500	16.6%
900–1,100	21.8%
1,800–2,100	15.7%
3,000–4,000	20.6%
Total	96.4%

Parameters

General.—Specimen storage expanded from 584 to 687 jars. This resulted in a decrease from 49 to 39 specimens per square foot of shelving during the recuration process. The actual number of jars measured for each of the parameters varied, particularly when measuring alcohol content. Many of the jars were too small, with too little fluid, to allow the use of a hydrometer.

Table 1 summarizes the descriptive statistics for the six parameters: number of jars measured, median, skewness, minimum value and maximum value. All of the parameters showed a skewed distribution. A skewness of zero indicates a normal distribution; none of these parameters were normally distributed.

Jar size and type.—Jars ranged in size from 150 ml to 4,000 ml, with a median of 1,000 ml. A frequency count indicated the collection used five basic jar sizes, accounting for 96.4% of all jars used (Table 2). Sixty percent of the jars were smaller than 1,200 ml. The amount of fluid actually in the jar and the type of jar were not consistently recorded by observers. Therefore, the data for these parameters were not used.

Number of specimens per jar.—This value ranged from one to 129 with a median of six. That is, half of the 560 jars had six or fewer specimens per jar (Fig. 1). A frequency count indicated that 75.4% of the jars had fewer than 20 specimens per jar.

Ratio of specimens to fluid.—Fifty percent of the jars had a ratio of 1:1.2 or less, indicating the volume of specimens to the volume of fluid visible above the specimens (Fig. 2). Because of the difficulty in estimating these ratios, there was a tendency by the observers to round off the values to whole and half numbers

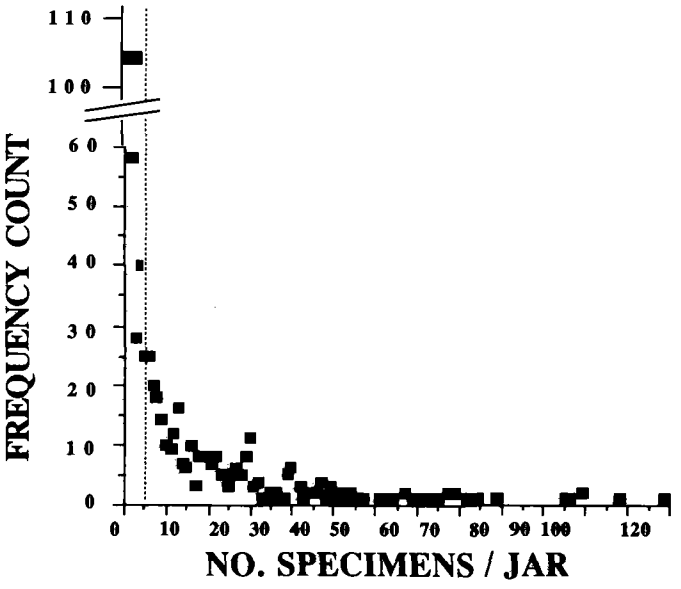

Figure 1. Plot of the frequency count for the number of specimens per jar. Median value of six specimens per jar is indicated by the dotted line.

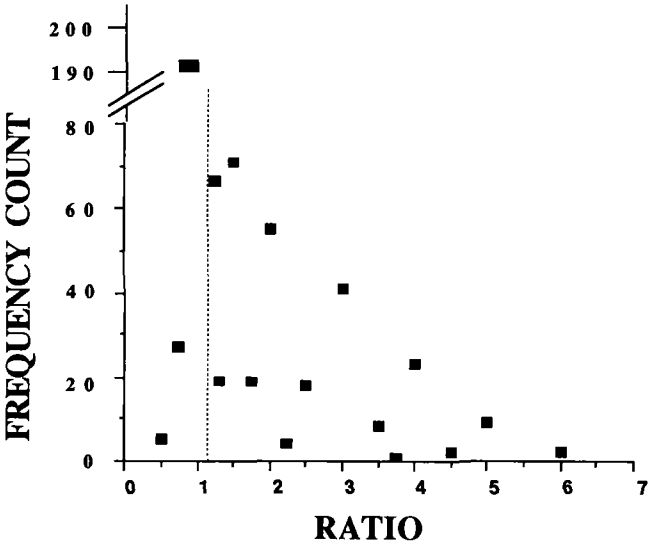

Figure 2. Plot of the frequency count for the ratio of volume of specimens to volume of fluid visible above the specimens in a jar. Median value of 1:1.2 is indicated by the dotted line.

(1, 1.5, 2, 2.5, etc.). The values were positively skewed indicating a larger percentage of small ratios, and the majority of jars (80.8%) had ratios of 1:2 or less.

pH.—pH values ranged from 5.0 to 7.0, with a median of 6.5. A majority (85.8%) of the fluids measured 6.5, and 90.6% of the jars had pH values of 6.5%

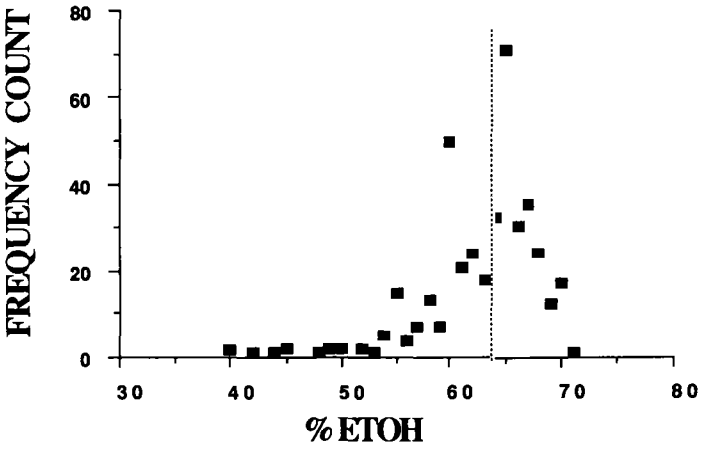

Figure 3. Plot of the frequency count for the percent of alcohol contained in the fluid. Median value of 64% is indicated by the dotted line.

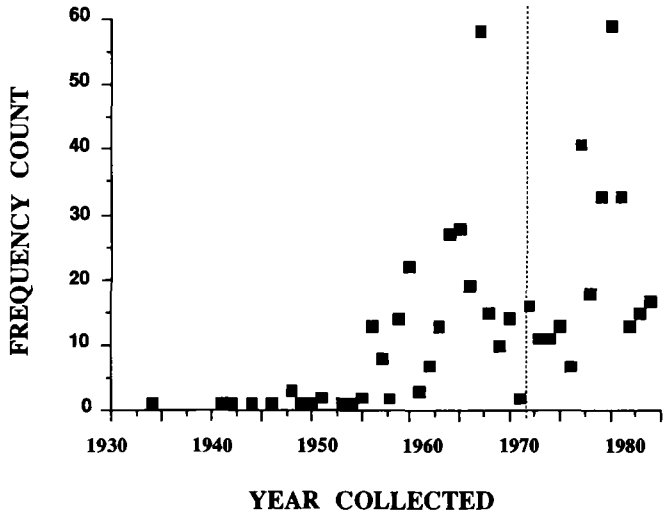

Figure 4. Plot of the frequency count for the year specimens were collected per jar. Median value of 1972 is indicted by the dotted line.

to 7.0%. The pH values were negatively skewed, indicating a larger percentage of high pH values. However, fifty-one jars had pH values of 5.0 or 6.0.

Alcohol concentration.—All of the jars contained ethyl alcohol, but tests were not conducted to determine the presence of formalin, buffering agents or other materials. Only 400 jars were measured for percent of alcohol content. These jars were generally at least 500 ml in size. Values for alcohol content ranged from 40% to 71%. Half of the jars had alcohol contents of 64% or less (Fig. 3).

Year collected.—Specimens preserved in fluid were collected between the years 1934 and 1984, with a median at 1972 (Fig. 4). Only 10% of the jars had specimens collected before 1960.

Table 3. Summary of taxonomic orders represented in total sample and subset where pH values are 5.0 or 6.0.

Taxonomic order	All jars		Jars with pH of 5.0–6.0	
	N	%	*N*	%
Marsupialia	15	2.6	7	13.7
Insectivora	20	3.4	7	13.7
Chiroptera	350	59.9	28	54.9
Rodentia	195	33.3	9	17.6
Miscellaneous	4	0.7	0	0
Totals	584	100.0	51	100.0

High Risk Situations

Correlations.—An analysis of the pairwise combinations for the six parameters for Pearson's and Spearman rank correlation coefficients resulted in no significant correlations.

Analysis of parameter tail regions.—The "tail regions" of distributions of parameter values were deemed most likely to contain fluid conditions that might put specimens most at risk. Therefore these regions were analyzed to determine trends that might help identify problem areas.

The tail region for the number of specimens per jar included thirty-one jars, representing less than 5% of the total number of jars. These contained more than 50 specimens per jar, and the majority (81%) of these jars contained bats. The medians for the 31 jars for pH and alcohol content were 6.5 and 64% respectively, the same as for the total sample of jars measured.

Thirty-three jars (5.9% of all jars) had ratios less than 1:0.75. This tail region was comprised primarily by bats (73%) and rodents (18%). The median for alcohol content for this sample was 60% compared to 64% for the total sample. The median for the number of specimens per jar was 22, compared to a median of 6 for the total sample.

Fifty-one jars (9.4% of the total sample) had pH values of 5.0 or 6.0. The median for the alcohol content of this sample was 61%. Table 3 summarizes the taxonomic composition of the total sample and this subset. Half of the jars of marsupials and one-third of the jars of insectivores had low pH values. In contrast, the bats and rodents were represented in this group in proportions similar to their proportions of the total population.

Jars with fluid containing less than 60% alcohol represented 18% of the 400 jars measured (65). The medians for this subset for the parameters of pH, the number of specimens, and ratio were 6.5, 21, and 1:1 respectively. These jars, therefore, had more specimens per jar, a smaller specimen to fluid ratio, but a similar pH level when compared to the total sample.

Ten percent, or 79, of the jars had specimens collected before 1960. These jars did not have medians for pH, alcohol content or specimen to fluid level ratios that differed greatly from the total sample.

Jars with specimens exposed to air.—Six jars contained specimens that were exposed to air above the fluid level. Table 4 summarizes pertinent data for these jars. All were large jars and contained more specimens than the total sample

Table 4. Summary of data for jars with specimens exposed to air. Measurements were made before and after topping off the jars with 75% ethyl alcohol.

Jar size (ml)	pH		% alcohol		Number of specimens	Year
	Before	After	Before	After		
3,000	6.5	6.5	65	68	18	1967
4,000	6.5	6.5	40	59	35	1977
1,900	6.5	6.5	60	65	—	—
2,000	6.5	6.5	58	63	9	1980
4,000	6.0	6.0	53	59	15	1975
4,000	6.0	6.0	42	55	23	1978

median of six. The pH and alcohol content were measured for each jar, then the jar was topped off with fresh 75% ethyl alcohol and the measurements retaken. There was no change in the pH value and minimal change in the alcohol content after adding fresh alcohol.

Discussion

Characteristics of the Collection

The parameters measured show distinct trends relative to the ranges, median values and distribution of values. In the absence of comparative data, it is impossible to say whether these are representative of only this specific collection or of mammal collections in general. The possibility of asymmetrical distribution patterns must, however, be accounted for in future studies when only a portion of a collection is sampled rather than the entire collection.

This collection is a relatively young collection of fluid materials. Only ten percent of the specimens were collected before 1960; the personal preferences of the earliest curator of mammals dictated that specimens be prepared as dry skins, skulls and skeletons and that fluid-preserved specimens were to be avoided. The fact that this collection exhibited relatively few jars with fluid having low pH values and alcohol levels may be the result of its age. Older collections may show more marked trends in storage condition parameters.

The history of preparation techniques and collection management procedures documented for this collection are probably typical of most mammalian systematics collections. Until recently, fluid-preserved mammal specimens have been used less frequently for research, have been acquired in smaller quantities than other preparation types, and have generally received a lower priority for collection care. The latter is particularly true in view of limited financial resources and staff for collection care. Therefore, it is not unlikely that the trends documented in this study are unusual.

The size of the jar by itself does not appear to affect the fluid conditions measured. It is more likely that the size of the jar in combination with the type of closure is a more critical factor, influencing both evaporation rates and degree of crowding in the container. The size of the jar can be objectively measured, but the type of jar and closure are highly variable among collections. In order to obtain comparable data, a "dictionary" of jar types and closures needs to be developed. Descriptions of containers in use in various institutions, such as the descriptions

provided by Fink *et al.* (1978) and Lincoln (1989), are invaluable for developing a dictionary of jar types.

A high number of specimens in a single container does not necessarily indicate a low pH or low alcohol concentration in the fluid. But it does affect the degree of crowding and therefore the possibility of mechanical damage. It also increases the likelihood of a low ratio of volume of specimens to volume of visible fluid (due to a limited space within a container and possible evaporation). This study suggests that a low ratio indicates a lower alcohol concentration in the fluid.

Traditionally, a ratio of one volume of specimens to two volumes of fluid has been recommended as the minimum for storing fluid-preserved specimens. In this collection, with a typical maintenance pattern over the years, the majority of specimens have less than a 1:1.2 ratio. Ratios might be particularly useful for determining evaporation rates. However, these ratios are highly subjective ones and depend on the individual taking the observation. Ratios need a more objective definition both for systematic studies of storage conditions and for collection management needs.

An asymmetrical distribution of values would not be unexpected for pH values of the fluid. This would be especially true in the absence of buffering agents. One might ask, however, how rapidly the pH values might begin to show this type of distribution in the absence of fluid maintenance with or without buffering agents. To maximize efficient use of staff time, the ideal situation would be to identify a minimum time interval for systematically checking pH levels within a collection. Presumably this interval would vary depending on the conditions of the individual collection.

Fluids in this collection with the lowest pH values (5.0 and 6.0) also have a lower alcohol content. In this study, two taxonomic groups, marsupials and insectivores, were particularly affected by low pH values. These are not among the oldest specimens collected, but these groups generally have been handled less frequently for research purposes than the bats and rodents. There were also fewer acquisitions in these two groups over the 50 year time span than for bats and rodents. A question arises as to whether the low pH values are due to a low level of usage and/or maintenance (and very likely evaporation) or tied to the physical and chemical composition of specimens from these taxonomic groups.

Half of the containers held fluid with an alcohol content of 64% or less. Those with less than 60% alcohol had a relatively higher number of specimens, but the pH value remained at 6.5. Was the lower alcohol content due strictly to evaporation or possibly a continued leaching of water from the specimens? Considering that most specimens were prepared by rinses in tap water, then immediate immersion in 70–75% alcohol, it is possible that the specimens retained sufficient quantities of water to affect the final alcohol concentration of the fluid.

The practice of topping jars off rather than measuring the alcohol content and adjusting the alcohol level accordingly is more common than might be freely admitted. As supported by the data in Table 4, topping jars off with fresh alcohol does not correct the problems of low pH and low alcohol content in jars. Alcohol concentration levels are raised, but not to an acceptable level. These data suggest, therefore, that the asymmetrical distribution noted for alcohol concentration levels may reflect a combination of factors: evaporation, leaching of water from specimens, and periodic topping off of fluids with fresh alcohol. In the absence of

documentation, it is impossible to attribute the observations fully to one particular cause.

A bias was introduced in this study because the alcohol content was measured for fluids only in jars larger than 450–500 ml. This was due to the use of a hydrometer for measurements. It has been suggested that a density meter might be a more appropriate instrument, allowing both more accurate measurements and measurements of smaller quantities of fluid (Waller, personal communication).

The results from this study provide some indications for locating high risk situations for specimens, but the trends identified raise more questions than answers. For example, is there an acceptable risk level for the pH value and alcohol content of the fluid? Current literature suggests optimal levels, but to what degree are specimens harmed if maintained at a pH of 6.5 or an alcohol level of 65% ethyl alcohol? Are the optimal levels for mammals the same as those for other vertebrates? Do buffering agents have any long-term side effects on the specimen?

In view of how little is really known concerning the long-term effects of fluid preservatives, an emphasis should be placed on acquiring more data. Several researchers have begun projects to pursue these questions, but one of the primary needs is some standardization of terms and parameters to make data from various collections and projects comparable and to make measurements repeatable. To that end, the Assessment Subcommittee of the Society for the Preservation of Natural History's Conservation Committee has initiated a project to recommend some standards. Coordinated by Robert Waller, Canadian Museum of Nature in Ottawa, the committee plans to make recommendations concerning collection-background information, sample selection, kinds of specimen information that should be recorded, standard descriptors for containers and their contents, standard descriptors for specimen conditions, methods for characterizing preservation fluids including their identification, concentration, pH, concentration of impurities and specimen extractions (SPNHC-CC Assessment Subcommittee, 1990).

Implications for Collection Management

Based on the observations obtained in this study, some implications for the management of fluid-preserved mammal specimens can be suggested. Documentation of fixation, treatment and maintenance must be improved. This is an overwhelming prospect when faced with the numbers of specimens that might be acquired. However, it is possible to document thoroughly the standard procedures and then note variations for specific specimens. Recommendations have been developed by the Conservation Committee of the Society for the Preservation of Natural History Collections for documenting the preparation and conservation of biological specimens (Garrett, 1989). These should serve as the basis for developing documentation guidelines for individual collections.

Space is always at a premium; to obtain at least a 1:2 ratio of specimens to fluid, specimens were expanded to an average of 39 specimens per square foot of shelving. This is not meant to be used as an optimal level, but rather a tool when planning for expansion. Figures such as this one will be more useful once data from multiple collections have been determined.

Our collection could standardize jar purchases to four basic sizes: 500 ml, 1,000

ml, 2,000 ml, and one gallon or 4,000 ml. Approximately 40% of the purchases would be for the smallest of these sizes. Having a knowledge of the quantities of jars actually used in a collection makes it easier to estimate quantities for ordering, and therefore improve opportunities for obtaining discounts or pursuing joint orders with other institutions.

The fluid in individual jars should be systematically, not randomly, checked for pH and alcohol content. Jars with low specimen to fluid ratios should be considered particularly suspect, but there are insufficient data to make it possible to easily locate jars with low pH or low alcohol contents. Topping off low fluid levels without checking other fluid parameters is not recommended.

Conclusions

Trends in six storage condition parameters were identified for a collection of approximately 8,800 fluid-preserved mammals. Less than 10% of the containers held fluid with low pH levels (5.0, 6.0) and approximately 18% had fluids with alcohol contents of 60% or less. Half of the containers with low ratios for volume of specimens to volume of visible fluids had alcohol levels of 60% or less.

In view of the observations made for this collection, it is obvious that similar studies of other collections of fluid-preserved specimens are needed to determine whether these patterns are representative of only this collection or of collections in general. To make such studies useful, the standardization of data parameters and improved documentation of procedures and treatments are essential.

Data characterizing fluid-preserved collections make it possible to improve the management of the collection by identifying the physical parameters that might affect the long-term preservation of the specimens as well as by improving the efficiency of operations.

Acknowledgments

Thanks are extended to the individuals who recorded and computerized much of the data for this project: J. C. Morales, S. Norris, and B. Anderson. Discussions held by the Assessment Subcommittee of the Society for the Preservation of Natural History Collections' Conservation Committee have proved to be invaluable. The recuration and computerization of the Texas Cooperative Wildlife Collection mammal specimens was supported by the Department of Wildlife and Fisheries Sciences, Texas A&M University, and by a grant from the National Science Foundation (BSR-8320523) to D. J. Schmidly, P. S. Cato, and L. J. Folse, Jr.

Literature Cited

Cato, P. S. 1986. *Guidelines for Managing Bird Collections.* Museology No. 7, Texas Tech Press, Lubbock, 78 pp.

Fink, W. L., K. E. Hartel, W. G. Saul, E. M. Koon, and E. O. Wiley. 1978. *A Report on Current Supplies and Practices used in Curation of Ichthyological Collections.* American Society of Ichthyologists and Herpetologists, Oceanographic Sorting Center, Smithsonian Institution, Washington, D.C., 63 pp.

Garrett, K. 1989. Documentation guidelines for the preparation and conservation of biological specimens. Collection Forum, 5(2):47–51.

Horie, C. V. (ed.). 1989. *Conservation of Natural History Specimens: Spirit Collections.* The Manchester Museum and Department of Environmental Biology, The University of Manchester, 115 pp.

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

Knudsen, J. W. 1966. *Biological Techniques.* Harper and Row, New York, 525 pp.

Lincoln, R. 1989. Storage containers. Pp. 53–63 in *Conservation of Natural History Specimens: Spirit Collections* (C. V. Horie, ed.). The Manchester Museum and Department of Environmental Biology, The University of Manchester, 115 pp.

Quay, W. B. 1974. Bird and mammal specimens in fluid—objectives and methods. Curator, 17(2): 91–104.

Rogers, S. P., M. A. Schmidt, and T. Gutebier. 1989. *An Annotated Bibliography on Preparation, Taxidermy, and Collection Management of Vertebrates with Emphasis on Birds.* Special Publication No. 15, Carnegie Museum of Natural History, Pittsburgh, 189 pp.

Schmidly, D. J., W. R. Barber, P. S. Cato, and M. E. Retzer. 1985. The collection management practices of the Texas Cooperative Wildlife Collection, Texas A&M University. Unpublished document available from Department of Wildlife & Fisheries Sciences, Texas A&M University, College Station, TX 77843.

SPNHC-CC Assessment Subcommittee. 1990. Defining standard procedures for assessing the condition of a fluid-preserved collection. Pp. 437–440 in *Preprints of the 9th Triennial Meeting of the International Council of Museums—Committee for Conservation, Dresden DDR, August 26–31, 1990.* (K. Grimstad, ed.). ICOM, Paris.

Suzumoto, A. Y. 1989. Review of *Conservation of Natural History Specimens: Spirit Collections.* Collection Forum, 5(2):80–81.

Wagstaffe, R., and J. H. Fidler. 1968. *The Preservation of Natural History Specimens.* Vol. 2. Broadwater Press, Ltd., Philosophical Library, New York, 404 pp.

Waller, R., and D. E. McAllister. 1986. A spot test for distinguishing formalin from alcohol solutions. Pp. 93–99 in *Proceedings of the 1985 Workshop on Care and Maintenance of Natural History Collections* (J. Waddington and D. M. Rudkin, eds.). Life Sciences Miscellaneous Publications, Royal Ontario Museum, Toronto, 121 pp.

Williams, S. L., and C. A. Hawks. 1987. History of preparation materials used for Recent mammal specimens. Pp. 21–49 in *Mammal Collection Management* (H. H. Genoways, C. Jones, and O. L. Rossolimo, eds.). Texas Tech University Press, Lubbock, 219 pp.

Williams, S. L., R. Laubach, and H. H. Genoways. 1977. *A Guide to the Management of Recent Mammal Collections.* Special Publication No. 4, Carnegie Museum of Natural History, Pittsburgh, 105 pp.

INFRARED SPECTROSCOPIC ANALYSIS OF CENTRAL AND SOUTH AMERICAN AMBER EXPOSED TO AIR POLLUTANTS, BIOCIDES, LIGHT, AND MOISTURE

R. SCOTT WILLIAMS, JANET B. WADDINGTON, AND JULIA FENN

Canadian Conservation Institute, 1030 Innes Road, Ottawa, Ontario K1A 0C8, Canada (RSW); Department of Invertebrate Palaeontology (JBW); and Conservation Department (JF), Royal Ontario Museum, 100 Queen's Park, Toronto, Ontario M5S 2C6, Canada

Abstract.—Specimens of Central and South American amber were exposed to high levels of common air pollutants, biocides, light, and varying relative humidity to identify potentially damaging conditions. Changes were assessed visually and by Fourier Transform Infrared spectroscopy. Changes in spectra were consistent with the effects of oxidation due to aging. Knowledge gained from this ongoing study will be used to plan preventive conservation strategies for the storage and display of amber.

The literature on amber deals predominantly with its botanical significance, its identification and provenance, or its repair and restoration, but is sparse on the prevention of its deterioration, especially by environmental control. Amber progressively degrades, eventually to complete disintegration, by atmospheric oxidation accelerated by light and heat (Beck, 1982). To ascertain which factors contribute most to its degradation, we examined the effects of selected environmental conditions and atmospheric pollutants on amber said to be from the Dominican Republic. Based on these tests, we recommend environmental parameters for safer storage and display.

MATERIALS AND METHODS

Small blocks of amber, polished over ten years ago, were sawn into several pieces, each retaining at least one old polished side. One piece from each block was retained as a control. Blocks were exposed to vapors from common air pollutants (concentrated ammonium hydroxide, 50% formic acid, acetic acid, hydrogen sulfide gas), cleaning agents, biocides (naphthalene/paradichlorobenzene/camphor mixture, Vapona No Pest Strips, Phostoxin) and adverse physical conditions (fluctuating relative humidity (RH), UV and visible light). These are all conditions that are encountered in museums. Further details about the experimental method are available from Fenn and Waddington on request.

Detailed visual assessments of changes caused by air pollutants, biocides and cleaning agents were reported by Waddington and Fenn (1988). Visual effects of other agents on the same specimens are reported here. To detect chemical changes, Williams examined specimens by Fourier Transform Infrared (FTIR) spectroscopy (Low and Baer, 1977) after about a year of airing following exposures. IR spectroscopy has been widely used to analyze amber and other resins in studies on provenance or botanical affinities (Beck, 1986; Langenheim, 1969).

Samples were removed from several locations on a ten year old polished face and on a freshly sawn face of each specimen. To assess variations in composition with depth, surface material was removed from a layer less than 0.2 mm thick by scraping with a scalpel, then deep material was excavated from more than 2 mm deep in a hole dug where surface material had been removed. The samples cover surface areas about 1–2 mm^2 and weigh less than 1 mg (about the size of the period at the end of this sentence). Scrapings and chips were mounted in a diamond anvil microsample cell in a beam condenser (Laver and Williams, 1978) for recording spectra on a Nicolet 5DX Fourier Transform Infrared (FTIR) spectrometer.

Results and Discussion

Infrared Spectra of Fresh and Naturally Aged Controls

Samples of unaltered, virgin amber taken from deep within control specimens are referred to as Fresh Controls. Spectra of Fresh Controls from six different specimens are of three slightly different types (with three, two and one members, respectively). Figure 1 shows representative IR spectra of each type of amber. All spectra closely resemble those of types of Central and South American ambers published by Langenheim and Beck (1968), but are quite different from those of Baltic, North American, and New Zealand ambers (Langenheim, 1969). All are characterized by sharp absorptions, especially at 3080, 1650, and 885 cm^{-1}, due to carbon-carbon double bonds (C=C), and several small absorptions between 1250–1000 cm^{-1}, due to carbon-oxygen bonds (C-O) of acid and ester components (Langenheim, 1969). The spectra of ambers in this study contain the same absorptions, but in slightly different ratios, indicating that these ambers have the same components in different proportions.

Figure 2 shows the IR spectra of crizzled and exfoliated outer polished surface layers of the same specimens. These specimens, in storage since polishing more than ten years ago, are referred to as Naturally Aged Controls. Waddington and Fenn (1988, Figs. 1, 4) show examples of typical exfoliated and crizzled surfaces.

Spectra of Naturally Aged Controls show decreased absorptions due to C=C bonds at 885, 1645 and 3080 cm^{-1} accompanied by increased and broadened absorptions at 3800–3100 (with the typical profile of organic acids), 1720, 1250 and 1170 cm^{-1}, all from C-O bonds in acid and ester functional groups. These changes are consistent with the hypothesis that C=C double bonds are oxidized to acid and ester groups during normal atmospheric aging (Beck *et al.*, 1965). The 885 cm^{-1} band is attributed to an exocyclic methylene group (Beck, 1986), a particular type of C=C bond which is prone to oxidation to produce acid and ester groups. Decreases in the intensity of this band reflect the extent of degradation of the amber.

As can be seen from Figures 1 and 2, the IR spectra, and hence the compositions, of Naturally Aged Controls from the three types of amber are very similar to each other, much more alike than the Fresh Controls.

All IR spectra from surfaces of control specimens sawn less than a year previously showed changes due to oxidation. Some spectra were indistinguishable from the ten year old Naturally Aged Controls. Although surfaces showed no visual changes, IR spectra showed that invisible oxidative degradation occurs within a year of exposing a fresh surface by sawing. Oxidation may be faster on these rough and fuzzy sawn surfaces than on smooth polished ones since the former have larger surface areas available for oxidation.

Air Pollutants

Waddington and Fenn (1988) reported that degradation from exposure to ammonia, formic acid, acetic acid, and hydrogen sulphide were visually similar, with the only difference being in the speed of the degradation—crazing, crizzling, and exfoliation occurred anywhere from three weeks for acetic acid to three hours for hydrogen sulphide. These were interpreted as physical rather than chemical reactions, probably due to stress caused by swelling and contraction at different vapour concentration.

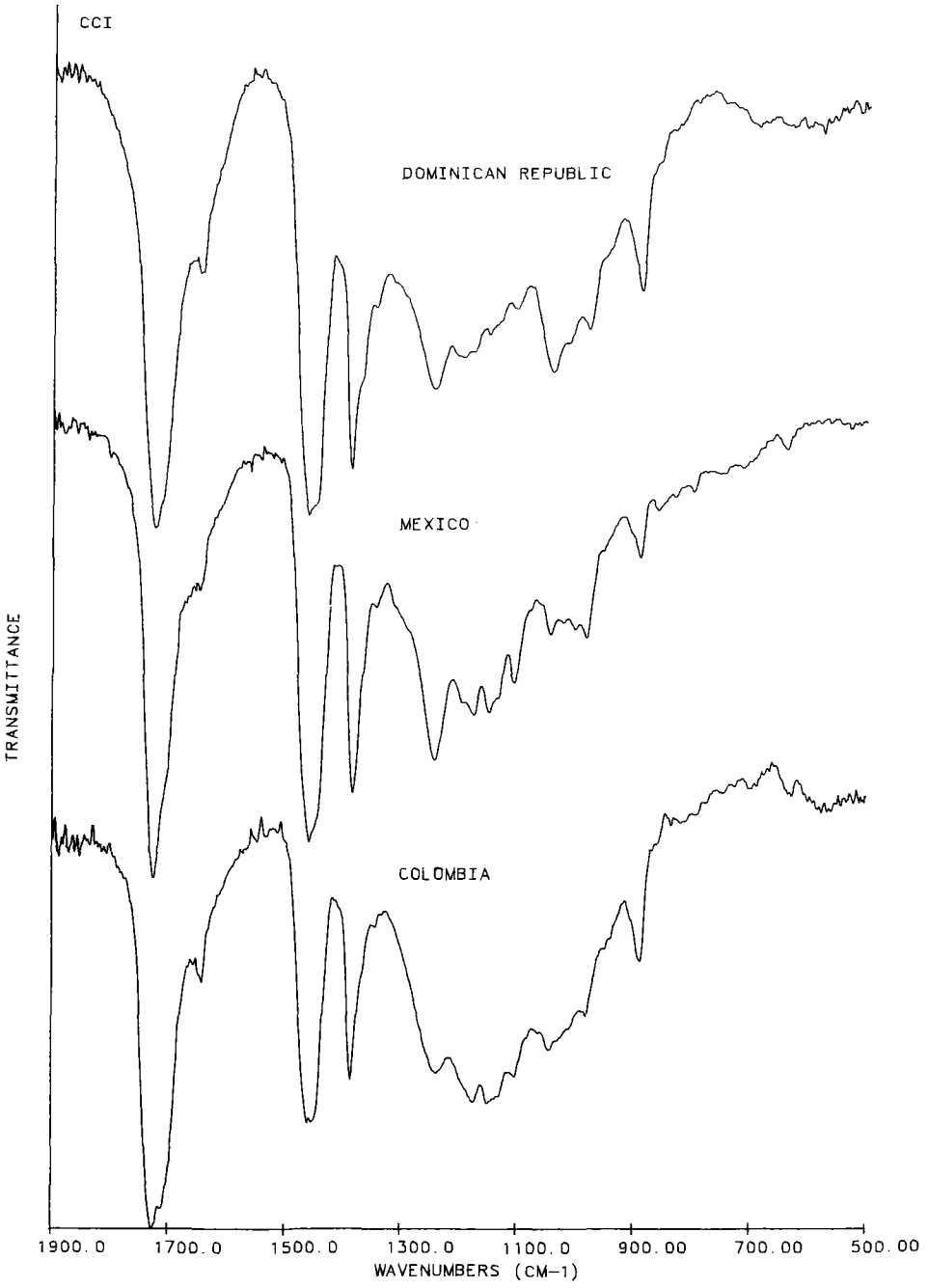

Figure 1. Fresh Control Samples: Infrared spectra of three types of undegraded amber, freshly exposed by sawing. These three types correspond to those described by Langenheim and Beck (1968) as Dominican Republic I, Oligocene (top); Chiapas, Mexico I and/or II, Oligo-Miocene (middle); and Giron, Colombia II (bottom).

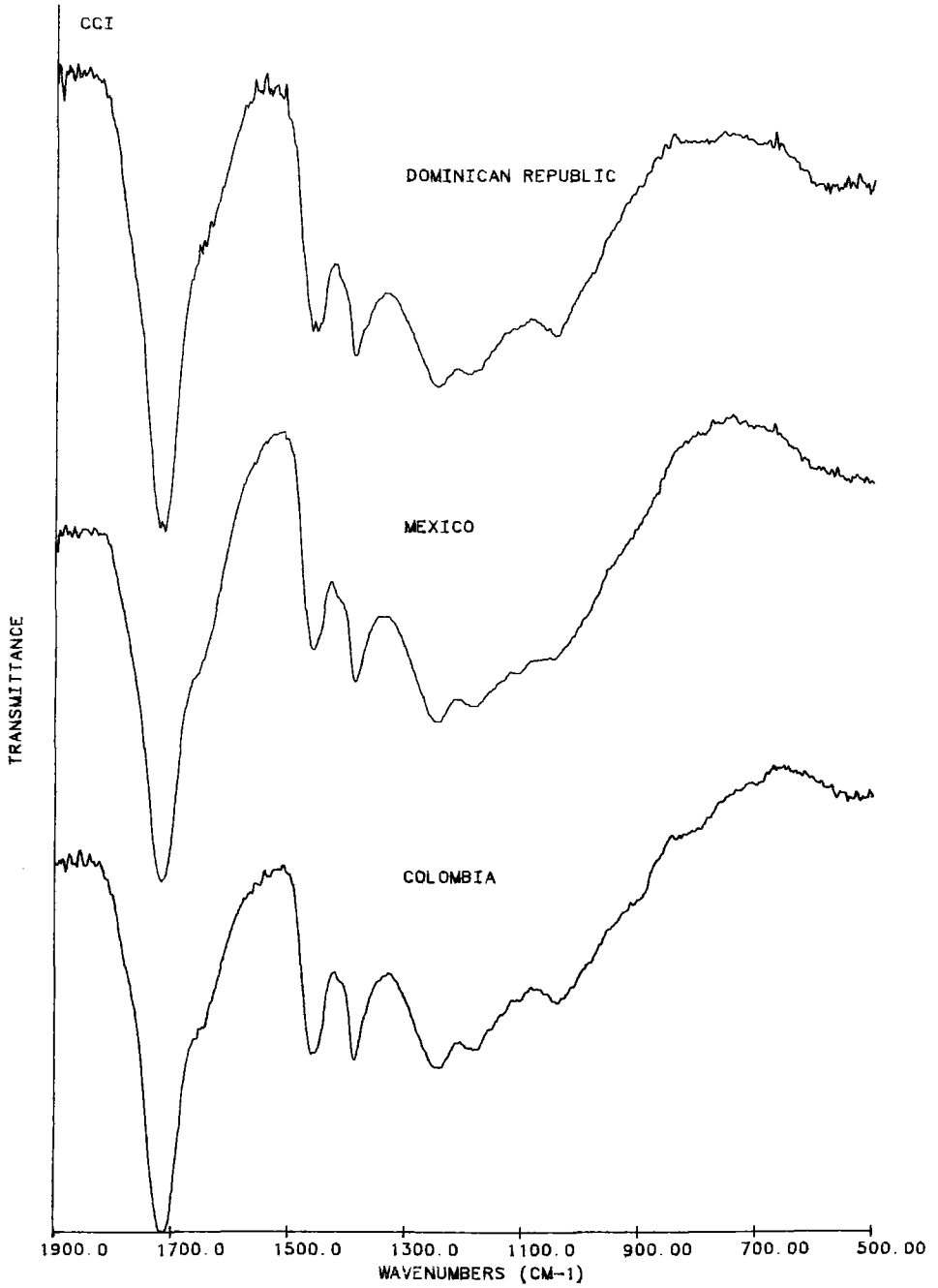

Figure 2. Naturally Aged Control Samples: Infrared spectra of naturally aged amber from surfaces polished more than ten years ago, corresponding to the three types shown in Figure 1.

IR spectra of these degraded ambers were not appreciably different from those of Naturally Aged Controls (Fig. 3, compare to Fig. 2). Changes look like normal oxidation aging and are not related to pollutants. This is consistent with our earlier conclusion that the crizzling, crazing and exfoliation was due to physical or mechanical rather than chemical processes. The specimens were exposed to the pollutants shortly after being cut. Freshly cut surfaces are less brittle than old degraded ones and may be less damaged because they can dissipate stresses due to swelling and contraction more easily than more brittle degraded surfaces.

Visible and Ultraviolet Light

A specimen exposed to 800 lux visible light at room temperature for seven months showed no appreciable change either visually or spectroscopically. A second specimen exposed to UV light (General Electric F20T12.BLB, 20 watt black light) for the same period showed no visible change, but its spectrum showed greater changes than any other exposed specimen. There were very large increases in absorption for all bands related to acids and esters and an initially strong 885 cm^{-1} band was completely destroyed (Fig. 4). This indicates greatly increased oxidation. The deterioration caused by UV light was only a shallow surface feature, not detected in samples from 2 mm below the surface. Presumably the light was filtered by the amber itself.

Biocides

All surfaces of specimens softened when exposed to vapours from Vapona No Pest Strips (active ingredient dichlorvos, a chlorinated organic phosphate formulated as a 20% concentration on a strip of polyvinyl chloride plasticized with di-2-ethylhexyl phthalate) or to a mixture of camphor, naphthalene, and paradichlorobenzene. After exposure to No Pest Strips surfaces could be marked with a finger nail. Also, the old polished surface developed a striking pattern of scratch marks that appeared to be an enhancement of original polishing marks. Several months after exposure was terminated, IR spectra showed that dichlorvos was still present in the aged surface but had desorbed from the freshly cut surface (Fig. 5). This concurs with the observation of Williams, Hawks and Weber (1986) that dichlorvos is readily sorbed by plastics, and reinforces their doubt that it desorbs within 72 hours.

Specimens exposed to naphthalene, camphor, or paradichlorobenzene individually showed no visible alteration but in combination they caused cracking and severe softening of both old and new surfaces. IR spectra of specimens exposed to a mixture of all three show that all are absorbed (Fig. 6). Although these vapour phase biocides seem to cause little or no chemical damage, the problems caused by prolonged softening (dust adsorption, loss of surface gloss, and possible surface sag) make their use either as insect repellants or corrosion inhibitors unacceptable where amber is stored.

One specimen was exposed five times to Phostoxin, the fumigant currently in use at the ROM. In spite of the fact that two of these fumigations took place at high humidities no damage to the amber was recorded. No absorbed Phostoxin was detected in IR spectra. If Phostoxin was absorbed, it was not retained by the amber.

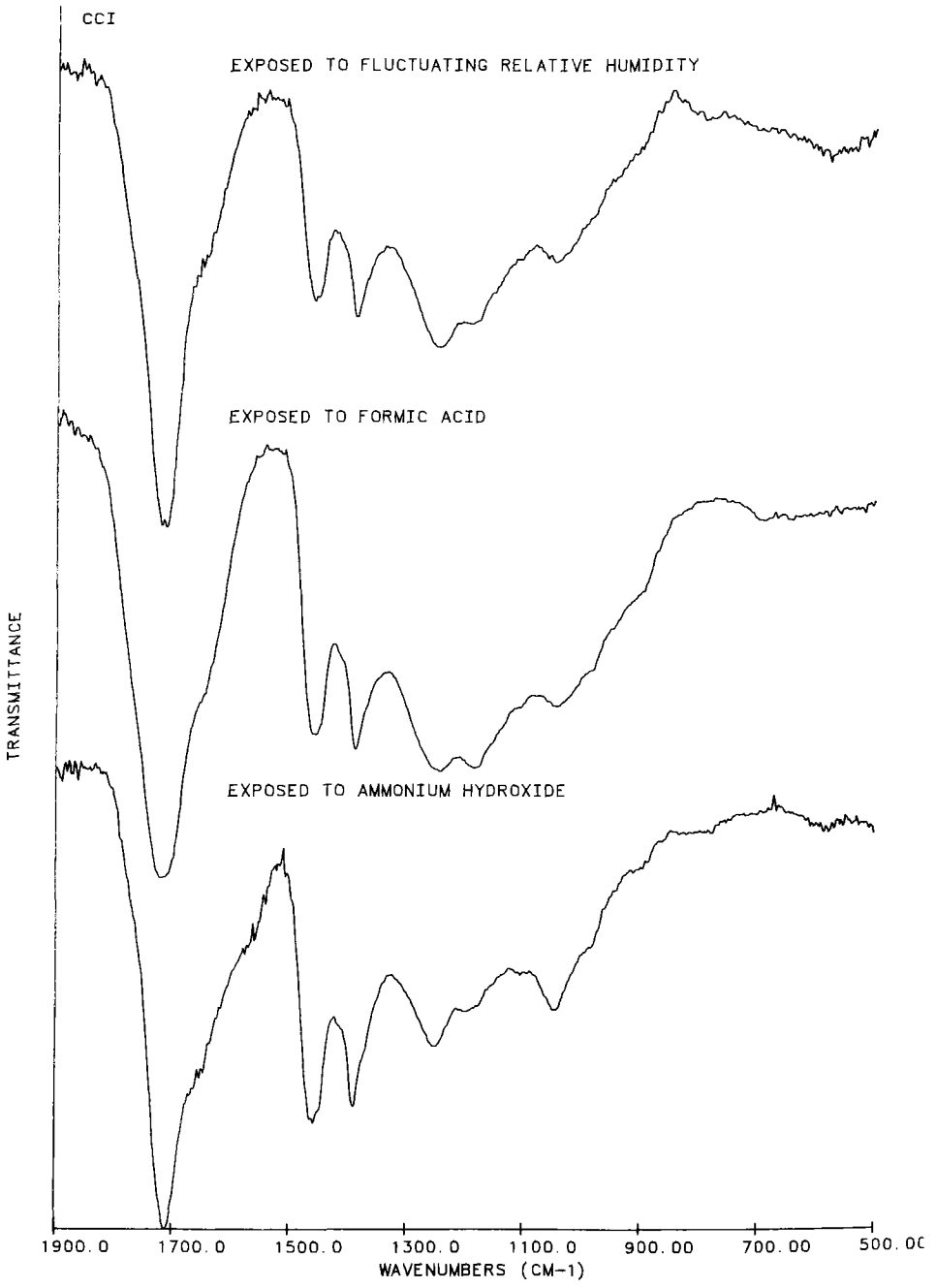

Figure 3. Infrared spectra of ambers exposed to fluctuating relative humidity (top); 50% formic acid (middle); ammonium hydroxide (bottom).

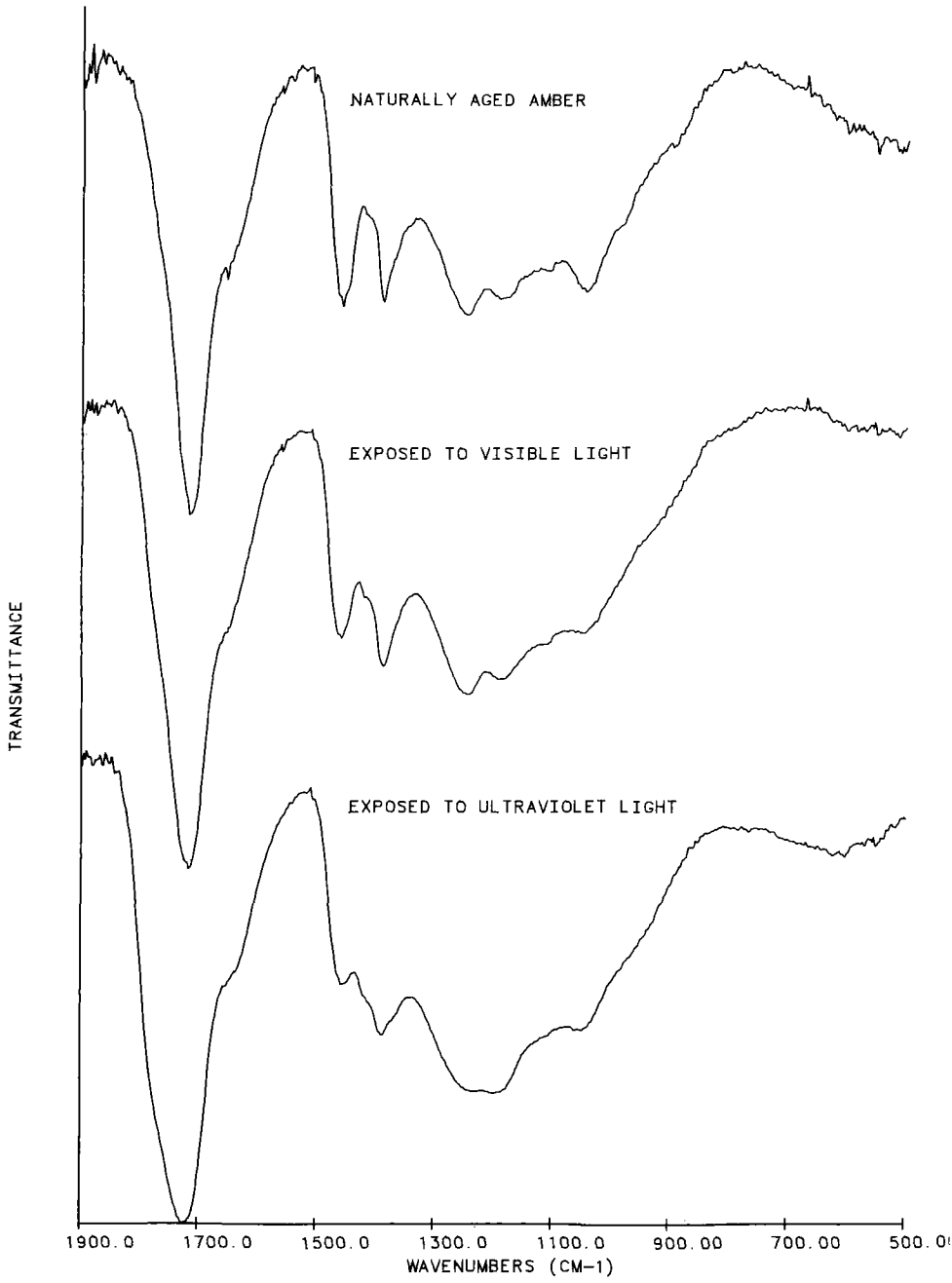

Figure 4. Infrared spectra of ambers exposed to visible light (middle) and ultraviolet light (bottom) with the Naturally Aged Control (top) for comparison.

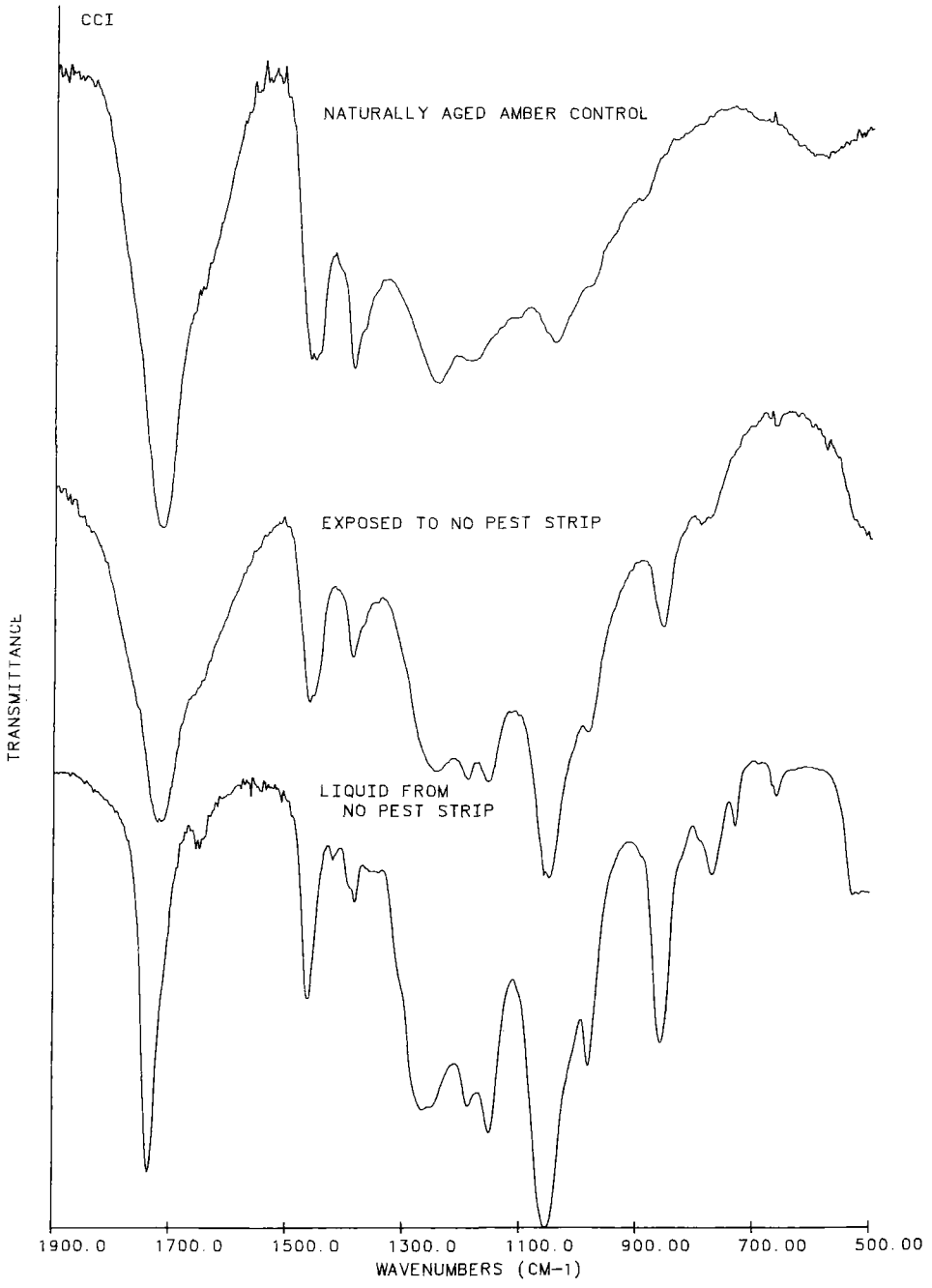

Figure 5. Infrared spectra of amber exposed to Vapona No Pest Strip (middle). Compare this to the liquid oozing from the No Pest Strip (bottom) and with the Naturally Aged Control (top). The liquid contains dichlorvos and phthalate plasticizer.

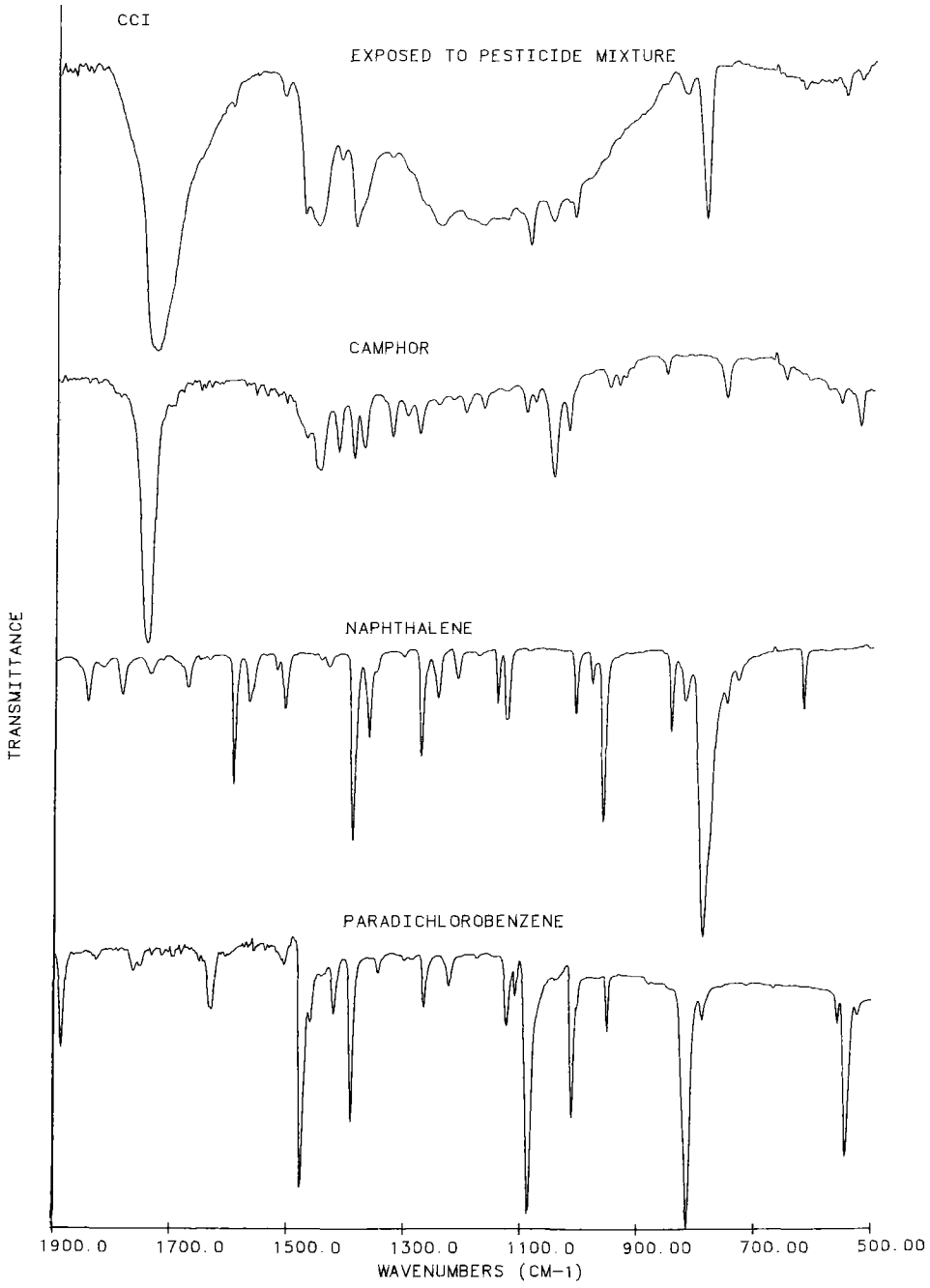

Figure 6. Infrared spectrum of amber after exposure to a mixture of camphor, naphthalene, and paradichlorobenzene (top) with spectra of pure camphor, naphthalene, and paradichlorobenzene for comparison.

Relative Humidity

Amber specimens exposed to fluctuating RH showed the same type of coarse surface cracking on the polished surfaces as observed on specimens and artifacts in ROM collections. It was difficult to initiate this type of cracking above 45% RH even when they were subjected to quite sudden decreases of 30% RH; however even minor changes below 35% RH caused immediate gaping surface cracking. After acclimatizing in the laboratory at approximately 35% RH, the cracks in these very badly damaged test specimens closed within 24 hours and were visible only under the stereomicroscope. The amber artifacts in the collections unfortunately do not show this self healing characteristic. Presumably repeated fluctuation makes the deformation permanent.

IR spectroscopy indicated little effect resulting from exposure to high RH other than a slight degradation in the freshly cut surface which may indicate that elevated humidity accelerates degradation. It would be a mistake to generalize on the basis of so few specimens that the safest RH levels for amber lie in the range 35% to 45%. Nevertheless it does seem safe to state that amber is more humidity sensitive than has generally been realized. Open cracks, as well as affecting the translucency of the amber, promote deterioration by exposing fresh core material to oxidation. Thus the degradation of amber is probably accelerated by both high and low RH levels, but particularly by low. We are currently in the process of devising an adaptation of the microclimate generator (Wilson, 1985) so that we can examine the reaction of a much broader selection of amber types within clearly defined humidity ranges.

Conclusions

Oxidative degradation of amber that is not apparent visually can be detected by IR spectroscopy. Decreases in the intensity of the 885 cm^{-1} band in the IR spectrum of amber reflects the extent of degradation. If samples can be taken, it may be possible to determine how deeply degradation penetrates in a particular specimen.

Preliminary data suggest that amber can best be protected by 1) eliminating ultraviolet light; 2) avoiding contact with vapour phase biocides and corrosion inhibitors (especially in tightly closed containers where the vapour concentration can reach high levels); and 3) maintaining a stable moderate humidity at room temperature. Although several vapour phase biocides cause softening and other damage to amber surfaces, Phostoxin had no apparent effect on amber. Amber specimens that appear undegraded and intact may have weakened and friable surfaces, and therefore should be displayed only in soft, shock absorbent support systems.

Acknowledgments

The authors are grateful to Curt Beck, who reviewed the manuscript and offered many helpful suggestions.

Literature Cited

Beck, C. W. 1982. Authentication and conservation of amber: Conflict of interests. Pp. 104–107 in *Science and Technology in the Service of Conservation: Preprints of the Contribution to the Wash-*

ington Congress, 3–9 September 1982 (N. S. Bromelle and G. Thomson, eds). International Institute for Conservation of Historic and Artistic Works, London.

———. 1986. Spectroscopic investigation of amber. Applied Spectroscopy Reviews, 22(1):57–110.

Beck, C., E. Wilbur, S. Meter, D. Kossove, and K. Kermani. 1965. The infrared spectra of amber and the identification of Baltic amber. Archaeometry, 8:96–109.

Langenheim, J. H. 1969. Amber: A botanical inquiry. Science, 163:1157–1169.

Langenheim, J. H., and C. W. Beck. 1968. Catalogue of infrared spectra of fossil resins (ambers). I. North and South America. Botanical Museum Leaflets, Harvard University, 22(3):65--120.

Laver, M. E., and R. S. Williams. 1978. The use of a diamond cell microsampling device for infrared spectrophotometric analyses of art and archaeological materials. Journal of the International Institute for Conservation - Canadian Group, 3(2):34–39.

Low, M. J. D., and N. S. Baer. 1977. Application of infrared Fourier transform spectroscopy to problems in conservation. Studies in Conservation, 22(3):116–128.

Waddington, J. and J. Fenn. 1988. Preventive conservation of amber: Some preliminary investigations. Collection Forum, 4(2):25–31.

Williams, S. L., C. A. Hawks, and S. G. Weber. 1986. Considerations in the use of DDVP resin strips for insect control in biological research collections. Biodeterioration, 6:344–350.

Wilson, S. 1985. Micro-climates in the Royal Ontario Museum. Abstract, International Institute for Conservation-Canadian Group, 11th Annual Conference, Halifax, May 17–19.

OBSERVATIONS ON ENZYME PREPARATION EFFECTS ON SKELETAL MATERIAL

SALLY Y. SHELTON AND JOHN S. BUCKLEY

Materials Conservation Laboratory and Vertebrate Paleontology Laboratory, Texas Memorial Museum, University of Texas, Austin, Texas 78758

Abstract.—Enzyme-based methods for preparing disarticulated skeletons for dry storage have been described in several publications. A large collection of lower vertebrate skeletons, primarily fish, was donated to the Vertebrate Paleontology Laboratory, Texas Memorial Museum, in 1979. Recent observations indicate that many specimens in this collection are damaged by the preparation method (maceration in a heated solution of a commercial enzyme-based laundry compound). An analysis of the problems in this and other comparable collections suggests that any enzyme-based preparation method may lead to similar problems if the enzymes are not specifically known, used at controlled concentrations and durations, and specifically denatured at the conclusion of preparation.

The Clair Ossian collection of disarticulated skeletal material was donated to the Vertebrate Paleontology Laboratory (VPL), Texas Memorial Museum, in 1979. An inventory in 1988 showed 776 specimens of fish, 66 amphibians, 97 reptiles, and fewer than 50 birds and mammals. It is the single largest holding of fish material in the VPL's Recent skeletal comparative collection, comprising over 80% of the catalogued specimens. Many taxa are represented by single specimens; the primary value of the collection is its availability for use in comparative studies in the skeletal morphology of lower vertebrates.

Disarticulated, dry fish skeletons are not commonly used outside the comparative collections maintained for paleontological or archeological purposes. Fish skeletons tend to be small and fragile in many taxa, and are more often studied in ichthyology as articulated specimens through clearing and staining (Taylor, 1967) or as ligamentary preparations (Konnerth, 1965). The Ossian collection is a valuable adjunct to specific vertebrate paleontology studies and would be difficult to replace without duplicating Ossian's extensive field work.

In the 1988 inventory, serious problems with the condition of the fish bones were noted. Six hundred thirty-nine of the specimens (82.3%) showed some degree of damage, including abnormal brittleness and opacity, breakage, and encrusted deposits on the bone surface. Normal fish bones prepared by simple maceration may show deposits if soft tissues are not adequately removed, but, in general, fish bones show a high degree of translucency (especially the smaller bones) and surface detail. The fish bones in the Ossian collection which are opaque and brittle are unusable for any study and have lost many key characteristics. These problems are not apparent in any other vertebrate group prepared by Ossian in the VPL collections.

HISTORY

The specimens in Ossian's collections were prepared using a solution of "Biz," an enzyme-based pre-soak laundry compound (Ossian, 1970). Using a suggested concentration of two tablespoons of "Biz" to one quart of water, heated to a temperature of 50–70°C, Ossian placed whole fish in the heated solution and allowed them to remain "until the bones are free or the solution is exhausted."

Specimens which were previously preserved required longer preparation times than did fresh specimens, but no standard times are indicated for either fresh or preserved specimens.

Ossian's article was the first real indication that the severe problems observed in the VPL collection could be traced to the preparation method. In analyzing this method as described in the article, we noted three procedures which are questionable.

1. *Animal specimens were placed in the solution whole and received no further preparation after enzyme digestion of the soft tissue.* Tissue allowed to adhere to bones in solution, as is sometimes seen with hurried or careless maceration, accounts for encrusted or greasy deposits on the bone surfaces. Removal of these deposits is possible, but the bone surface is permanently pitted or etched in many cases.

2. *After removal from the "Biz" solution, the bones were rinsed with water and air-dried; residual enzymes were not identified or denatured.* This suggests the possibility of continuing enzyme digestion of bone and ligament proteins, which would leave only the crystalline hydroxyapatite framework of the bone. If this has occurred, the remaining material would be fragile, brittle, and easily broken, which is consistent with the patterns of damage noted.

3. *No attempt to remove stomach contents or extraneous material was made.* Gravel, fishhooks, and small crustaceans are found with several specimens. Their inclusion may contribute to mechanical breakage as the boxes in which the specimens are contained are moved.

It is assumed that the actual preparation of the specimens in the collection closely followed these documented preparation methods. While several steps in the procedure may permit the possibility of immediate or long-term damage to the integrity of the specimen, we suggest that the use of a commercial enzyme-containing compound at varying and unrecorded concentrations is the single most damaging factor in this approach.

Observations

The major problem in the Ossian collection is the extreme opacity and brittleness of many of the fish bones. These are broken easily by slight motion or handling, and breakage was observed in one specimen exposed to an unexpected but minor air current. 28.9% of all specimens in the fish collection are opaque and brittle; 30.5% of all specimens are affected by breakage of key skeletal elements.

Breakage and opacity are associated with specimens which seem to have been overcleaned or to have been left in contact with the enzyme solution long enough to effect the destruction of the protein framework of the bones. This may have occurred after the bones were removed from solution and boxed. The procedure as described by Ossian makes no provision for denaturing the enzyme solution at the end of preparation. Changes in the structure of these bones, including surface and subsurface cracks, opacity, and loss of thin edges, are easily apparent under magnification and polarized-light microscopy. The size of these bones is often under 1 cm, which makes their consolidation problematic at best; thus, their research value is effectively lost.

A lesser problem is seen in the specimens with encrusted or greasy deposits on the bone surface. These are insoluble in water or ethanol, but are manually removable. The deposits are associated with areas of reduced surface sculpturing and detail, suggesting that the material may etch the bone surface. 14% of all specimens in the fish collection are affected by the deposits.

Both problems effectively limit the use of the bones for accurate comparative work; the opaque and brittle bones cannot be handled, and the encrusted ones may lack key surface characteristics. Very thin fish bones are found to be warped in specimens affected with either problem. Warping and other morphometric changes in fish bones can be caused by exposure to heat alone, which induces morphological changes in the collagen (Richter, 1986). The loss of valid morphometric data reduces the targeted research value of the collection.

Other problems noted in this collection include the presence of dermestid frass in greasy or undercleaned material, metallic flakes (which may represent iron oxide particles from old screens or jars used in the process), and crystals which were not immediately identifiable. Crystals of comparable shape and appearance were produced by allowing a concentrated "Biz" solution to air-dry. The resulting crystals were indistinguishable under normal and polarized light from the crystals in specimen boxes, suggesting that these specimens may not have been rinsed at all after enzyme digestion, permitting crystals to form from the drying solution. Most disturbingly, there was almost no skeletal material in the boxes containing crystals; it is possible that these bones contained a sufficiently high amount of enzyme solution to permit complete protein digestion and collapse of the entire bone.

Discussion

Enzyme maceration of skeletal material has often been described procedurally (Luther, 1949), but steps for denaturing these enzymes and the long-term effects of these procedures have seldom been reported. The advantage of enzyme-based preparation methods is the use of a rapid-acting and specific chemical to complete soft tissue digestion. In describing the use of enzymes for use in paper conservation, Grattan *et al.* (1980) point out that "[c]ommercially available enzymes are often found to vary in composition and activity, and they are often mixtures of several enzymes." Thus, the specificity of the commercial compound and the predictability of its results, desirable and otherwise, are often unknown.

Mayden and Wiley (1984) note problems in fish specimens at the University of Kansas (KU) collections, prepared using Ossian's method, which correspond to the problems observed in the VPL collections. The authors recommend the use of a known enzyme-buffer solution (either trypsin or pancreatin) at a known concentration and standard time to digest soft tissue, as described by Dingerkus and Uhler (1977). They also use Alizarin Red-0.5% aqueous KOH solution to stain small bones, so that they will be easier to find in the enzyme-buffer solution. After controlled enzyme cleaning, the bones were allowed to air-dry from a solution of 70% ethyl alcohol. Mayden and Wiley noted that digestion of unmineralized and desirable connective tissues also occurs with this method, resulting in the loss of teeth in some prepared specimens. No enzyme denaturation is included in the procedure, and no controlled testing is described. Mayden has noted that

decalcified specimens often deform in preparation, and suggests that this may result from prolonged storage of specimens in formalin (R. Mayden, personal communication).

Pancreatin itself is a combination of 3 enzymes: alpha-amylase or amylopsin, a polysaccharide digester; steapsin (pancreatic lipase), a fat digester; and trypsin (protease), a protein digester. C. Hawks (personal communication) believes that this is the compound used in commercial enzyme pre-soaks, but this has proved difficult to verify.

T. Cassidy (personal communication) has described the use of an enzyme compound of papain and bromain for skeletonization. She discontinued the use of the enzyme after noticing that overexposure caused softening and transparency. The skeletons which were treated with this compound are not documented in her collections. The destruction caused to small bones by overexposure to enzymes is noted by Cumbaa (1983), who has abandoned the use of a Canadian enzyme detergent previously used in the same way as "Biz."

The "Biz" method caused damage of another kind in higher vertebrate material prepared at the Museum of Zoology at the University of Wisconsin (UWZS), Madison. Bones from a modern camel (*Camelus* sp.) were placed in a "Biz" solution in a standard simmering tank with a copper intake pipe. The solution covered the pipe for an extended period of time, which caused an electrolytic reaction, turning the affected bones blue. After examining the affected bones from this specimen (which also includes normally-colored bones which were not "Biz" prepared once the problem became known) and other green- or blue-tinged specimens in the UWZS and VPL collections, we believe that "Biz" solutions in contact with copper-containing metals of any kind may cause similar discoloration (E. Pillaert, personal communication). This can include metals in screens used to drain the specimens from the solution.

Without knowing the specific composition of "Biz," particularly the compound in use 20 years ago, at the time the Ossian collection was prepared, it is difficult to target the specific enzyme pathway which caused the damages. A representative of Procter and Gamble, who could not divulge proprietary information, was able to say that the formulation of "Biz" was changed in 1981 with the removal of amylase. Amylase is a polysaccharide digester; its presence or absence alone should not account for the effectiveness of protein digestion. Collections that have used "Biz" solutions since 1981 have not noticed problems comparable to those seen at the VPL (G. McDonald, personal communication), but a long-term study is in order.

Without having seen the Mayden and Wiley material, we are not in a position to assess the long-term effects of alizarin staining or air-drying from alcohol. We concur with their recommendations to use only a known enzyme or enzyme compound at a known concentration for the digestion of soft tissue. To that, we would add that the use of any enzyme must be followed by its denaturation at the conclusion of its use. This is not a simple process. Heat denaturation exposes the bone to the risk of warping, and strong chemical denaturants may trade one problem for another.

Preliminary experiments indicate that, at room temperature (77°F) and Ossian's recommended concentration, the "Biz" compound tested in 1988 is no more effective at removing soft tissue than is standard maceration in water at the same

temperature. Effectiveness in digesting soft tissue is gained at the expense of exposing the bone to levels of heating which may not be acceptable.

One factor not documented in the Ossian records is the preservation of the specimens before preparation. It is not possible to determine which specimens were previously fixed in formaldehyde or preserved in alcohol. Fluid-preserved specimens may react differently to the preparation method than do fresh specimens, as noted by R. Mayden with reference to the KU material, but this cannot be proven without further experimentation.

Conclusions and Recommendations

In general, we cannot recommend the use of enzyme-based preparation methods for dry-storage skeletal material without further study of the specific biochemistry of the compounds used and their potential long-term effects. Any use of an enzyme must include denaturation of that enzyme at the conclusion of preparation; if the denaturation of the enzyme poses a further threat to the integrity of the specimen, then an alternative to that enzyme must be found. Treatment times and standard solutions must be tailored to the size and nature of the specimen. We concur with Mayden and Wiley in their recommendation that proprietary compounds not be used for this purpose, because their specific formulation and components are unknown and often unavailable. Further long-term studies of the denaturation and effects of the specific enzymes mentioned in this survey will aid greatly in identifying effective skeletonizing techniques which do not contribute to the disintegration of the specimen.

Acknowledgments

Information on the use of this and similar methods has been generously provided by C. Ossian, ARCO Oil and Gas Company; R. Mayden, University of Alabama; E. Pillaert, University of Wisconsin; T. Cassidy, Transvaal Museum; and G. McDonald, Cincinnati Museum of Natural History. Early versions of this study benefitted greatly from the reviews and suggestions of J. Simmons, University of Kansas; A. Suzumoto, Bishop Museum; C. Hawks, National Museum of Natural History, Smithsonian Institution; S. Williams, Carnegie Museum of Natural History (currently at The Museum of Texas Tech University); K. Garrett and L. Barkley, Natural History Museum of Los Angeles County; P. Cato, Texas A&M University (currently at the Virginia Museum of Natural History); C. Bramblett, E. Lundelius, R. Toomey, and R. Rainey of the University of Texas; W. Lyons and C. Romero-Sierra, Queen's University and two anonymous reviewers. Austin Community College provided analytical and technical support. This research was supported in part by NSF Grant #BSR-8513053, "Management Enhancement for Fossil Vertebrate Resources in the Texas Memorial Museum," awarded to W. Langston and E. Lundelius. Publication No. N.S.-12 of Texas Memorial Museum.

Literature Cited

Cumbaa, S. L. 1983. Osteological preparation techniques used by the Zooarchaeological Identification Centre. In *Proceedings of the 1981 on Care and Maintenance of Natural History Collections* (D. J. Faber, ed). Syllogeus, 44:29–35.

Dingerkus, G., and L. D. Uhler. 1977. Enzyme clearing of alcian blue stained whole small vertebrates for demonstration of cartilage. Stain Technology, 52:229–232.

Grattan, D. W., J. St. Hilaire, H. Burgess, and J. C. McCawley. 1980. The characterization of enzymes for use in paper conservation. International Conference on Conservation of Library and Archival Material and the Graphic Arts, preprint 53.

Konnerth, A. 1965. Preparation of ligamentary articulated fish skeletons. Curator, 8(4):325–332.

Luther, P. G. 1949. Enzymatic maceration of skeletons. Proc. Linnaean Soc. London, 161:146–147.

Mayden, R. L., and E. O. Wiley. 1984. A method of preparating disarticulated skeletons of small fishes. Copeia, 1984(1):230–232.

Ossian, C. R. 1970. Preparation of disarticulated skeletons using enzyme-based laundry "pre-soakers." Copeia, 1(2):199–200.

Richter, J. 1986. Experimental study of heat induced morphological changes in fish bone collagen. Journal of Archaeological Science, 13(5):477–481.

Taylor, W. R. 1967. An enzyme method of clearing and staining small vertebrates. Proceedings of the United States National Museum, 122(3596):1–17.

INTEGRATING SPECIMEN DOCUMENTATION, PROCESSING, AND DATA AUTOMATION IN A MAMMAL COLLECTION: A CASE STUDY OF AN ACCESSION DATABASE

SUSAN M. WOODWARD

Department of Mammalogy, Royal Ontario Museum, 100 Queen's Park Crescent, Toronto, Ontario, M5S 2C6, Canada

Abstract.—A microcomputer database has been designed to house accession or acquisition information for single specimens and collections of mammal specimens. Location and status fields in the accession database permit the tracking of physical location, stage of preparation, curation, and data automation of specimens. Single specimen data from the accession database can be directly uploaded to the departmental collection database. The system optimizes the efficiency with which departmental staff are able to perform their functions related to specimen processing. It also serves to integrate specimen documentation, processing, and data automation activities.

Many people have written about the advantages of computerizing museum collections and the use of microcomputers to achieve this end (Folse *et al.*, 1987; Holm, 1986; McLaren *et al.*, 1987; Seymour, 1986; Seymour, 1988; Woodward, 1989a; Woodward, 1989b; Woodward and Eger, 1987). The primary aims of computerization in these papers are to meet the requirements of research, teaching, and museum display activities and to aid in collection management.

The Department of Mammalogy, at the Royal Ontario Museum (ROM) required a system to facilitate managing a large collection (approximately 100,000 specimens) with an acquisition volume of about 1,300 specimens annually (average of last six years). Centralizing location and status information was necessary to prevent specimens from "falling between the cracks" between time of acquisition and installation. When an inconsistency in information arose it needed to be sorted out readily. Standardizing the information collected and its format would serve to establish good documentation practices.

This paper reports how an Accession Database, housed on a microcomputer, can be used to track the processing status and location of specimens from the time they are first acquired to the time of their final installation into the collection. The database also houses all documentation for singly acquired specimens. Because data for these single specimens need only be entered once, creation of the Accession Database improves documentation efficiency. This database serves to integrate specimen documentation, processing, and data automation activities for the entire department.

AUTOMATING THE ACCESSION BOOK

The flow of processing specimens in Mammalogy is illustrated in Figure 1. In the past, a series of handwritten accession books (designated by use of lower case) have listed all specimens acquired and accessioned within the department. These documents are sometimes referred to as acquisition or catalogue ledgers. Each mammal specimen receives an individual accession number. The original field data for specimens acquired singly are found in an accession book. Often no

MAIN STAGE IN PROCESSING	STEP IN PROCESSING	STATUS
LAB	Accession specimens received by department	PREParation
	. . .	
	Lab preparation of specimens	
	. . .	
HOLDUP	Temporary storage in Holdup section of collection	VERIfy
	. . .	
CURATION	Curation of specimens	
	. . .	
DATABASE MANAGEMENT	Enter specimen data into Departmental Database	INPUT or TRANSfer
	. . .	
	Production of specimen cards and labels	C&L for "Cards and Labels"
	. . .	
	Tying labels onto specimens	INSTall
	. . .	
	Installation of prepared or conserved/repaired specimens into collection, and filing specimen cards when necessary	
	. . .	
	Convert and upload specimen data from Departmental Database to the CHIN Database	COMPleted
	. . .	
	Completed preparation and documentation	

Figure 1. Main states and steps of processing specimens, and commonly used Status codes associated with the processing steps (Department of Mammalogy, ROM).

information other than that in an accession book is associated with single specimens. The original field data for collections of specimens are documented on field catalogues, standardized data sheets used in the field to document the biological information, locality, and other data for individual specimens within a series from a collecting trip or a specific collector. In the accession book, a general description is used to identify the contents of a collection for collection management purposes (e.g., "Small mammals," rather than biological nomenclature of each species).

Processing specimens in-house, after having documented accession book information has not changed since having begun automation with personal computers in 1984 (Woodward and Eger, 1987). Once specimens have been prepared and curated, data for specimens are entered in the Departmental Database (Fig. 1). The in-house PC system permits editing and production of cards and labels on site. Once the specimens have been installed into the collection, the Departmental Database data are converted and uploaded to the CHIN (Canadian Heritage Information Network) Database. The CHIN Database (begun in 1987) is housed on a mainframe system with software that has powerful retrieval, global editing, and report generation capabilities.

Handwritten accession books exist for all specimens accessioned in the department prior to June 1984. It is not likely that these records will ever be automated. All records since that date, until recently, had been entered on the computer using a word processing package (Word Perfect 4.2). The intent of automating the word processing version of the accession book to a database management package (dBase III +) is to:

1) Encourage complete and consistent data gathering at the time of acquisition of specimens by standardizing the data entered and its format, and by documenting the system.
2) Provide a check to ensure that missing data are acquired within a reasonable time by the individual who accepted the specimen.
3) Facilitate tracking the status and location of specimens within the department from the time they are accepted to the time they are installed into the collection.
4) End the necessity to re-enter data from an accession book to the Departmental Database for single specimen records.
5) Diminish the number of printouts required when accession information is updated. The Accession Book contains relevant accession documentation only. Specialized printouts contain temporal tracking and status information.
6) Provide staff with the specific information necessary for them to improve job efficiency by minimizing the time and effort spent on organizational and documentational tasks pertaining to specimen preparation, conservation, and curation. Specialized print-outs contain only the sorted information necessary to perform the required tasks at a particular stage in the processing of specimens.
7) Permit flexible and reliable sorting, searching, and retrieval of accession information necessary since data are entered in fields in a predictable and retrievable way.
8) Permit computer generation of field catalogues for singly acquired specimens from frequent contributors to the collection (e.g., zoos, game farms, wildlife branches of governments, etc.).
9) Facilitate tallying collection statistics, e.g., annual acquisitions or characteristics of subsets of the accessions (e.g., specimen nature, taxa, or locality).
10) Insure against the destruction of valuable accession information. Back-ups of the database are kept on site and off site to avoid loss resulting from disasters.

Processing Specimens and the Status Field

Appendix 1 lists and defines the fields in the Accession Database and indicates how they are used. Subsets of these fifty fields are used to generate the specific listings that address the documentation and tracking needs at functional stages in the processing of specimens prior to installation into the collection.

There are four main stages in processing specimens described here as Lab, Holdup, Curation, and Database Management Activities (Fig. 1 and Appendix 1). The progress of a specimen through the processing stages is indicated by a code in the status field of the Accession Database. Less commonly used status codes are described later in the text. It is the contents of the status field that permits specialized listings to be generated for documentation and tracking purposes at the necessary processing stages. This field's contents are also used to determine the information to be printed in the Accession Book.

Lab Activities

Upon accessing a specimen or collection an Accession Form (Fig. 2) is filled out manually in the preparation lab and filed in an accession binder. Temporal fields are entered in pencil to permit easy revision by lab personnel as processing progresses. Noting changes on the Accession Form saves the extra steps of making individual change sheets and bringing the change sheets to the Database Manager for updating the Accession Database, as occurred in the past. The most current lab and specimen information between database updates resides in the lab, on the Accession Forms.

The Accession Database records are updated monthly from the Accession Forms to lessen the likelihood of accidental loss of information. A paper clip is affixed to the top left corner of the relevant Accession Form whenever a change is made on it. These changes may include a change in location, an addition to the data (e.g., measurement or breeding data), or an entry of a new accession. The paper clip indicates that a database update is necessary; it acts as a flag to the Database Manager who updates the database monthly.

When transferring a newly accessed specimen or collection, part of a specimen or collection, or the final material from a collection to holdup, a Transfer Form (Fig. 3) is completed by lab personnel. The information on the Transfer Form permits the personnel managing holdup to manually append the holdup listing, when necessary, and to locate the proper place to house material received from the lab.

Holdup Activities

When specimens from a collection are brought to holdup from the lab, three fields have a "Y" entered on the holdup listing (Fig. 4) to denote that at least *some* of the specimens of a particular collection have been prepared and reside in holdup. These three fields are COLLSN for presence of skins in collection holdup, COLLSL for presence of skulls and/or skeletons in collection holdup, and COLLALC for presence of alcoholic material in collection holdup. On the holdup listing (Fig. 4), these three fields are titled as "SN" for skin, "SK/SL" for skull/skeleton, and "ALC" for alcoholic, respectively, for simplicity sake. COLLLOCATN specifies the location in which specimens are housed in holdup. The lo-

ACCESS NO _____ DATE ACCESSED _____

ADDED / DONATION / EXCHANGE / PURCHASE / STAFF / STAFF-MAMM

QUANTITY ____ IDENTIFICATION _____

COMMON NAME _____

COUNTRY/PROVINCE/COUNTY _____

LOCALITY _____

_____

LAT _____ LONG _____ LOCACC ____ ELEVATION _____

HABITAT _____

SPEC NATURE _____ SEX ___ AGE _____

TL	TV	HF	EAR	TRAGUS	FA	WT
_____	_____	_____	_____	_____	_____	_____

BREEDING DATA _____

COLLECTOR(S) _____

COLL DATE _____ DIED DATE _____

EXTRA INFO _____

_____

_____

_____

_____

LOCATION WITHIN DEPARTMENT, DOCUMENTATION, AND STATUS

IN LAB:

WALK IN	BUG ROOM	CABINET
_____	Y	_____

OTHER LOCATIONS OF SKIN / SKULL / SKELETON

_____

IN COLLECTION: SN ____ SK/SL ____ ALC ____ LOCATION _____

CATALOGUE: Y / N PERMIT: Y / N ACCEPTED BY: _____

STATUS: PREP / VERI / INST / LOST / DISC

Figure 2. Accession Form.

```
==========================================================
ACCESSION NOS: _____

COLLECTOR: _____

CATALOGUE:      Y  /  N      STATUS:  PREP  /  VERI  /  INST

NOTES: _____

       _____

==========================================================
```

Figure 3. Transfer Form.

cation designated may be one or more cabinet numbers, the code "TC" for teaching collection, or the term "INSTALLED" for installed into the collection. All alcoholic material is housed in a single room on a labelled, open shelving unit that makes locating material simple, thus location data are not necessary.

Frequently the skins are brought to holdup prior to completion of associated skeletal material. Also, small batches of specimens from a collection are often completed at one time. The status field remains as "PREParation" until all specimen material within a collection is completed. Upon receipt of a completed series of specimens from the lab the Transfer Form (Fig. 3) will indicate the change in status. The status on the holdup listing is changed to "VERIfy." This indicates that the entire collection is in holdup. At this time the remaining specimens enter holdup and any field catalogue and associated information is transferred from the lab to the field catalogue file.

A Holdup Form is used to enter the relevant data for new material acquired between database updates that do not appear on the holdup listing. The form's format mirrors that of the holdup listing (Fig. 4) with columns of underlined blank spaces to facilitate filling out the form. When a new specimen or collection is brought to enter holdup it is documented on the Holdup Form.

Curation Activities

A curation listing (Fig. 5) of specimens with the status of "VERIfy" permits tracking the progress of assignments given to curatorial staff. Unique letters after VERI indicate who has been assigned the task of "verification" for a particular specimen or collection, e.g., VERI S, where "S" stands for Susan. A code missing the unique letters signals that no one has been assigned to perform the necessary curation activities.

During the process of verification a specimen or collection has to have individual specimens identified and aged (Woodward, 1989a); all data should be reviewed for obvious errors, and co-ordinates and location accuracy codes need to be assigned to the locality data. The staff member doing the work reports completion to the Database Manager. When only coordinates and location accuracy codes are required for a collection the status becomes, "COORDinates required."

Database Management Activities

The Database Manager maintains the Accession Database, and prints and distributes the necessary updated lists to staff. The remaining steps in processing specimens and their associated data are also carried out by or supervised by the

ACCESS NO.	COLLECTOR	CAT.	STATUS	SN	SK/SL	ALC	COLL'N LOCATION
99202 - 99211	BURBANK, BONNIE ET AL	Y	PREP	Y	Y		187B
99106 - 99165	OMNR	Y	VERI S	Y	Y		123A-128B
99201	PETERSON, RL	N	VERI	Y	Y		189A
88088*	SCHIES, YVONNE DR	N	PREP				INSTALLED
99168 - 99174	SEYMOUR, KEVIN	Y	PREP			Y	

Figure 4. Holdup Listing.

Database Manager. Once curation is completed, the status code is changed to "INPUT from field catalogue" or "TRANSfer data" (Fig. 1). Data for collections with a status code of "INPUT from field catalogue" are input manually onto the Departmental Database from field catalogues. When the status code is "TRANSfer data," a single specimen's data are ready to be transferred from the Accession Database directly to the in-house Departmental Database by using the dBase "Append" command. With a minimal amount of editing by the Database Manager, the data meet the format requirements of the Departmental Database. The fields in the Accession Database that are read directly to the Departmental Database include information pertaining to a museum specimen that is most often associated with a specimen when acquired. Other less frequently associated data for which Departmental Database fields exist (e.g., type, colour, and parasites) are entered in one of the extra information fields of the Accession Database. These data are easily transferred to the appropriate field in the Departmental Database using cursor editing.

If cards and labels are not going to be produced within a reasonable length of time the status code becomes "C&L," for "cards and labels," until these hard copy products can be produced. Once cards and labels have been produced the status code is changed to "INSTall" until labels have been tied onto specimens and the specimens are installed into the main collection. After installing specimens, filing specimen cards, and uploading data to CHIN are completed, the status code is changed to "COMPleted."

There are some specimens for which cards and labels have been produced and skeletal material for those specimens has been installed into the main collection. The skins however are being tanned. The status code for these specimens is "~COMP," for "almost COMPleted." Once the skin is installed into the collection the status code is changed to "COMPleted." The status code for a collection for which a portion of the specimens have been completely processed is "PART of

Record#	ACCNO	ACCNOEND	COLLECTOR	SPECNAT	STATUS
2	99106	99165	OMNR	CARCASSES; SL	VERI S
8	99201		PETERSON, RL	SSS-TAN	VERI

Figure 6. Database Management Listing.

ACCESS NO.	COLLECTOR/IDENTIFICATION	STATUS	COORD	ENTER	C&L	INST	COMP	OTHER
99106 - 99165	OMNR MARTES AMERICANA	VERI S	___	___	___	___	___	___
99201	PETERSON, RL VULPES VULPES	VERI	___	___	___	___	___	___

Figure 5. Curation Listing.

collection completed." Once the remaining specimens are completed the status code is changed to "COMPleted."

All database and installation related activities are tracked using the Database Management listing (Fig. 6). This listing permits documentation of all potential status codes (i.e., processing steps) that occur once specimens have entered holdup, with a status code of "VERIfication." Changes in status noted on this listing are used to update the Accession Database.

The Accession Book

If the status of a specimen is "COMP," the term "Complete" is printed with the accession record in the Accession Book (Fig. 7). Discarded material, lost material, and partly completed single specimens and collections are also indicated as such. Otherwise, status information is not printed in the Accession Book due to its temporal nature.

The Accession Database

The Accession Database replaces the handwritten accession books to document accessioned specimens and permit the location and status of specimens undergoing preparation to be tracked in a standardized and centralized manner. The information routinely captured on the Accession Database is listed on the Accession Form (Fig. 2). Appendix 1 lists and defines the fields in the Accession Database and indicates at what processing stages they are used. To prepare specimens for installation into the collection, they must pass through the steps of lab preparation (L), holdup storage (H), curation (C), and data entry (DD). Figure 8 illustrates the flow of documentation, specimens, and tracking data in Mammalogy (ROM); this shows the different databases and the specialized program-generated listings used.

There are fifty fields of data in the Accession Database. The biological data for single specimens are directly transferred from the Accession Database to the Departmental Database. The Departmental Database is transitory in nature but permits in-house cursor editing and generation of hardcopy products needed to document specimens. The CHIN Database is the mainframe repository of all records input on the Departmental Database PC system.

There are three fields listed in Appendix 1 that are specific to accession documentation (AD only): ACCESSDATE (accession date), METHOD (method of acquisition), and QUANTITY (quantity of specimens in acquisition). Some data specific to accession documentation appear in the EXTRAINFO (extra information) fields also. Examples of these type of data are the address of the collector and the method of capture. These data appear in the Accession Book printout (Fig. 7) but are edited out after data are transferred to the Departmental Database (DD).

```
99166              NO CATALOGUE; NO PERMIT       LOST              ACCESS DATE:  1 JUN 1989        RECORD NUMBER:  3
------                 1 TAMIASCIURUS HUDSONIUS          --                     SS                PURCHASE
LOCALITY:  CANADA  NEWFOUNDLAND
           TWIN FALLS, LABRADOR

TL      TV      HF     EAR  TRA    FA      WT       SEX  AGE                BREEDING
305     100     37     15                 110      F
COLLECTOR:  BYERS, SHEILA                                                 COLLDATE: 19700904
EXTRAINFO:


99167              CATALOGUE; NO PERMIT          PART COMPLETE     ACCESS DATE:  6 JUN 1989        RECORD NUMBER:  4
------                 1 MACROPUS RUFOGRISEUS BENNETTI      -RED-NECKED WALLABY-     SSS-TAN           DONATION
LOCALITY:                                                                                             FN = PM7766
           CAPTIVE

TL      TV      HF     EAR  TRA    FA      WT       SEX  AGE                BREEDING
1425    585     225    90                 13950    F    A; 7 YEARS 1 MONTH
COLLECTOR:  METRO TORONTO ZOO                                                                 DIEDDATE:  19890603
EXTRAINFO:  ZOO BORN, TORONTO, 13820430; PERITONITIS, INTESTINAL PERFORATION, RENAL KLOSSIELLA;
            TEACHING COLLECTION

99168 - 99174      CATALOGUE; PERMIT                                ACCESS DATE:  0 JUN 1989        RECORD NUMBER:  5
---------------        7 -BATS-                                                  SSS; ALC          ADDED
LOCALITY:  JAMAICA
           ST CLAIR CAVE

COLLECTOR:  SEYMOUR, KEVIN
EXTRAINFO:  SEE 99689-100104



99175              CATALOGUE; NO PERMIT          DISCARDED         ACCESS DATE:  20 JAN 1989       RECORD NUMBER:  6
------                 1 CANIS LUPUS                        -ARCTIC WOLF-          --                DONATION
LOCALITY:                                                                                             FN = PM7799
           CAPTIVE

TL      TV      HF     EAR  TRA    FA      WT       SEX  AGE                BREEDING
                                               28800    F    A; 10 YEARS 8 MONTHS
COLLECTOR:  METRO TORONTO ZOO                                             COLLDATE: 19890120      DIEDDATE:  19890115
EXTRAINFO:  ZOO BORN, TORONTO, 19790528; INTESTINAL OBSTRUCTION


99176 - 99200      CATALOGUE; NO PERMIT          COMPLETE          ACCESS DATE:  20 JAN 1989       RECORD NUMBER:  7
---------------        25 -BATS-                                                 SSS; ALC; OTHER   STAFF
LOCALITY:
           PUERTO RICO; US VIRGIN ISLANDS

COLLECTOR:  WADDINGTON, JANET                                             COLLDATE: 1989NOVDEC
EXTRAINFO:



99201              NO CATALOGUE; NO PERMIT                         ACCESS DATE:  20 JAN 1989       RECORD NUMBER:  8
------                 1 VULPES VULPES                   --                     SSS-TAN           STAFF-MAMM
LOCALITY:  CAN  ONTARIO  WELLINGTON
           BOREAL FARMS, RR 1, ERAMOSA TWP

TL      TV      HF     EAR  TRA    FA      WT       SEX  AGE                BREEDING
889     315     150    90                 3200     F    J
COLLECTOR:  PETERSON, RL                                                  COLLDATE: 19890120      DIEDDATE:  19891020
EXTRAINFO:


99202 - 99211      CATALOGUE; NO PERMIT                            ACCESS DATE:  6 JUN 1989        RECORD NUMBER:  9
---------------        110 DICROSTONYX TORQUATUS         --                     SSS               DONATION
LOCALITY:
           CAPTIVE; LAB STOCK; FROM PEARCE POINT, NWT

COLLECTOR:  BURBANK, RONNIE; DICROSTONYX COLLECTION
EXTRAINFO:  ADDRESS:  UNIV OF TORONTO, ERINDALE
```

Figure 7. Accession Book printout.

Appendix 1 lists the 16 fields that are used for accessioning and tracking purposes. These fields are not transferred to the Departmental Database (marked as AD and/or T but not DD). Thirty-four fields in the Accession Database are transferred directly to the Departmental Database (DD) for single specimens. These are primarily collection and biological fields.

The data captured in location fields for lab and holdup activities include type of material (Woodward, 1989b), cabinet designation, and shelf designation, where applicable. The eleven fields in the Accession Database that are required for lab or preparation and conservation activities (L) are listed and defined in Appendix 1. No specialized listing is required in the lab since the Accession Forms contain all of the information required for tracking processing at the lab stage.

Nine fields most useful for holdup activities (marked "H" in Appendix 1) are used to generate a "holdup listing" (Fig. 4). This listing is sorted by collector rather than accession number, as all other listings are, since the contents of holdup cabinets and collection catalogues traditionally have been organized by collector in the ROM Mammalogy Department. Accession number series is listed to uniquely identify each collection in holdup. Updated data are manually noted on the holdup listing. The listing is used by the Database Manager to update the Accession Database fields concerning holdup specimens and their location(s).

A "curation listing" of collections requiring curation is generated using the "List" command in dBase (Fig. 5). Ten fields (marked "C" in Appendix 1) are used to generate this listing. The listing includes only specimens or collections with the relevant status code (i.e., STATUS>="VERI").

A "database management listing" identifies all collections that are in the process of being documented on the Departmental Database or will be ready to be documented once "VERIfication" is completed (Fig. 6). Seven fields (ACCNO and ACCNOEND, listing the accession number series of the collection, COLLECTOR, GENUS, SPECIES, COMMONNAME, and STATUS) are used to generate this listing. Changes in status of a particular single specimen or collection of specimens are marked on the blank in the appropriate status code column.

A generalized "tracking listing" of all collections that are being processed somewhere in the department is the final program-generated listing (Fig. 9). Seventeen fields (marked "T" in Appendix 1) are used to generate the listing. This summary listing has the specific data from the desired fields converted to generalized forms to produce an easily readable synopsis. For example, the data for the LABWALKIN (lab walkin freezer location) field would include the shelf number and possibly the type of material, yet on the tracking listing only "FRE" (for freezer) appears. At a quick glance one can see that at least some material from an specimen or collection is in the freezer. Similarly, a "Y" in the COLLSN (presence of skins in collection) field is translated to "SN" (for skin) on the listing. By the presence or absence of data in other fields, one can determine if some or all of the material for a specimen or collection is in one place.

General Information

The Accession Book is presently reprinted twice a year. Changes and additions resulting from lab preparation include such things as external measurements and breeding data. Any information changes other than those involving tracking and lab preparation are made on the centrally located copy of the Accession Book.

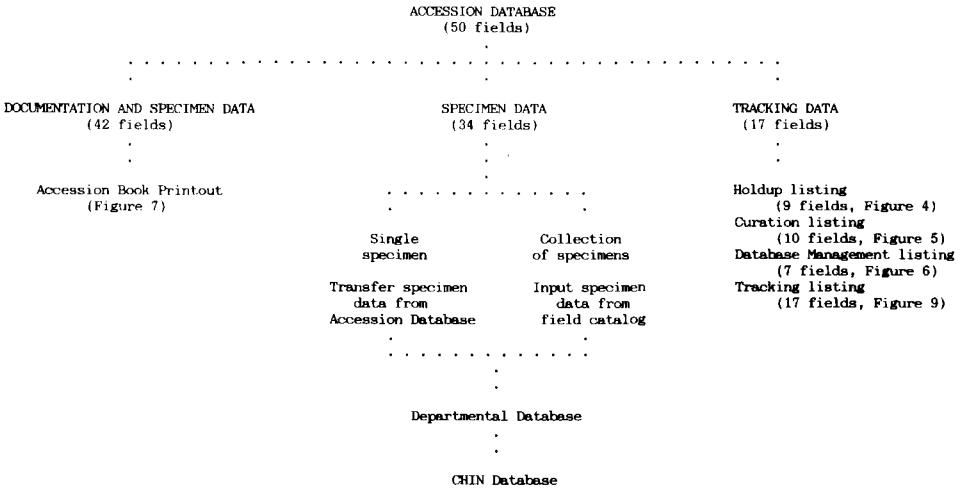

Figure 8. Flow of documentation, specimen, and tracking data (Department of Mammalogy, ROM).

Changes are initialed so that any subsequent queries may be addressed to the individual who made the change. Any edited pages are paper clipped to alert the Database Manager to update the database accordingly.

All collections undergoing work in the lab have an Accession Form filled out. Specimens that return to the lab for conservation purposes also have their location tracked by this computer system. Accessions like this have the ACCNO (accession number, beginning of series) field flagged with an asterisk (*) to denote the full accession information for the material is documented in a handwritten accession book. When conservation is completed and the specimen is returned to the main collection, the database record is simply deleted from the Accession Database because full accession information is documented elsewhere. When specimens are to return to the collection the Status code becomes "INSTall," rather then "VER-Ify," which indicates specimens are to go to holdup. Thus, the Accession Form

ACCESS NO.	COLLECTOR/IDENTIFICATION	STATUS	FREEZER/BUGROOM/CABINET/OTHER	HOLDUP MATERIAL & LOCATION	
88088*	SCHIES, YVONNE DR NYCTEREUTES PROCYONOIDES	PREP	SN-TANNERY		INSTALLED
99106 - 99165	OMNR MARTES AMERICANA	VERI S		SN,SL,	123A-128B
99166	BYERS, SHEILA TAMIASCIURUS HUDSONIUS	LOST			
99167	METRO TORONTO ZOO MACROPUS RUFOGRISEUS	COMP'	FRE,	SN,	188B
99168 - 99174	SEYMOUR, KEVIN -BATS-	PREP	BUG,CAB,	ALC,	
99201	PETERSON, RL VULPES VULPES	VERI		SN,SL,	189A
99202 - 99211	BURBANK, RONNIE ET AL DICROSTONYX TORQUATUS	PREP	FRE,BUG,CAB,TAXIDERMY	SN,SL,	187B

Figure 9. Tracking Listing.

binder in the lab has the most up to date information about the location of specimens in the lab.

After updating, any Accession Form that has a status of "PREParation" will remain in the lab binder. Any Accession Forms with the status of "VERIfy" or "INSTall" are archived for use in sorting out problems, should they arise. The archival Accession Forms are filed by accession number.

Revised copies of the holdup listing, curation listing, database management listing, and tracking listing are produced after each monthly update. Completed, discarded, or lost specimens or collections do not appear on these listings.

The Database Manager has the master copy of the Accession Database stored on hard disk. An off site backup of the Accession Database is also housed on a hard disk and on floppy diskette. A current copy of the Accession Database is housed on hard disk on a computer accessible by all departmental members.

Discussion

As we proceed through the "Information Age," it becomes more and more important to automate the wealth of information that we all possess, to facilitate its dispersal amongst interested users (Naisbitt, 1982). Museum collections are invaluable sources of information, particularly as biological populations dwindle and financial and political considerations make it impossible to replace existing specimens (Raven, 1988). The trend to automate information for specimens housed in museums exemplifies this need for a process to facilitate dissemination of information.

Libraries commonly subscribe to integrated library automation systems to capture existing publisher and library information about books that have been ordered and in turn provide information to the system about previously unrecorded documents acquired by the subscribing library. ATLAS, BASIS, BLIS, and SIMS name just a few of these systems available (Merilles, 1989; Powell and Slach, 1985). These systems provide libraries with more accessibility to information via terminals, with good retrieval capabilities, and with improved inventory control.

On a much smaller scale, integrated systems like the one presented in this paper serve to optimize the data gathered pertaining to specimens and to facilitate the speedy and complete preparation and documentation of specimens. This in turn helps the information to become available to consumers (including researchers, students, and the public) more readily. Furthermore, the use of single copy, handwritten ledgers that are difficult and/or costly to "back up" should be discouraged today as the information value, if not monetary value, of museum specimens increases.

The Accession Database presented here centralizes the information that until recently has been kept in a variety of locations within the department. The fields used directly address the information needs of the Departmental Database and the staff of the department. The content and format of all accession documentation (AD) and tracking (T) fields was developed after individual consultation with the personnel who actually do the work and use the information.

Data capture is facilitated by standardizing information. Accession Forms mirror the Accession Database contents and serve to cue lab personnel to enter the necessary data. Accession Book print-outs are standardized, facilitating visual scanning when searching for specific information. Standardized print-outs also

serve to familiarize users with proper terminology and format used in the database. Searches on subsets of the database are also facilitated since standard data should be captured for each record and usually only a single field need be searched to locate a specific record.

It is the status field that integrates this Accession Database system with all activities associated with specimen preparation, curation, and documentation within the department. Status codes should suit the processing system for which they apply. They should be intuitively obvious so that they are easily understood by users and do not have to be translated on print-outs generated by programs.

The entire system is fully documented in an Accession Database Manual (available from the author) to ensure that all staff in the department are aware of the system and how it works. The document also serves to orient new employees about the activities occurring within the department. The manual clearly documents the progression of a specimen through the stages from acquisition to installation into the main collection. Each field is documented by defining it, describing its format, and indicating the type of data to be entered in the field. Examples are used to illustrate acceptable types of field contents.

This system allows data for single specimens to be uploaded directly from the Accession Database to the Departmental Database once the specimens are prepared and curated. Duplication of data entry for single specimens and its inherent cost in time and introduced errors is avoided. Data transferred from the Accession Database to the Departmental Database are edited to meet the requirements of format and information content. Cursor-editing on the microcomputer permits these changes to be made quickly.

A further application for this Accession Database is to generate field catalogues for single specimens received frequently from a single collector. The Mammalogy Department, receives many specimens from the Metropolitan Toronto Zoo. In the past, a separate field catalogue was prepared by hand documenting newly acquired specimens. This field catalogue is now generated from the Accession Database, removing another redundant, manual, time-consuming task.

A preliminary response to the system from lab personnel (J. Borack, personal communication) is that it seems as if much more time is spent at documentation with the system reported here. Upon further discussion however, it has become apparent that all the documentation activities are now focused. Instead of a number of separate (and often redundant) systems to keep track of specimen location, all information is recorded on the relevant Accession Form. As it should, documentation funnels through the lab where the collector brings the specimen(s) initially and where most preparation and biological documentation occur. When asked, no type of information kept in the Accession Database could be identified that was not useful. A better way to keep track of the specimens (numbering in the hundreds at any one time) and their respective parts undergoing a whole host of processing and conservation treatments in various locations within the lab could not be suggested.

Personnel working in the collection area of the department (W. Hlywka and L. Lortie, personal communication) find that the system is easy to use. It also helps formalize collection policy by setting standard procedures to follow when accepting specimens. They find that they now know where everything is located. Because more information is available for holdup activities (i.e., accession number series),

confusion between different collections with the same collector name is eliminated. Many institutions use a unique number to identify each acquisition. At the ROM collections have traditionally been identified by collector name and area collected or season and/or year collected.

From a supervisory standpoint (J. L. Eger, personal communication), the Accession Database acts as a useful summary of ongoing activities within the department and helps to pinpoint collections that need attention. This, in turn, facilitates assigning tasks to individuals. The curation and tracking listings make it easy to note assignments on the listings and follow up on progress routinely.

It was pointed out (J. Borack, personal communication) that the loss of a staff member and the subsequent reassignment of the responsibilities of maintaining the accession book, and documentation, identification, and automation of data of single specimens to the author presented an opportunity for changing the previous system. Having developed the Departmental Database and having a programming knowledge in dBase III+, an opportunity to integrate the whole collection procedure for the department presented itself. As Database Manager, it is found that by using the Accession Database, data entry for the Accession Book is much easier. Furthermore, it is easier to spot incomplete records because data entry is standardized and has become routinized. As the author was the person who finally had to deal with incomplete data for records, a system that encouraged complete data gathering was deemed necessary. Finally, data do not need to be entered a second time when the documentation is ready for entry to the Departmental Database.

Smaller museums or disciplinary collections may not need such a complex system. In fact, it may be easier to track the status and location of specimens/artifacts manually for smaller collections where only a few staff are involved in preparation, conservation, curation, and database management activities. However, the intent of automating and integrating the documentation process is just as relevant to a small collection, as a large collection. The quantity of specimens/artifacts should not deleteriously affect or preclude quality!

At present, this system is not fully automated because of the physically detached locations of the lab and the collection, an absence of a departmental computer network, and various personnel's present unfamiliarity with the operation of computers. In the future it would be profitable to automate the lab activities and eliminate the need for the Accession Form. It is not likely the holdup operation will be automated, for a communication link with the lab would be necessary to permit the use of a single copy of the Accession Database. Because of the physical separation of the lab and the collection, and differing personnel performing lab and holdup activities the Transfer Form will probably always exist. The amount of manual documentation done at the holdup stage probably does not warrant the expenditure to obtain the computer linkage. Furthermore, the manual holdup records act as a "check" on the location data documented in the lab. This check draws attention to and permits solving discrepancies in status and location documentation within a month of them having occurred. It also precludes the need of an audit trail of location data. Furthermore, in this system, an audit trail would simply take up space documenting steps that are obvious given the current status.

The system presented here attempts to optimize manpower productivity and integrate accession documentation with specimen documentation. With the power

of microcomputer technology and programming knowledge, automated systems are an obvious route to take to organize record keeping, and permit specimen tracking and data transfer. It is also becoming a necessity to perform collection management tasks in a cost effective manner with today's restrictions in budgets and personnel.

Note.—For information on how to obtain a copy of the database structure, all of the associated programs, and documentation of the system described here, please contact the author.

ACKNOWLEDGMENTS

I would like to dedicate this paper to the late R. L. Peterson who gave me my start in museum work in mammalogy and microcomputers. I appreciate his encouragement of independent thought and constructive change in documentation practice.

I would like to thank R. Burbank, S. Byers, K. Rumbold, Y. Schiks, K. L. Seymour, and J. Waddington for constructive criticism of this paper. The members of the Mammalogy Department at the ROM are also to be thanked for their helpful suggestions and appraisals of the system presented here. Finally, I thank John Simmons, Associate Editor, *Collection Forum,* and three anonymous reviewers for their critiques.

LITERATURE CITED

Folse, L. J., P. S. Cato, and D. J. Schmidly. 1987. Hybrid computer system at Texas A&M University. Pp. 135–143 in *Mammal Collection Management* (H. H. Genoways, C. Jones, and O. L. Rossolimo, eds.). Texas Tech University Press, Lubbock, iv + 219 pp.

Holm, E. 1986. Records management in the Department of Ichthyology and Herpetology, Royal Ontario Museum. Pp. 55–61 in *Proceedings of the 1985 Workshop on the Care and Maintenance of Natural History Collections* (J. Waddington and D. Rudkin, eds.). Royal Ontario Museum Miscellaneous Publication, Toronto, 121 pp.

McLaren, S. B., H. H. Genoways, and D. A. Schlitter. 1987. The computer as a collection management tool. Pp. 97–110 in *Mammal Collection Management* (H. H. Genoways, C. Jones, and O. L. Rossolimo, eds.). Texas Tech University Press, Lubbock, iv + 219 pp.

Merilles, B. 1989. Canadian library integrated systems: Third annual survey. Canadian Library Journal, 46:181–187.

Naisbitt, J. 1982. *Megatrends: Ten New Directions Transforming Our Lives.* Warner Books, Inc., New York, 290 pp.

Powell, J. R., and Slach, J. E. 1985. How to evaluate integrated library automation systems. Online, March:30–36.

Raven, P. 1988. Keynote address *at* 1988 Annual Meeting of The Society for the Preservation of Natural History Collections. Pittsburg, 30 May–03 June. Note appearing in The Association of Systematic Collections Newsletter, 16(4):3.

Seymour, K. L. 1986. Standardization and indexing of terminology for vertebrate fossils on the CHIN PARIS cataloguing system. Pp. 63–68 in *Proceedings of the 1985 Workshop on the Care and Maintenance of Natural History Collections* (J. Waddington and D. Rudkin, eds.). Royal Ontario Museum Miscellaneous Publication, Toronto, 121 pp.

———. 1988. Computerized specimen and preparation/conservation worksheets for fossil vertebrates. Collection Forum, 4(2):46–50.

Woodward, S. M. 1989a. Collection automation: Tailoring database and collection management to suit a natural history collection. Collection Forum, 5(2):60–72.

———. 1989b. A coding system for mammal collections: Mixing documentation needs, tradition, and computers. Collection Forum, 5(2):73–78.

Woodward, S. M., and J. L. Eger. 1987. Microcomputer system at Royal Ontario Museum. Pp. 129–133 in *Mammal Collection Management* (H. H. Genoways, C. Jones, and O. L. Rossolimo, eds.). Texas Tech University Press, Lubbock, iv + 219 pp.

Appendix 1. Fields in the Accession Database, their uses and definitions. (Abbreviations for uses are: AD = Accession Documentation, L = Lab, H = Holdup, C = Curation, T = Tracking, DD = Departmental Database.)

Field name	Uses						Definition
	AD	L	H	C	T	DD	
ACCEPTEDBY	AD	L	·	·	·	·	—who accepted the material for accessioning. This person is responsible for ensuring documentation is complete.
ACCESSDATE	AD	·	·	·	·	·	—date the material was accessed
ACCNO	AD	L	H	C	T	DD	—the accession number of a specimen or the beginning accession number in a collection series. Those specimens for which full accession information appears in a handwritten Accession Book, have an asterisk (*) entered after the beginning accession number to flag the specimen or collection.
ACCNOEND	AD	L	H	C	T	·	—the last accession number in a collection series. This must be kept separate from the beginning accession number for sorting purposes.
AGE	AD	·	·	·	·	DD	—age
BREEDING1	AD	·	·	·	·	DD	—breeding data
CATALOGUE	AD	L	H	C	T	·	—presence or absence of a field catalogue
COLLALC	·	·	H	C	T	·	—indicates specimens are in alcoholic holdup
COLLDATE	AD	·	·	·	·	DD	—date a specimen is collected or range of dates over which a collection is collected
COLLECTOR	AD	·	H	·	T	DD	—names of collector(s) of a specimen or collection of specimens
COLLNO	AD	·	·	·	·	DD	—collection number or field number of a specimen. This is not entered for a collection of specimens.
COLLSL	·	·	H	C	T	·	—indicates skeletal material is in the collection holdup
COLLSN	·	·	H	C	T	·	—indicates skins are in the collection holdup
COLLLOCATN	·	·	H	C	T	·	—denotes the location within the research collection or teaching collection of holdup skin and skeletal material
COMMONNAME	AD	L	·	·	T	·	—common name of a collection of specimens when it is a mixture of taxa, e.g., "BATS, RODENTS"
COUNTRY	AD	·	·	·	·	DD	—country of origin
COUNTY	AD	·	·	·	·	DD	—county of origin
DIEDDATE	AD	·	·	·	·	DD	—date of death
EAR	AD	·	·	·	·	DD	—ear length
ELEVATION	AD	·	·	·	·	DD	—elevation at which collected

Appendix 1. Continued.

Field name	Uses						Definition
	AD	L	H	C	T	DD	
EXTRAINFO1	AD	·	·	·	·	DD	
EXTRAINFO2	AD	·	·	·	·	DD	
EXTRAINFO3	AD	·	·	·	·	DD	
EXTRAINFO4	AD	·	·	·	·	DD	—extra information that does not have a uniquely defined field yet is necessary to capture, as accession or specimen information. There are four of these fields, defined to sizes that are easily printed on the screen and hardcopy products.
FOREARM	AD	·	·	·	·	DD	—forearm length
GENUS	AD	L	·	·	T	DD	—genus
HABITAT1	AD	·	·	·	·	DD	—habitat
HINDFOOT	AD	·	·	·	·	DD	—hindfoot length
LABBUGROOM	·	L	·	·	T	·	—presence of material in the bugroom
LABCABINET	·	L	·	·	T	·	—cabinet location of material in the lab
LABOTHER	·	L	·	·	T	·	—other locations material may be found when it is undergoing preparation or conservation
LABWALKIN	·	L	·	·	T	·	—where material may be found within the walkin freezer
LATITUDE	AD	·	·	·	·	DD	—latitude
LENGTH	AD	·	·	·	·	DD	—total length
LOCACC	AD	·	·	·	·	DD	—location accuracy of coordinates
LOCDESC1	AD	·	·	·	·	DD	—locality description
LOCDESC2	AD	·	·	·	·	DD	
LONGITUDE	AD	·	·	·	·	DD	—longitude
METHOD	AD	·	·	·	·	·	—the method of acquisition of material. Possible terms are ADDED, DONATION, EXCHANGE, PURCHASE, STAFF, STAFF-MAMM.
PERMIT	AD	·	·	·	·	DD	—the presence or absence of a collecting permit on file
PROVINCE	AD	·	·	·	·	DD	—province
QUANTITY	AD	·	·	·	·	·	—the number of specimens in an accession entry. This field is numeric so that dBase may be used to count acquired specimens fitting defined parameters of other fields, e.g., count of all the specimens collected in 1989.
SEX	AD	·	·	·	·	DD	—sex
SPECIES	AD	·	·	C	T	DD	—species
SPECNAT	AD	·	·	C	T	DD	—nature of specimens in collection (See Woodward 1989b for description of coding system used.)
STATUS	AD	L	H	C	T	·	—status of the specimen in the processing system
SUBSPECIES	AD	·	·	·	·	DD	—subspecies, if given
TAIL	AD	·	·	·	·	DD	—tail length
TRAGUS	AD	·	·	·	·	DD	—tragus length
WEIGHT	AD	·	·	·	·	DD	—weight

BOOK REVIEWS

A GUIDE TO MUSEUM PEST CONTROL, 1988, L. A. Zycherman and J. R. Schrock, eds. (Foundation of the American Institute for Conservation and Association of Systematics Collections, Washington D.C., 205 pp.). This book is the long-awaited successor to the 1980 volume "Pest Control in Museums." With the exception of two sections, the entire text has been reworked and reorganized. It is considerably easier to read than the earlier volume, and contains a great deal of useful information, as well as some material that is already outdated.

The volume is divided into four sections: I. Policy, Law and Liability; II. Pests and Pest Identification; III. Treatment; and IV. References. Section I contains the recommendations for institutional policies that were part of the 1980 volume, as well as completely revised and updated information on institutional and personal liability and on federal regulations. The policy recommendations were transferred intact from the old edition as the editors considered them to have lost none of their validity over the years. In many cases this is true, but some of the recommendations clearly reflect a chemical-based approach to pest control that is rapidly being replaced by less hazardous methods.

Section II has a very good illustrated guide to the identification of common museum pests, and articles on cockroaches, wood-infesting Coleoptera, and trapping techniques for Dermestid and Anobid beetles. The article on cockroaches is valuable as to their habits, but recommends materials and procedures that are outdated and unnecessary, and that in many cases are clearly at odds with the principles of an Integrated Pest Management program as outlined in Section III. Section II also includes lists of materials and the pests that cause damage to them, as well as a list of insects and other creatures that are classified only as nuisances.

Section III opens with a glossary of pest control terms from the 1980 volume; it is clearly and concisely presented and one of the sections that is of permanent value as a reference tool. Following this are a number of valuable articles summarizing the known hazards of chemical pesticides, both to human beings and to museum collections; these articles contain information that has been hard to come by. It is to be hoped that the authors will give us periodic updates via journal articles.

This section also has a concise statement of the principles of Integrated Pest Management programs, which are designed to take care of an entire institution as a unit: building, collections, public spaces, offices, food service areas and so on, all with the minimal use of chemical means of pest control.

The bibliography in Section IV is a useful reference tool for museums (though it, too, will need regular updates). The editors note that much of the material on pest control relates to agriculture, and is not easily available to conservators and other museum personnel.

The book has something of a split personality; not the fault of the editors but a reflection of the current state of affairs in museum pest control. Some articles promote the new approach, for example, documentation of chemical hazards and IPM programs. Other parts of the book reflect the need to educate people who will be heavily involved in the choice, and possibly the actual use, of chemical pesticides. A good basis for a museum pest management program, for example,

would require a combined and edited version of the Recommended Institutional Policies in Section I, and the IPM summary in Section III.

There is no question that this book should be part of the library of every conservator and collections manager. However, when the book is recommended to those with little experience in pest control, it should be accompanied by a caveat on the subject of chemicals.—*V. Greene, The University Museum, 33rd and Spruce Sts., Philadelphia Pennsylvania 19104.*

NOTES FROM A WORKSHOP ON BIRD SPECIMEN PREPARATION, 1989, S. P. Rogers and D. S. Wood, compilers (Section of Birds, Carnegie Museum of Natural History, Pittsburgh, PA, 117 pp.). During the past decade, increasing emphasis has been placed on preserving as much material as possible (e.g., skin, skeleton, tissue samples) from each bird specimen collected. A host of curatorial techniques has therefore been developed or resurrected to maximize the use of these specimens. A workshop was held in conjunction with the 107th stated meeting of the American Ornithologists' Union at the Carnegie Museum of Natural History in August 1989, to "encourage inter-museum communication among staff members responsible for the care and management of (avian) collections," and to "highlight recent developments in bird specimen preparation." The result is a compilation of 12 presented papers, introduced by Rogers and Wood.

In the opening contribution, Dickerman describes his methods of "schmoo" preparation for large and small birds. A schmoo provides a viable alternative to flat skins for many who wish to preserve a skeleton while maintaining a round skin for comparison with traditional study skins. However, many may find that Dickerman's descriptions would be more useful if accompanied by illustrations. In contrast, Spaw provides easy-to-follow, well-illustrated descriptions of techniques used to produce four types of "combination" specimens (i.e., round skin/bony spread wings, round skin/skeleton, flat skin/skeleton, skeleton/bony spread wings), and Garrett provides a notably thorough account of collection management techniques (i.e., preparation, storage, cataloging and labeling) for flat skins and other non-traditional skin preparations. Garrett's contribution contains an assessment of tears, grease damage, feather loss, label loss, and insect damage in a sample of 275 flat skins. Hackett and Zink present a brief summary of techniques used to preserve frozen tissues. Also included in the workshop notes are Ouellett's directions for the construction of a light weight, durable, drying and carrying case for field use, Gerwin's discussion of the use of hexanes in specimen preparation, Harris' suggestions for preparing durable skins for classroom use, Septon's description of techniques used to make exhibit mounts from previously prepared skins, Cole's discussion of freeze-drying, and Kiff's splendid summary of egg and nest preparation techniques.

The longest contribution in the workshop notes is Matthiesen's treatment of osteological collections. Far from a skeleton outline, the author fleshes out her paper with a discussion of virtually every aspect and problem associated with the curation of an osteological collection. She strongly advocates the use of cold-water maceration to produce disarticulated post-cranial skeletons, but her description

of the potential problems related to maceration may convince many readers not to bother.

Rather than addressing a specific preparation technique, Paulson provides an overview of bird specimen collection and preparation from a "user's" perspective. His thoughtful comments highlight some important considerations regarding what specimens to collect, what data to include with specimens, what type of specimen (e.g., flat skin, round skin) to prepare, and what preparation methods to follow.

This collection of papers, essentially a proceedings of informal presentations, is stapled together, with format, print style, and approach varying from one paper to the next. I noted several minor typographical errors, and many of the techniques included have been described in some form elsewhere. Nevertheless, I find this to be a handy, useful reference, with some valuable suggestions. It should prove a worthwhile addition to the library of anyone responsible for the care and management of avian systematic collections.—*C. R. Preston, Department of Zoology, Denver Museum of Natural History, 2001 Colorado Blvd., Denver, Colorado 80205.*

HANDBOOK OF PALEO-PREPARATION TECHNIQUES, 1984, H. H. Converse. (Privately published at Gainesville: available from Florida State Museum, University of Florida, iii + 123 pp., appendices). *Handbook of Paleo-Preparation Techniques,* by the late Howard H. Converse, Jr., is a compilation of the preparation techniques used or suggested by Converse. Most of the book appears to be addressed to preparators with limited previous experience. The book is an uncritical description of techniques used by or known to Converse, many of which could benefit from an objective reappraisal.

Converse has based his text on the procedures in use at the Florida State Museum, where he worked. He describes the systems used for record-keeping, field collecting, laboratory preparation, restoration and exhibit preparation, and molding and casting. Appendices include a list of materials and suppliers, a bibliography, and conversion tables for English and metric measurements.

The kind of documentation of materials and methods included in this volume is all too rare in paleontology preparation. The techniques described by Converse are, or have been, in common use throughout the vertebrate paleontological collections of the world. A book such as Converse's serves as a reference point for tracing the history of methods and materials in common use, and may make it easier in the future to determine what treatment was used for a given specimen. Thus it is historically important for preparators, curators and conservators, as a capsule account of some commonly encountered treatments of vertebrate fossil material.

The major drawbacks of this text are (1) the old-school assumption that all fossils must be consolidated, glued, filled, painted, and otherwise restored, whether they are intended for exhibition or not, and (2) Converse's apparent unfamiliarity with some of the techniques described, which are not described clearly or logically. A novice preparator depending on this book as a reference would not have enough information to make the best decisions about which specimens should be kept free of chemical contamination of any kind for analytical testing, and would also not have enough information about some key techniques to perform them well.

The best section of *Handbook* deals with the need for detailed and accurate record-keeping in fossil collections. Too often this is neglected or glossed over. Converse uses examples of forms used at the Florida State Museum for documenting materials, procedures, and locations. One slight drawback is his recommendation of "thinned Duco cement" to cover a number written on a specimen; the disadvantages of the cellulose nitrate adhesives are well known.

Although Converse recommends a wide range of adhesives and consolidants, he provides little information on their potential deterioration, or on the possible hazardous effects of exposure to dusts or solvent fumes. Their use is not as mandatory as Converse implies. Some specimens may need repeated consolidation, but some need none at all until they are considered for casting. It is better to avoid the use of any nonremovable substance if its use is not warranted by the state of the material, and all specimens which are so treated should have the treatment documented for future reference.

Converse also endorses the use of beeswax as a hardener and consolidant, citing its use in the preservation of "many of the great mammoth skeletons of the nineteenth or early twentieth centuries." This is not recommended by other preparators today, and is almost never used. Converse's recommendation of materials without any mention of their possible deleterious effects haunts the whole volume.

Handbook is also marred by poor writing, including repeated grammatical and spelling errors. In spite of this, Converse credits several people who provided editorial assistance.

Converse's book is an example of a major problem in existing preparation handbooks: the unrefereed volume that attempts to codify existing practices without any objective reappraisal. Other examples include *Handbook of Paleontological Techniques* (B. Kummel and D. Raup, eds., 1965) and *Paleotechniques* (R. M. Feldmann, R. E. Chapman, and J. T. Hannibal, eds., 1989).

Information on new methods and materials, as well as the deleterious effects of some traditional methods and materials, has been slow to appear in refereed publications. Only with recognition of the professional status of preparators, and encouragement of refereed publications by them, will the best techniques be identified and disseminated to those who most need the information. Paleontological preparators are responsible for the treatment and handling of some of the most scientifically important specimens existing. It is vital that references and journals for this field be of the best quality, and that personal prejudices, damaging techniques, and untested assumptions do not become codified by rigid tradition and perpetuated in print.—*S. Y. Shelton and R. H. Rainey, Materials Conservation Laboratory and Vertebrate Paleontology Laboratory, Texas Memorial Museum, Austin, Texas 78705.*

REVIEWERS

Special thanks are extended to the following for reviewing manuscripts:

J. Anderson, G. D. Baumgardner, L. Barkley, C. W. Beck, C. Bossert, P. S. Cato, E. Censky, C. Del Re, J. Fenn, C. A. Hawkes, E. Holm, S. Koob, W. Lyons, V. Mast, E. Merritt, C. Messenger, C. Patterson, C. Romero-Sierra, C. Rose, K. Seymour, S. Shelton, J. Snider, R. R. Waller

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.

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

Photographs must be printed on glossy paper, with sharp focus and high contrast essential for good reproduction. Photos should be trimmed to show only essential features.

Each figure should be numbered with arabic numerals and be referred to in the text. Legends for figures should be typed on a separate sheet of paper at the end of the manuscript. Magnification scale, if used, should be indicated in the figure by a scale bar, not in the caption. Notations identifying the author and figure number must be made in pencil on the back of each illustration. All illustrations must be submitted as an original and two copies. Note placement of tables and illustrations in the margins of the manuscript.

Evaluation of a manuscript.—Authors should be aware that the following points are among those considered by the editorial staff when evaluating manuscripts: 1) Is the content appropriate to the purpose of the journal and society? 2) Are the contents clearly and logically presented and the paper well organized? 3) Is the methodology technically and logically sound? 4) Does the paper contribute to the body of knowledge and literature? 5) Is the study integrated with existing knowledge and literature? Is the literature cited appropriate for the study? 6) Are the conclusions supported by sufficient data? 7) Does the title reflect the thrust and limitations of the study? 8) Are the tables and figures clearly presented? Are they necessary to support the text?

Submission Procedure

Manuscripts intended either as feature articles or general notes should be submitted in triplicate (original and two copies) to the Managing Editor. Letters to the Editor and correspondence relating to manuscripts should be directed to the Managing Editor. Books for review should be sent to the Associate Editor for Book Reviews.

CONTENTS

Articles

The effects of freezing and freeze-drying on natural history specimens. ... *Mary-Lou Florian* 45

Characteristics of a collection of fluid-preserved mammals and implications for collection management. ... *Paisley S. Cato* 53

Infrared spectroscopic analysis of Central and South American amber exposed to air pollutants, biocides, light, and moisture. ... *R. Scott Williams, Janet B. Waddington, and Julia Fenn* 65

Observations on enzyme preparation effects on skeletal material. ... *Sally Y. Shelton and John S. Buckley* 76

Integrating specimen documentation, processing, and data automation in a mammal collection: A case study of an accession database. ... *Susan M. Woodward* 82

Reviews

A guide to museum pest control, by L. A. Zycherman and J. R. Schrock, eds. ... *Virginia Greene* 99

Notes from a workshop on bird specimen preparation, by S. P. Rogers and D. S. Wood, compilers ... *Charles R. Preston* 100

Handbook of paleo-preparation techniques, by H. H. Converse. ... *Sally Y. Shelton and Robert H. Rainey* 101