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AN INVESTIGATION OF PH CHANGES IN A SELECTION OF FORMALDEHYDE BUFFERING AGENTS USED ON A FISH, PARASITOLOGY RESEARCH COLLECTION

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Abstract.—Problems with acidity were being encountered in a research fish parasitology collection preserved in various concentrations of formaldehyde solutions. Initial conservation work failed to correct this problem despite using some form of buffering control for the acidity in the replacement formaldehyde solutions. As a result work was carried out to look into more effective means of buffering acidity in this material by choosing a range of suitable buffering agents, monitoring the pH levels over a period of time and comparing their ability to control acidity through a series of acid titrations. The buffers chosen were all sodium based and their action was compared when used with 4% formaldehyde solutions, made up in both saline and deionised water. The final results suggested that using 0.05M sodium-β-glycerophosphate in solutions made up in deionised water was the most effective means of buffering the fish parasitology material.

Conservation work has been carried at the National Museum and Galleries of Wales, Cardiff (NMW) on a fish parasitology research collection. Much of the material was collected during research cruises in 1990 and 1991 and consists largely of elasmobranch fish intestines fixed and preserved in 10% formaldehyde. Since collection, the specimens had remained in the formaldehyde originally used as both the fixative and the preservative. Checks revealed an acidic pH, often less than 4, with a substantial yellowing of the solution in most of the cases. This suggested possible problems from lipid leaching or protein dissociation were developing. It was decided to keep the material preserved in formaldehyde rather than transfer to an alcohol based preservative. This decision was based on the researchers using this material who in numerous previous investigations of parasites in the elasmobranch intestine had found formaldehyde a good preservative for examination of specimens by both light and electron microscopes (H.H. Williams, personal communication). Thus, it was decided to replace the existing formaldehyde preservative with a buffered solution of 4% (0.04M) formaldehyde. Formaldehyde made up in saline solution with the addition of 5% (0.05M) sodium acetate was initially used, utilising the natural buffering effect of seawater supported by the addition of a buffering agent. The aim was to achieve a pH of 6–7 which is considered advantageous for the long-term preservation of proteins (Steedman, 1976) as it is close to the isoelectric point of most proteins. It is at this point that proteins are at their least soluble. However, subsequent monitoring found the pH levels to be unsatisfactory. Within a few months pH levels were close to the previous storage values and it was decided to investigate the problem in more detail.

METHODS AND MATERIALS

A selection of buffering agents were chosen from those recommended by Pearse, 1968; Mahoney, 1973; Steedman, 1976; and Harris, 1990, all of which were sodium based. A number of elasmobranch stomachs and intestines were removed from their original formaldehyde preservative and briefly rinsed

Table 1. List of buffering solutions used in the investigation.

Solution	Buffer	Concentration	pH of fluid	Specific gravity (g/cm³)
4% (0.04M) formaldehyde in deionised water	No buffer		3.3	1.009
	Sodium acetate	0.05M or 4% w/v	6.8	1.010
	Sodium-β-glycerophosphate	0.05M or 15% w/v	8.5	1.017
	Sodium-β-glycerophosphate	0.01 M or 2.5% w/v	7.8	1.011
	Na/Na_2**	(see below)	7.1	1.019
4% (0.04M) formaldehyde in saline	No buffer		8.8	1.020
	Sodium acetate	0.05M or 4% w/v	8.5	1.022
	Sodium-β-glycerophosphate	0.05M or 15% w/v	8.9	1.029
	Sodium-β-glycerophosphate	0.1M or 2.5% w/v	8.7	1.022
	Na/Na_2**	(see below)	white precipitate formed on mixing	

** Na/Na_2: 3.5g sodium di-hydrogen orthophosphate and 6.5g of disodium hydrogen orthophosphate in 1 litre of 4% formaldehyde (Steedman, 1976; Mahoney, 1973).

in water for use in the investigation. A note was made of all original pH and specific gravity levels. The pH readings were taken using a Whatman PHA230® meter with an Orion® combination probe. The calibration of the meter was checked on a daily basis. Although the meter is said to have an accuracy of ±0.01 it was found that readings tended to fluctuate whilst being taken and thus an error of ±0.05 was considered to be more accurate. Readings were thus taken to the nearest 0.1. Density readings were taken using a Paar DMA35® digital density meter.

The buffering agents were tested in two batches of 4% formaldehyde, one made with deionised water, and the other with commercially available artificial sea water salts to simulate the use of sea water (saline). Natural seawater is often used to make up formaldehyde solutions due to its availability on marine research cruises and because of its inherent, although temporary buffering effect (Steedman, 1976). Unbuffered 4% formaldehyde in both deionised water and saline without specimens was used as the controls. The solutions used and their respective pH values are tabulated in Table 1.

The specimens, which were already fixed, were placed in a fresh solution of 4% formaldehyde, plus the buffer if used, and its pH was immediately measured. Readings were then taken daily for 1 week and then on a weekly basis.

To provide information on the range and efficiency of each of the buffers a series of titrations were run on the buffered formaldehyde solutions in deionised water. 50 ml samples of each solution were titrated with 0.1M hydrochloric acid (HCl) whilst continually monitoring the pH changes using a pH probe and methyl orange indicator (endpoint pH 2.9–4.6).

Results

4% Formaldehyde solutions in deionised water.—The results are shown in Figure 1. All the buffered solutions initially showed a drop in pH, which stabilised after two to three days. Overall, the most consistent readings were taken when using the sodium dihydrogen orthophosphate/disodium hydrogen orthophosphate salt mix as the buffer, though the sodium-β-glycerophosphate also gave results which kept the pH level above 6. It is interesting to note that the addition of a specimen to the unbuffered 4% formaldehyde caused a rise in the pH level. The pH of the unbuffered 4% formaldehyde solution remained at around 3.

4% Formaldehyde solutions in saline.—Figure 2 shows the results obtained using a saline formaldehyde solution. The addition of a specimen to the saline formaldehyde without additional buffering salts causes a rapid drop in pH level similar to that obtained with the equivalent deionised solution, to less than pH 5. The addition of the buffering salts reduces this effect especially with sodium-β-

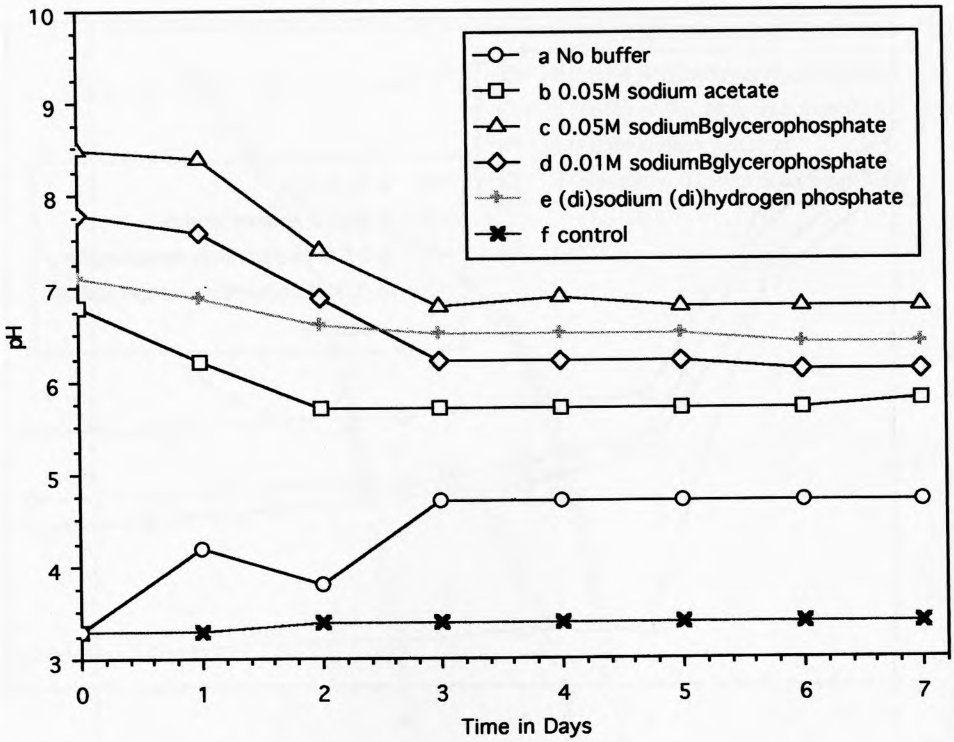


Figure 1. Changes in pH with deionised formaldehyde solutions.

glycerophosphate. However the sodium dihydrogen orthophosphate/disodium hydrogen orthophosphate salt mix gave a precipitation reaction on mixing with the saline formaldehyde solution and was unusable.

Thus, although the addition of buffering salts to the saline formaldehyde solutions does maintain the pH at a higher level than using saline formaldehyde on its own, the same salts appear to be more effective when using formaldehyde solutions in deionised water. This is best indicated in Table 2 where a direct comparison is made. There is also the problem of the possibility of a reaction occurring between the saline solution and the buffering agent as demonstrated by the sodium dihydrogen orthophosphate/disodium hydrogen orthophosphate precipitation reaction.

Long-Term Results

Table 2 shows a comparison of the results after one week and after a three month period. Longer term results suggest that 0.05M sodium-β-glycerophosphate will be the most suitable for maintaining pH levels in 4% formaldehyde solutions for the preservation of elasmobranch intestines.

Acid Titration Results

The results are as shown in Figure 3. The steeper the curve the smaller the change in pH for a given amount of acid neutralised. Figure 3 also demonstrates the effective region of buffering with each sodium salt. Thus the sodium-β-glyc-

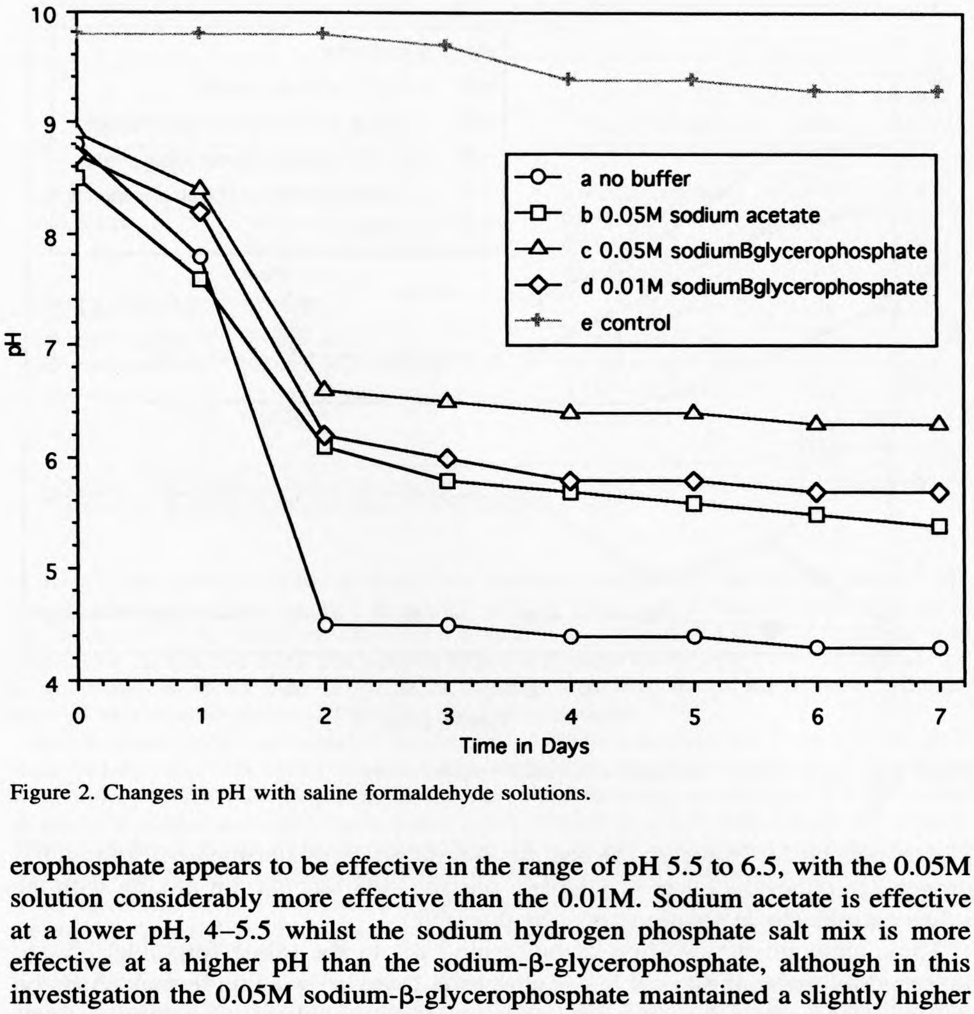


Figure 2. Changes in pH with saline formaldehyde solutions.

erophosphate appears to be effective in the range of pH 5.5 to 6.5, with the 0.05M solution considerably more effective than the 0.01M. Sodium acetate is effective at a lower pH, 4–5.5 whilst the sodium hydrogen phosphate salt mix is more effective at a higher pH than the sodium-β-glycerophosphate, although in this investigation the 0.05M sodium-β-glycerophosphate maintained a slightly higher pH value than the sodium hydrogen phosphate salt mix when used for the preservation of the elasmobranch intestines.

Summary of Results

The most effective of the buffering agents when using *saline* solutions was 0.05M sodium-β-glycerophosphate. However, as was demonstrated with the so-

Table 2. A comparison of the pH levels after a three month period.

Buffer	pH value after 1 week		pH value after 3 months	
	Deionised	Saline	Deionised	Saline
Control	3.4	9.3	3.5	7.4
No buffer	4.7	4.3	4.6	4.2
Sodium acetate	5.8	5.4	5.3	5.2
0.05M sodium-β-glycerophosphate	6.8	6.3	6.6	6.3
0.01M sodium-β-glycerophosphate	6.1	5.7	5.8	5.5
(di)sodium (di)hydrogen-orthophosphate	6.4	—	6.1	—

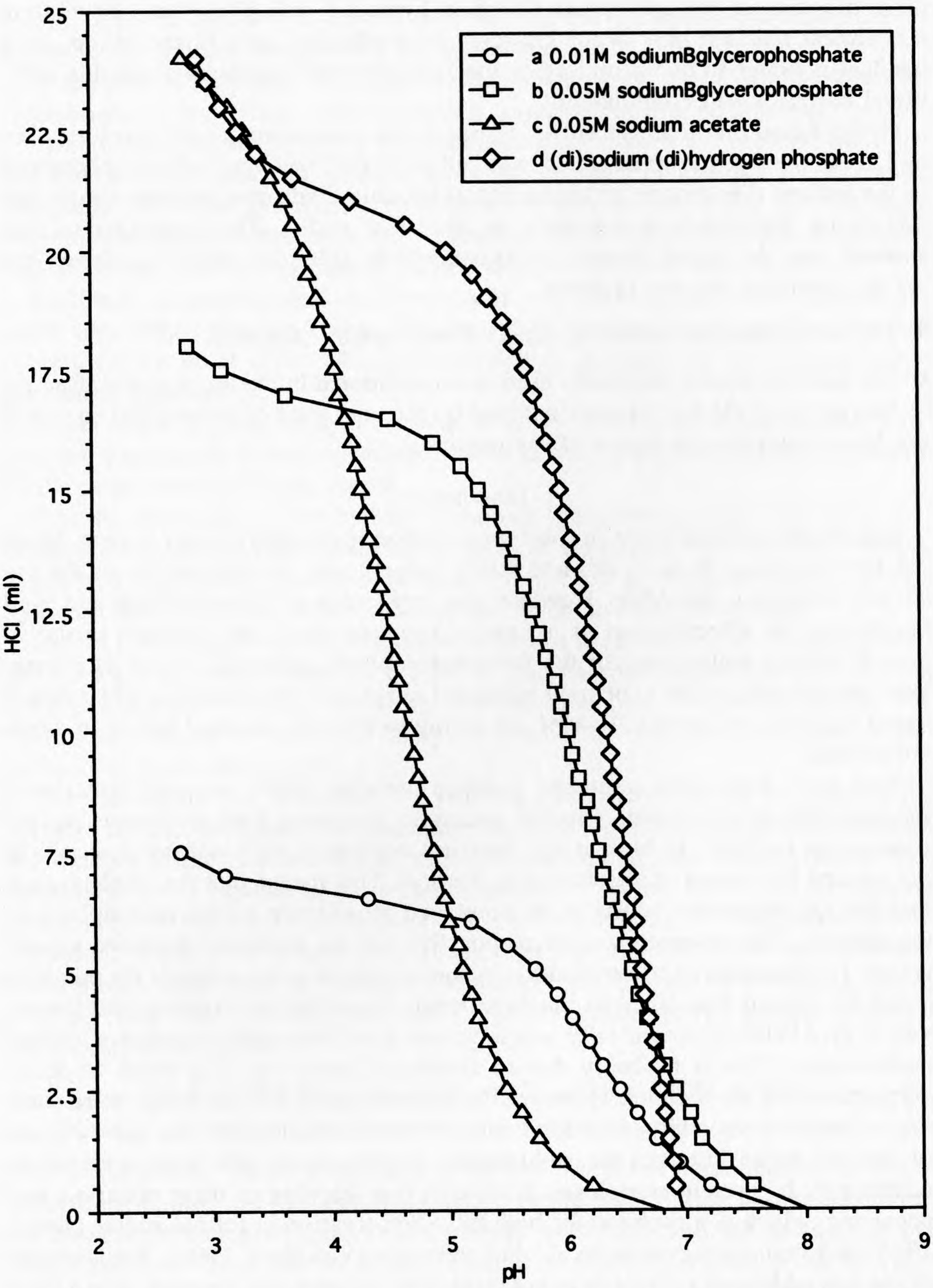


Figure 3. Acid titration results: pH curves for buffered formaldehyde solutions when titrated against 0.1M HCl.

dium dihydrogen orthophosphate/disodium hydrogen orthophosphate salt mixture a chemical reaction may occur between the buffer and salts in the saline. As a result it is better to avoid mixing saline formaldehyde solutions using this additional buffering salt combination.

It was found that the best buffering agents for maintaining a pH level between 6–7 from the agents investigated was either 0.05M sodium-β-glycerophosphate or the sodium dihydrogen orthophosphate/disodium hydrogen orthophosphate salt mix using formaldehyde solutions in *deionised water.* The investigation also showed that the initial change in formaldehyde solutions failed to correct the acidity problems for two reasons:

- The saline solution buffering capacity was rapidly saturated.

- The sodium acetate originally used as an additional buffering agent is effective in the region of pH 4–5 as demonstrated by the acid titration results and so would not have maintained a higher pH as required.

Discussion

The use of formaldehyde in fluid preservation is currently under review. Modern factors arising from health and safety issues make the elimination of the use of this substance desirable. However the properties of formaldehyde are well known and its effectiveness as a fixative suggests that it will remain in use in natural history collections for the foreseeable future, although its use as a long-term preservative tends to be now restricted to specific requirements, with ethanol based solutions of around 70–80% appearing to become standard within museum collections.

This study highlights a specific problem with the NMW research material in the parasitology collection. The fish intestines are being kept until time and resources are available to look at any parasites contained, their relative positions in the gut and the means of attachment to the host. This means that the whole system that the gut represents needs to be preserved in addition to the morphology of the parasite. The research worker responsible for the material expressed a preference for the material to be retained in formaldehyde until a search for parasites could be carried out, since in his experience formaldehyde fixation and preservation give better taxonomically usable results than those with subsequent alcohol preservation. This is probably due to shrinkage occurring as a result of tissue dehydration by the alcohol. However the elasmobranch fish intestines were starting to break down owing to acidification of the formaldehyde. The preservation of the gut tissue involves the stabilisation of fatty acids and lipid materials in addition to the protein complexes. It appears that leaching of these materials was occurring, which is a problem for both fluid preservation in formaldehyde (Jones, 1976) and fluid preservation in alcohol solutions (Von Endt, 1994). Replacement of the formaldehyde solution was not correcting the problem for more than a short period, hence this investigation.

Causes of Acidity

Even the purest formaldehyde solutions show marked acidity (Steedman, 1976). Neutralisation by sodium hydroxide will see a return to an acid pH within a few days, especially when solutions are made up in deionised water. The use of buffering agents to control the pH can prevent this, but the addition of animal specimens to the solution complicates the chemistry.

A number of reactions can cause acidity in aqueous formaldehyde solutions (Steedman, 1976; Walker, 1964). Possible reactions causing acidity are:

Cannizzaro reaction.—When non-aldolisable aldehydes are present, then dismutation can take place to produce acids and alcohols of identical chain length. Generally, the reaction requires the presence of strong hydroxides but can occur when formaldehyde is heated in the presence of acids. However, in dilute solutions and at normal room temperatures the reaction will proceed very slowly.

Oxidation of formaldehyde to formic acid.—In dilute solution at room temperature very little oxidation occurs. The extent of this reaction is small relative to other ways by which a low pH can be produced, and may not be as important as previously believed.

Dissociation of formaldehyde to weak acids.—In dilute solutions at room temperature formaldehyde can dissociate as a weak acid, partly through the formation of the monomer methylene glycol.

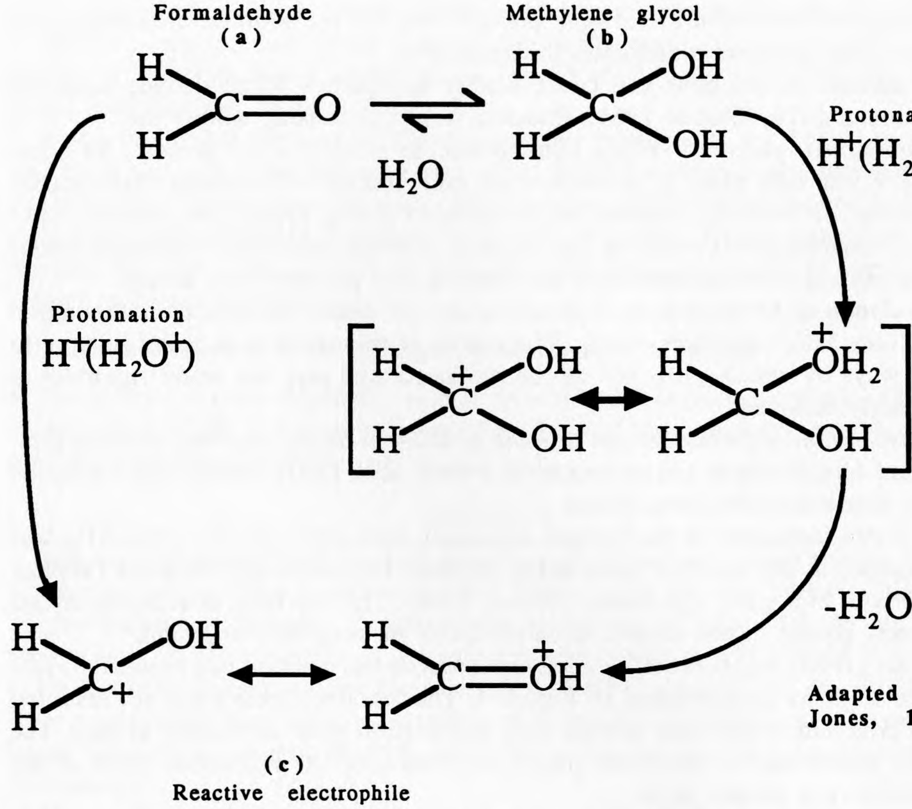
It is this formation of the hydrate monomer, methylene glycol, $CH_2(OH)_2$, that is regarded as the reactant when using aqueous formaldehyde solutions (Walker, 1964) with biological specimens (Pearse, 1968). The resulting attachment of two hydroxyl groups to one carbon atom produces an unstable compound.

Jones (1976) suggests that in aqueous solutions the reaction can proceed further in two ways as demonstrated in Figure 4. The reactive electrophile (c) resulting from protonation becomes greater in concentration with increasing acidity. The (a)–(c) mechanism is the more likely as a result of the inductive effect of the carbon/oxygen double bond.

The carbonium ion produced is a reactive electrophile and is responsible for many of the fixative effects of formaldehyde. If the formaldehyde is buffered then the fixative effect is reduced due to fewer carbonium ions being present. The carbonium ion is capable of electrophilic attack on protein molecules by reacting with many of the functional groups causing crosslinking of the protein chains (Stoddart, 1989). This creates insoluble macromolecular complexes and thus prevents protein loss from the tissues. Sorensen (1908, quoted by Steedman, 1976) demonstrated that formaldehyde reacts with the amine (NH_2) groups in amino acids (e.g., with glycine):

$$\underset{\text{glycine}}{NH_2CH_2COOH} + \underset{\text{formaldehyde}}{CH_2O(aq)} \rightarrow \underset{\text{methyleneaminoacetic acid}}{CH_2{:}NCH_2COOH} + \underset{\text{water}}{H_2O}$$

This consequently causes a lowering of the pH due to the neutralisation of amine groups, explaining the immediate reduction in pH when fixing tissues. However, the material in this investigation was already fixed, and thus the decrease in pH would not have been due to protein fixative reactions but must relate to other components of the animal tissue. A whole range of fatty acids, phospholipids and carbohydrates are present, all of which are less than ideally fixed by formaldehyde and are the most labile during fixation (Jones and Gresham, 1966; Jones, 1976). Some fatty acids will dissolve in the fixative due to the presence of one or two hydroxyl groups making the molecules more hydrophilic and therefore more soluble. Unsaturated fatty acids can be converted to 1,3 glycols with eventual loss by irreversible reactions to other products such as dimer complexes, especially if



Adapted from Jones, 1976

Figure 4. Possible mechanisms for the production of the carbonium ion.

fixation is prolonged. Some lipids and phospholipids have been shown to have increased solubility in formaldehyde solutions. The introduction of hydroxyl groups into the molecules can stimulate the migration of the lipids into the fixative before they become crosslinked and polymerised by further reaction of the unsaturated bonding. However, with prolonged fixation the lipid molecules can become converted to macromolecules, but these cease to behave as lipids. The effects of formaldehyde fixation on carbohydrates seem to be relatively unknown, though ethanol based preservation appears to hold components such as glycogen in place better than formaldehyde, though overall little fixation occurs (Jones, 1976).

The importance of controlling acidity in aqueous formaldehyde solutions being used for long term preservation is to prevent the development of the carbonium ion, which is done by preventing an acidic pH using a buffering agent. This stops the 'fixative' effect of formaldehyde and prevents the buildup of the reactive electrophile in the solution which is now being used as a preservative. The control of this electrophile also prevents further reactions with "unfixed" components in the animal tissue, especially over prolonged periods of time benefitting long term preservation. However, the nature of this chemistry remains unclear, especially as to the exact interactions between formaldehyde and the biological specimen.

Control of pH Levels

Since the neutrality of formaldehyde seawater solutions is maintained for short lengths of time, the practise has been to use buffering agents to control pH levels, especially once fixation is complete and preservation is required. Storage between pH 6–7 is considered advantageous as it is around this point that most proteins are at their least soluble, known as the isoelectric point. At low pH levels proteins can become brittle causing limbs and other delicate features to break off easily. At high pH proteins tend to be more translucent and thus could start gelatinising (Steedman, 1976).

A buffer solution is considered to be a solution in which the hydrogen ion concentration is practically unchanged by dilution and which resists a change of pH on the addition of small amounts of acid or alkali. It is desirable that a buffering agent should maintain a precise level over a long period of time, and not react with the specimen. Steedman *et al.* (1976) did much work on the effects of buffers in the preservation of plankton samples and looked into a whole range of buffering agents. Fundamentally, buffers control pH levels by removing excess hydrogen ions. Such solutions can be made from a weak acid and the sodium salt of the acid. In this case the formaldehyde is considered to be a weak acid (Steedman, 1976) since it is capable of giving up a proton to a base, partly through the formation of methylene glycol, and a sodium salt is added which is intended to be compatible with the formaldehyde. Any H^+ ions appearing in the solution will combine with the disassociated sodium salt reducing the buildup of hydrogen ions in the solution. With formaldehyde solutions this should reduce the effects of protonation and thus limit the formation of the reactive electrophile as demonstrated in Figure 4.

Conclusions

If formaldehyde is used as a long term preserving medium then the control of acidity is required. The effectiveness of buffering agents in formaldehyde appears to vary with the animal type being preserved and this probably relates to changes in the proportions of amino acids, fatty acids and carbohydrates. Other compounds, such as calcium carbonate in shells, will also effect the control of pH. Formaldehyde solutions being used for preservation should be made up in deionised water and utilise a suitable buffer. The pH levels should initially be monitored over a period of two-three weeks as this will indicate if the buffering effects are working. Long-term monitoring should ideally be part of a general collection maintenance programme.

Acknowledgments

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AN INVESTIGATION INTO THE COMPOSITION OF BOTANICAL WAX MODELS WITH A VIEW TO THEIR CONSERVATION

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Abstract.—The Department of Biodiversity and Systematic Biology, within the National Museum and Galleries of Wales has a valuable collection of wax plant models which have been modelled for the collection since 1908. Wax conservation data is quite limited but certain recommendations have been made concerning environmental conditions for storage. The temperature should be 13–20°C and never exceed 25°C with a RH of 50–60%. However, as the properties of waxes vary, effective research into the composition of each model was necessary to develop guidelines to aid the conservation of the models. A condition survey, carried out in 1993 on the collection of models, disclosed that the recommended conditions were not necessarily ideal. Part of the collection was housed within a cool, dry environment and the other in a room with a constant temperature of 25°C with a RH 20% lower than recommended. The results were confusing as the collection in the warmer environment was of a more stable condition. This, therefore, raises the problem that wax requirements may be specific depending on age and composition. Samples of the wax models were analysed successfully using Gas Chromatography Mass Spectrometry. By comparing the spectra with wax standards their content and composition could be established. It is hoped that this research will lead to a greater understanding of the typical compositions used by wax modellers and how these mixtures degrade over time.

The National Museum and Galleries of Wales (NMGW) is home to a valuable collection of approximately one thousand botanical wax models dating from as early as 1908. Each depicts life size structures of inflorescence, fruits and seeds. Wax has been used for modelling for several thousand years due to its being easily moulded and sculpted and mixing easily with other media. The addition of the latter enables the softening or hardening of the wax as required. Wax also has a translucency which, in the case of botanical wax models, gives a natural appearance. This is particularly important when considering exhibitions. Some botanical material can lose its colour, shape and texture on drying and cut material can only last a few days, so being able to display life-like models of rare and extinct plant material is highly beneficial for display and education.

There are numerous types of wax and resin used for modelling, but beeswax is usually the preferred medium due to its versatility and stability, remaining largely unchanged with age. Analysis of beeswax derived from both old and new models revealed similar compositions with any noticeable differences being due to fluctuations in the diet of the honey bee (*Apis mellifera*). These being so small to be of negligible significance (Mills & White, 1994).

Beeswax is a complex mixture of hydrocarbons, esters and free acids. The esters can be divided into several groups: monoesters, diesters, triesters, hydroxy-monoesters and hydroxy-polyesters. The hydrocarbon chain ranges from 25–35 in carbon (C) number with C27 being the most common chain length and even carbon-numbers being less numerous (Mills and White, 1994). Beeswax is virtually insoluble in water (although slightly soluble in water vapour), but is slightly soluble in a narrow range of solvents, with solubility increasing with temperature (Masschelein-Kleiner, 1985). It has a melting point (M.P.) of 63–64°C and is purified by melting and filtering. The glass transition temperature (T_g) indicates the temperature at which a glassy material starts to change to a flaccid material (Horie, 1994). The T_g of beeswax is very close to its melting point (Fisher Scientific UK, 1997). Although normally fairly brittle, beeswax becomes plastic when warm and mixes readily with many other waxes when molten. It also has a high adhesive strength due to polar components (Masschelein-Kleiner, 1985). The impurities are oxidizable fractions which contribute to discoloration upon exposure to light (Bennett, 1963). Paraffin wax is probably the second most common wax used for modelling because it is cheaper than pure beeswax but can mix with beeswax to improve its properties. Paraffin wax consists of >90% straight chain alkanes, having a molecular weight of approximately 300 (Horie, 1994). The carbon chain length ranges from 22–27 (Masschelein-Kleiner, 1985). The volume of paraffin wax shrinks by 13–14% on solidification (Mozes, 1982). The low molecular weight of paraffin wax would suggest a soft wax with a low T_g. However, due to the crystalline nature of some paraffin waxes the softening temperature can be between 40–65°C (Horie, 1994) and have a melting point of around 52–57°C (Masschelein-Kleiner, 1985). Although different manufactures produce slightly different ranges. With temperatures higher than 40°C, paraffin wax can be subject to cold flow and become tacky, attracting dirt to the surface (Horie, 1994). It has non-polar properties and its low adhesive powers (Van der Waals forces) render it comparatively weak and probably contribute to its high melt flow index (Horie, 1994). Paraffin wax forms large crystals when solid and is more brittle than the tougher microcrystalline waxes, yet mixing the two increases the flexibility of both components (Bennett, 1963). These physical properties make it useful in modelling where strength and fineness of detail are not essential.

Working with waxes does give rise to problems. First, waxes can conceal other materials such as resins, lard and additive waxes which will alter its original characteristics, and second it releases solvents inherent to the wax itself, gradually over a period of time, causing the wax to become brittle and crack. Moreover, soft wax attracts dirt to its surface.

Mixing media modifies the characteristics of the wax, for example, the addition of beeswax to a soft wax such as petrolatum wax (mineral jelly) increases the melting point. The addition of 5%, 10% and 20% of yellow beeswax will increase its melting point 2°C, 3°C and 5°C respectively (Bennett, 1963). However, even wax of the same type can vary in composition depending upon its source.

Materials and Methods

A condition survey was conducted on the basement stores in 1993 and the results for the wax models housed within these stores was pooled. The wax models surveyed for this study ranged widely in condition and age, the majority being old, dry and brittle. The aim of the survey was to determine the condition of the surrounding environment and its affect on the collections housed there. The survey form was devised for mixed media including botanical specimens, photographs, wood specimens, wax models, prints and drawings. The condition of the collections reflected the store area for all collections except the wax models. Other criteria seemed to be affecting the varying deterioration of the wax and it was from this survey that this investigation began.

The variation in condition would be due to several contributing factors and it was the intention to

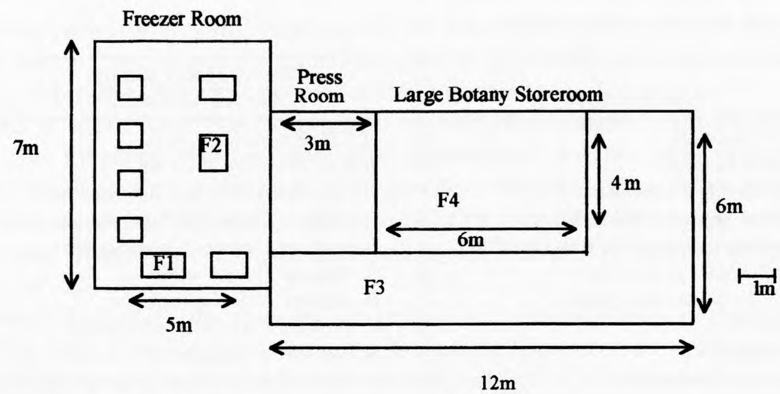


Figure 1. Plan of the Botany Storerooms.

try and determine which factors were the most deleterious to the models and for what reasons. It was not expected to produce clear cut explanations to all aspects of the models' deterioration. The movements of the models in and out of the storerooms were completely undocumented and so any premises could only be based on knowledge of the collections and their movements through staff over the last twenty years. However, it was expected that some conclusions could be made as to the composition of the models, storage conditions and age of the models. These three main areas should provide insight into why some models have remained in better condition than others and why some have become damaged beyond repair.

Storage conditions.—As wax is a sensitive medium it needs to be handled with care and stored appropriately. However, the ideal conditions may be different for new and aged waxes, as the models housed within NMGW did not appear to be benefiting from supposedly 'ideal' conditions. Contributing factors to wax degradation are too high or too low a temperature and RH, contact with certain metal ions (especially copper and stainless steel), photo-chemical homolysis and photo-oxidation.

Photo-oxidation is the breakdown of chemical bonds through the energy produced from light, especially the high energy frequency of ultra violet light. Photo-chemical homolysis produces radicals which are highly reactive species carrying unpaired electrons. Radicals are capable of catalysing chemical reactions within the wax, but remaining unchanged themselves. Wax can then undergo degradation, cross-linking, embrittlement and discoloration (Horie, 1994). The environmental conditions of the stores are therefore extremely important, for if conditions are unfavourable several different stages of degradation can be initiated.

The basement of the Museum houses two main Botany storerooms. The areas where the models are stored are shown as F1–F4 in Figure 1.

The Freezer room contains four freezers which contribute to the storeroom temperature of 25°C and a relative humidity (RH) of 30%. The main air-conditioned Botany store is maintained at a temperature of 20°C and RH of 45%. Waxes should be stored in cool temperatures, preferably between 13–20°C (Plenderleith and Werner, 1971). Such conditions help to reduce dirt adhesion, figure distortion and handling difficulties. Relative humidity also affects the stability of waxes and should be maintained in the 50–60% range to prevent shrinkage and cracking. In addition, a fluctuation in RH and temperature can lead to movement of the internal supports and frames resulting in stresses and damage to the model (Plenderleith and Werner, 1971).

The models in the Freezer room appeared to be in better condition than those in the air-conditioned store, and as the temperature and RH in the freezer room were far from ideal, it could be assumed that waxes do not always respond in a predictable way.

It was found that the Botany store contained a greater number of models with cracked and friable wax. On further examination, only certain areas of the models appeared damaged, cracked or broken which lead to the investigation of the structure of the models and to the composition of the wax itself. If other media had been added to the primary wax, for example beeswax, then the physical as well as chemical properties of the beeswax may have been altered. The need to identify the materials used in models is especially important when considering repairs. It is usual to make a repair with wax softer than the original to aid the removal of the repair if it is needed. (Murrell, 1977). It is also

Table 1. List of samples and standards.

	Wax Standards		Model Maker and the Wax Model Samples	Date Made
A	White beeswax	1	H.E.H. Smedley (fungus)	1908
B	English beeswax	2	H.E.H. Smedley *Triticum*	1909
C	Pure bleached beeswax	3	G. Edwardes *Triticum* (Germinating)	1926
D	Purified beeswax (NMGW)	4	E. Jenkins *Euphorbia helioscopia* (leaf)	1929
E	Manufactured paraffin wax (NMGW)	5	E. Jenkins *Chrysanthemum* (stem)	1931
F	Paraffin Wax & Ceresin	6	E. Jenkins *Viscum album*	1935
G	Mme Tussauds wax tinted	7	E. Jenkins *Helvella lacunosa*	1936
H	Carnauba	8	E. Jenkins *Polyporus sulphureus*	1938
I	Dammar	9	R. Herbert *Ginkgo biloba* (leaf)	1961
J	Synthetic Spermaceti	10	R. Herbert *Filipendula vulgaris* (leaf)	1962
K	Canada Balsam in xylene	11	Plowden and Smith sample	1984
		12	Dale Evans green leaf	1984
		13	Dale Evans unfinished model	1984
		14	Dale Evans unfinished red model	1984

important to implement the 6 foot, 6 inch rule, which is ensuring that the repair is imperceptible from a distance of 6 feet but obvious from six inches. It is usual to use uncoloured wax and paint over it afterwards or in the case of NMGW, the wax is coloured to a slightly paler colour than the original.

Historical Evidence.—Over the years three main botanical wax modellers have been employed at the NMGW, two of whom still live in Wales. The third, Eveline Jenkins started modelling in the 1920's, and worked for thirty years. She died in 1976 leaving informative notebooks, diaries and drawings describing her techniques, which were later used by the other two modellers. Jenkins used 50:50 (v/v) mixtures of pure white, bleached beeswax and paraffin wax for modelling larger items such as stems, fungi, large rootlets and moulds. For finer details, beeswax alone was used because of its strength and suitability for delicate modelling. Paraffin wax was added not only to soften the wax but to lessen the expense incurred. Castor oil, linseed oil, glycerine, turpentine, paraffin, arrowroot and talcum powder were also used with beeswax. Canada balsam, in small amounts, was used occasionally to prevent embrittlement of the beeswax, although, the addition of too much can cause embrittlement, (Jenkins, 1938) probably due to its acidic nature.

Unfortunately, there are models made between 1908 and 1929 with no data relating to composition. The combined effects of the materials in table 1. have not been widely documented and consequently analysis of the wax/composite material was undertaken.

Results

Three methods of analysis were undertaken. Fourier-Transform Infrared Spectroscopy (FTIR), Gas Chromatograph Mass Spectrometry (GCMS) and Gas Chromatography (GC). These three analytical methods are destructive. They require small pieces of sample, taken from not too obvious areas. Numerous models within the collections were already broken and cracked so small pieces could be taken for analysis without causing too much concern. The number of samples taken was kept to a minimum because of availability of different samples and the cost of analysis. Eleven standards and fourteen samples were taken (See table 1).

For analysis of the sample by FTIR a Nicolet™ 510 Spectrometer in conjunction with a Spectra-Techinfrared™ Research Microscope was used initially to obtain the spectra. The technique requires little preparation of the sample and results in the production of a low frequency interference pattern containing full intensity/frequency information as a plot of percentage transmission/absorption against wave number/wavelength (Mills and White, 1994). The resulting spectra relate to absorption peaks or transmittance peaks of functional groups within the wax at specific wave number/wavelength. This results in identification of specific components within the wax, but not necessarily quantities.

GCMS is more ideal for the analysis of complex samples than FTIR, but the preparation involved requires specialist knowledge. In this case samples were prepared by extraction with xylene and then derivatized (broken down into smaller molecular components to aid in separation) with diazomethane using methanol as the catalyst. When wax is being analysed by GCMS or GC it must reach a temperature of 350–400°C.

For analysis by GC, the samples are prepared in a similar way to those analysed by GCMS, i.e., dissolved and then derivatized to allow smaller components to be discerned. In this case the instrument employed had a capillary column of 25m × 0.32 mm made of aluminium clad quartz, and capable of reaching temperatures of 370°C.

Fourier-transform infrared spectroscopy.—FTIR is a very useful technique for characterising individual samples. The resulting spectra may then be compared with reference spectra. In this case, however, the technique did not aid the identification of the samples from the models. The spectra obtained from the standards were easily interpreted (Figure 2), but not for the samples because of the composite nature of the wax. Consequently this method of analysis was abandoned.

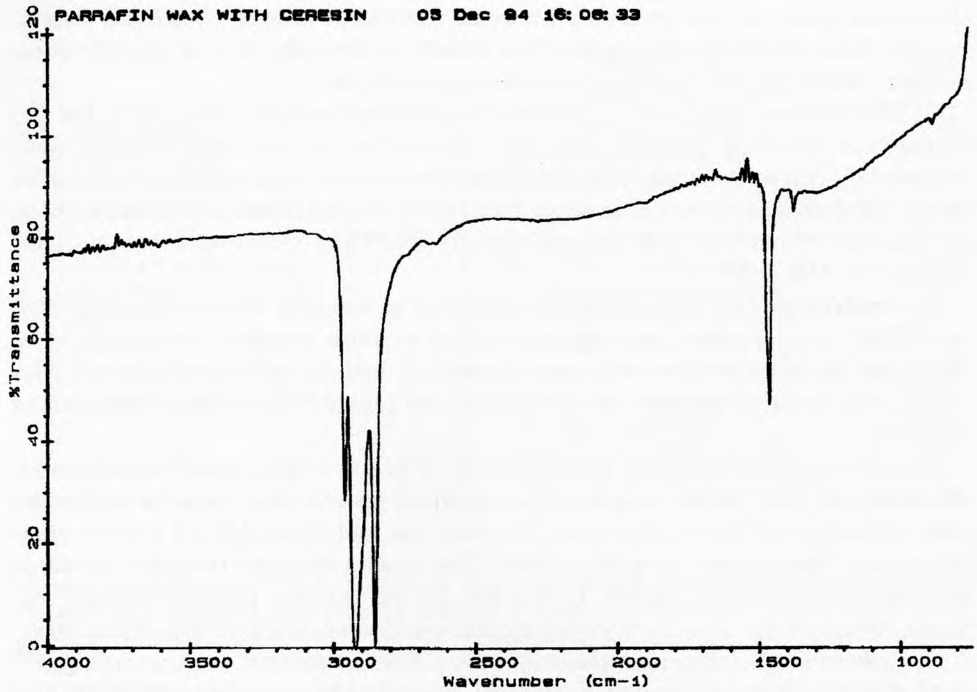
Gas chromatography mass spectrometry.—The instrument used, a Finnigan™ MAT Magnum ion trap, has a maximum operating temperature of 280°C. The results obtained probably relate to noise. This is background interference produced through inadequate calibration so that irrelevant readings resulted, for example, from the solvent used to prepare the samples (carbon tetrachloride, CCl_4 and silicon Si_4 from the ion trap). Analysis of the wax specimens would not have been possible due to the poor calibration and because the operating temperature of the instrument was not sufficiently high for vaporisation of the waxes.

Gas chromatography.—The instrument employed, a Carlo-Erba™ 5360 Mega, gave excellent results with easily read chromatograms. The chromatograms of the reference samples showed very good correlation's with those of the wax standards, allowing individual components to be distinguished, (see Figure 3). The quantities of individual components were not calculated at this stage.

Discussion

The wax compositions from the earlier models can be determined from the gas chromatograms. There appears to be no correlation between the type of modelling and wax used (See table 2.), but the more recent museum models conform with the historical evidence given by E. Jenkins: the main proportions of the model are a mixture of compounds, and beeswax alone is used in the finely detailed modelling.

The condition survey of the models indicated that the main stems in general were suffering, especially where joins occurred. Wax undergoes accelerated oxidation when in contact with certain metal ions, the rates being dependant upon the metal used. Copper and bronze cause the greatest damage while wrought and cast iron cause less deterioration. Surprisingly, stainless steel is also damaging to wax (Bennett, 1963). The wire used in the construction of most of the wax models is tinned copper wire which may provide a good level of protection by reducing



1500 cm^{-1} C-H bond stretch readings

2885 cm^{-1} C-H bond stretch readings

Figure 2. FTIR spectra showing functional groups.

the rate of oxidation. Both the beeswax and paraffin wax are refined, and this involves the removal of most oxidizable fractions. Oxidised wax becomes darkened, increases in hydrogen ion concentration, is brittle and less tensile (Bennett, 1963). There appeared to be no visible darkening, but the pH of the wax was found to be 4.0, which is acidic, and there were definite signs of brittleness and weakness.

Wax tends to retain its solvents, releasing them slowly over a long period of time. The release of solvents renders the wax dry, embrittled and susceptible to damage. Conservators should avoid incorporating solvents into materials used for repair, and they must be wary of using cleaning solvents because they will be retained, then gradually released causing shrinkage. The greater the quantity of solvent used then the greater the resultant brittleness. It would be expected that the lower carbon groups were being lost and the longer, more stable chains remaining after time, however further analytical work would be beneficial to de-

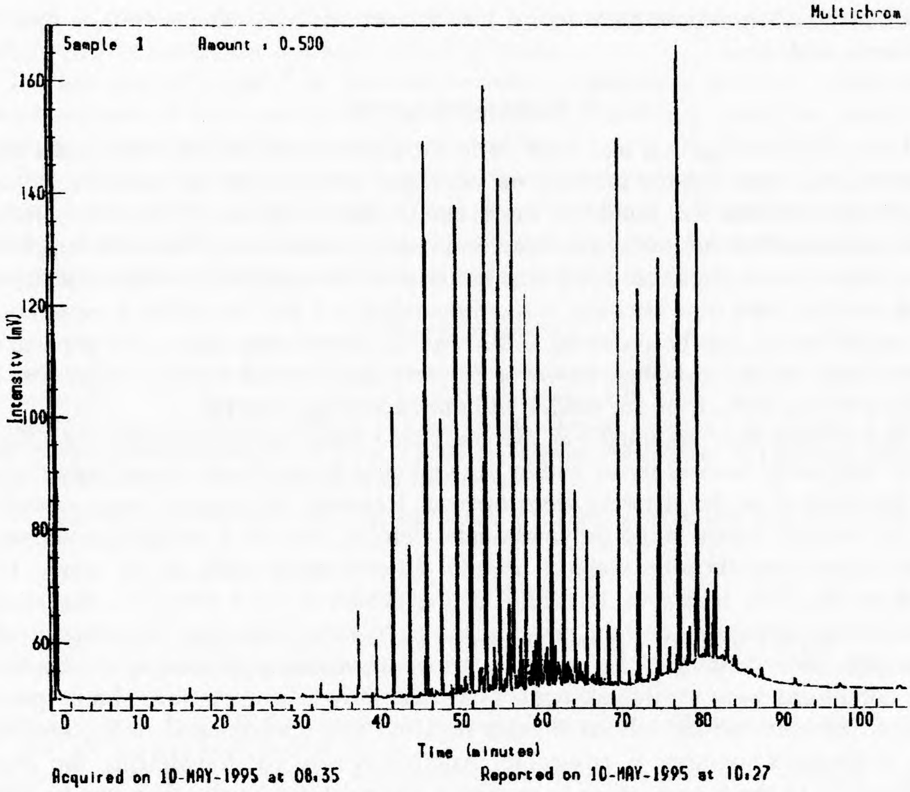


Figure 3. Gas chromatogram of *Viscum album* model.

Table 2. Wax model composition.

	Model Maker and the Wax Model Samples	Date Made	Type of Wax
1	H.E.H. Smedley fungus (stem)	1908	paraffin wax
2	H.E.H. Smedley *Triticum* (stem)	1909	paraffin and beeswax
3	G. Edwardes *Triticum* (stem)	1926	beeswax
4	E. Jenkins *Euphorbia helioscopia* (leaf)	1929	beeswax
5	E. Jenkins *Chrysanthemum* (leaf)	1931	beeswax
6	E. Jenkins *Viscum album* (stem	1935	paraffin and beeswax
7	E. Jenkins *Helvella lacunosa* (fruit body)	1936	beeswax
8	E. Jenkins *Polyporus sulphureus* (bracket)	1938	paraffin and beeswax
9	R. Herbert *Ginkgo biloba* (leaf stem)	1961	paraffin and beeswax
10	R. Herbert *Filipendula vulgaris* (leaf)	1962	paraffin and beeswax
11	Plowden and Smith sample	1984	paraffin and beeswax
12	Dale Evans green leaf	1984	beeswax
13	Dale Evans unfinished model	1984	beeswax
14	Dale Evans unfinished red model	1984	beeswax

termine which products were being lost as solvents and the percentage loss of solvents with time.

Recommendations

Once the investigation had been completed, recommendations were made and carried out. Repairing the models was necessary and was the first priority. Repair work ensures that the model is more stable and complete. It prevents further movement within the model structure and reduces corrosion of the wire supports. The models were repaired using wax softer than the original. For the majority of wax models, pure new beeswax is recommended as it will be softer. A new repair to an old model can be removed if the wax is newer/softer even after the waxes have been welded together, however for an ethical repair the new wax should adhere to the surface of the model without becoming uniform.

The models were re-housed as the conditions were unsuitable. The collections were originally housed loose within drawers which may have caused movement of the models as the drawers were opened. Recently the models were mounted on to perspex sheets using polycarbonate welding cord as a method of support. This offers non-abrasive support around delicate areas such as the stem. The perspex backing improves handling as the model is held firmly to the sheet, preventing movement, and the perspex can be handled instead of the model itself. The collections were then moved from the freezer room to the botany store where the conditions were stable and cool. The stable, lower temperatures should prove beneficial once the models have been repaired and consolidated. Also, keeping the collections together is advisable. Another reason for transferring the main collections to the botany store is to reduce natural light levels. Wax can become photo-oxidised by ultra-violet light. Reducing this will protect the wax from increased rates of degradation. As artificial light levels are still high within the storeroom placing the models in acid free boxes with lids was recommended. The boxes offer protection from handling, dust, slight fluctuations in the environmental conditions and from UV light. The models are placed on plastazote (an inert polyester foam) to reduce slip within the box during handling. To save on space, the plastazote is built up around the model to provide dividers so that more than one model could be placed within a box. The box can also be divided up into levels by placing a another layer of plastazote on top of the dividing walls so that models could be housed one on top of the other.

Once the models had been re-housed a complete record of every model was drawn up comparing registers information with the model, until each model had been verified and documented. Information is attached to the model through a label that is attached to the model by cotton string. A catalogue of all the models will soon be available.

Conclusion

Beeswax is a stable medium remaining unchanged for a longer period when used alone than when combined with paraffin wax. Paraffin wax contains a greater quantity of solvent than beeswax which, in the short term, means that it is easier to work with, but later the evaporation of the solvent will contribute to the drying and cracking of the wax. If ease of modelling was the only criterion, wax mixtures would be the obvious choice of materials but with regard to conservation, although it costs more and is more difficult to model, pure beeswax will give a better quality model for a longer period of time.

Further research could be directed towards quantitative analysis, where the exact amount of wax used could be determined. Flexibility could be measured through calculating the loss of solvents over time.

This research has proved very useful in determining suitable methods of repair, housing and packaging. However, it would be beneficial if a catalogue could be produced from other sources to try and assimilate as much data as possible on wax compositions of wax models held within other institutions.

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Note.—Substances considered in this paper are Subject to Control of Substances Hazardous to Health (COSHH) Act 1984.

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PROBLEMS FACING SMALLER HERBARIA

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Abstract.—Traditionally, herbaria have been viewed as playing a role in research and teaching as well as being a storehouse of botanical diversity. Recently there has been a growing concern regarding the lack of funding and appreciation for these invaluable resources especially at the less well-known institutions. Perceptions of the herbarium's role have changed somewhat, partly because of a greater emphasis placed on the sub–organismal aspects of plants but also because systematics, in general, is considered by some as being of much less importance than an understanding of plant genetics (due to a lack of understanding of what constitutes systematics). The problems facing herbaria today may also be a result of taxonomists' own inability or unwillingness to recognize and act on the herbarium's role as a museum and to instill respect for the herbarium-as-museum among our students.

Science museums, especially natural history museums, have played an important role in human culture by introducing people to the wonders of science and by educating them regarding the value and importance of science (Nicholson, 1991). Recognizing this, many museums have recently changed their strategies towards public education (Patton, 1991; Tirrell, 1991) from simple "show-and-tell" exhibits to the incorporation of more interactive experiences and current topics displays.

One field of the natural sciences that perhaps has not been given as much attention is the plant world. While there are botanical displays in many of the major museums, these often are subordinate to zoological or ecological themes or are placed in less visited corners. Arboreta and botanical gardens partially fill this niche, but climate, space, and mission affect what is planted. Herbaria are the repositories for collections of dried plants, but are often administered through academic departments. At smaller or less well-known colleges and universities, this has caused problems of perception, especially among institutions' administrators.

In general, the herbarium, in the simplest terms, can be defined as a collection of dried pressed plants attached in some way to sturdy paper. Any class reference collection would fall under this definition. A "herbarium as museum," however, has a bigger mission (Forman and Bridson, 1989) to promote an understanding of the plant world by: (1) acting as a source of botanical data for research; (2) providing verification of unknown entities against known specimens; and (3) preserving a record of botanical diversity. Unfortunately, many people view herbaria only in the simplest terms.

Furthermore, academic herbaria seldom have been considered museums or even parts of museums (even in the scientific community) and rarely are there displays (even simple ones) or tours associated with these herbaria. Unlike the museum herbarium, academic collections are not usually exposed to the public through "members nights" or other such public related activities that can help promote collections. In the most recent survey of herbaria (Holmgren *et al.,* 1990), 537 active herbaria were listed for the United States, with 77% being associated with

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colleges and universities; of these, nearly all were administered through a biology or botany department.

Problems for the Smaller Herbarium

Value

Anyone associated with biological collections knows there is tremendous value in preserving those collections, but it can be very difficult to convey this to legislators, regents, and the public. It may be self-evident that classes studying taxonomy can't always depend on greenhouse-grown material or botanical gardens, and field trips to exotic places are not always practical. Even the small herbarium can usually provide specimens for such demonstrations. The multiplicity of specimens in a herbarium can bring home concepts of variability and diversity far better than a small classroom reference collection and without the added expense of maintaining separate collections. The value to research is well-documented in the publication of research results.

However, dried and pressed plant specimens (especially older collections that are browned from inadequate storage in the past) have never developed "market value," unlike other natural history specimens such as shells or butterflies. Rarely does one find herbarium specimens sold in gift shops or auction houses. Dried and flattened plants simply do not have the flamboyance of other biological collections. Compare, for example, a specimen of the beautiful "metallic blue butterfly," *Morphodidius,* and a herbarium specimen of the carnivorous pitcher plant, *Sarracenia.* Even though the pitcher plant may have a fascinating life-history the plant specimen loses its showiness upon pressing and drying.

While education and research values must take precedence over market value, nevertheless, administrators often think in financial terms. How does one define the monetary value of the herbarium?

Technology

In an age when "cutting edge technology" requires high-priced equipment, herbaria are considered by some as anachronisms. The techniques used to collect and dry plants are basically the same as those first used by Luca Ghini in the 1500s (Arber, 1938). While our glues and mounting papers may be of archival quality and many herbaria are developing searchable computerized catalogs with graphics for the Internet, herbarium curation is still based on simple techniques. Unfortunately, "cutting edge technology" is used by some administrators as the gauge of importance.

Specimen Duplication

Since plant collecting and drying are relatively easy processes, botanists frequently collect more than one individual from a population. This became especially common after the taxonomic community realized that natural variation existed within species and that this variation could be due to genetic or to environmental factors. It has been common for taxonomists to collect many sets of duplicates (Anderson, 1996) to document that variability, but unlike other biological collections, one or two samples would be deposited in the home institution and the remaining material would then be sent to several other institutions in exchange for their duplicates, with major herbaria generally being the first recipients. Such exchanges have been described as an important contribution to herbarium growth and act as a "backup" in case the original is lost due to a disaster or because developing countries initially could not properly preserve and maintain collections (Forman and Bridson, 1989). Unfortunately, such exchange programs also created a general lack of uniqueness among herbaria, contributing to a decline in usage of regional and small herbaria.

Most researchers do not want to borrow specimens from many different institutions when they can get a representative sample from one or two of the major herbaria (see discussions in Anderson, 1996; Murray, 1995; Wieboldt, 1995), although the smaller or regional herbaria might have additional range extensions or even better examples of some of the variability within a species. Indeed it would be inefficient, both in terms of time and funds, to borrow material from all possible herbaria. At the same time, however, bypassing many of the small academic collections leads to under-utilization of those collections. It then adds to the difficulty in justifying, to administrators and granting agencies, the need for continued or increased funding for smaller herbaria.

Staffing

Herbarium curators are often not thought of as museum curators, particularly in academic circles. Herbarium curators and directors are primarily taxonomists drawn from faculty with expertise in plant systematics but not necessarily in museum operations or collections management and conservation. Indeed some plant taxonomists have not really considered the herbarium to be a museum.

Policies

Since herbarium collections tend to be separated from public museums, written policies on usage often have been lacking. Recently the Association of Systematics Collections (ASC) discussed the importance for biological collections to have written policies regarding usage of materials, access to collections, and proprietary ownership (ASC, 1991; Hagland, 1994). Taxonomists generally handle specimens with care but other visitors may not be given any orientation to policies or procedures. The herbarium is often considered simply as a special library in which the "books" are specimens.

How many times, for example, has a herbarium visitor "browsed" through a herbarium cabinet looking through specimens in a genus folder as if they were scanning a book? And while herbarium specimens are often used for demonstration purposes in various classes, how often do we explain the herbarium to those students? Do they leave class thinking the specimens came from a teaching reference collection, periodically replaced from time to time? Or do they think of the specimens as "museum" specimens, equivalent to antiquities from the pharaohs' tombs?

Separation from the Public

An underlying factor has been the general disassociation of herbaria and natural history museums. As mentioned above, herbaria generally are administered through academic departments of botany. This lack of association with the public museum and its fundraising connections has contributed to neglect on the part of some administrations, disinterest on the part of some botanists, and a lack of recognition and respect in general for herbaria. To some extent these problems are common to all collegiate biological collections (Humphrey, 1992), but outside the systematics community the herbarium, if at all recognized, is often regarded as something of a "library resource" rather than a museum containing a record of biodiversity.

When faced with budget cuts, high physical plant costs associated with occupation of large areas, and inflation in supply costs, herbarium staff are frequently asked to justify their existence. This is often difficult to do at the smaller or less well-known herbaria, given the problems outlined above.

Conclusions

For those of us in smaller herbaria or herbaria that are not well known, it may be time to re-evaluate our approach to survival. Herbarium curators can not afford to say to administrators "we're an important foundation facility," or "we're the backbone of research" and expect administrators to agree and then provide funding.

Is the extensive exchange program to our collective benefit, or would we be better served by having a more limited exchange, thereby making each state's collections more unique? Perhaps more selective standards should be used in accepting specimens, thereby giving collectors and donors a more structured view of collections. Herbaria should not be considered as depositories for any and all botanical samples; herbaria should be setting the standards of what is acceptable.

Most herbaria can not afford to subsidize botanical research, but perhaps research funds could be used to help support curation of specimens generated as part of research. Perhaps fees for services rendered should be instituted, at least for those researchers who receive grants for botanically oriented research but don't have a botanist as part of their research team (see discussion in Kimsey, 1996).

Students who are expected to make a collection as part of a class project should perhaps be expected to participate in the whole spectrum of curatorial duties with respect to those specimens: mounting, accessioning, and filing. Or, conversely, class reference collections might be prepared differently than herbarium specimens in an attempt to help bolster the perception that herbarium specimens are museum specimens, something different from simple reference material.

Promotional efforts could include tours of the herbarium by classes and garden groups. Such tours could then emphasize particular aspects of the collection rather than just explain what an herbarium is. Perhaps the tour group can view examples of the oldest collections, or specimens from historical expeditions, or examples of the morphological variation exhibited by some plant species. Use of the herbarium by state agencies and environmental consultants should also be encouraged. These groups can be important supporters but should not drive policy guidelines. Additionally, it is important to convey the idea to all visitors that the herbarium is a type of museum (Humphrey, 1991) and not simply a library.

Annual reports may help to convince administrators that herbaria are a major foundation for biology education and research. One way, for example, to demonstrate that the herbarium is used in myriad ways is to log all outreach activity, no matter how mundane or "typical," perhaps even including an estimate of the time involved, who was helped, and in what county if the person was from the general public (that is especially important for land-grant institutions). These annual reports can then be an excellent means of providing the statistics to support herbarium arguments for funding proposals.

Most important of all, perhaps, the small-herbarium community must start thinking of "our" herbaria as museums, even if only "inner" museums (Humphrey, 1991). We should relate more with other biological collections in our own institutions, perhaps even to become administratively united (e.g., Kansas State University, University of Nebraska, and just recently the University of Minnesota). We often share common problems, surely we can find common solutions. At the very least such connections can provide a united front to university administrators. We have an obligation to see to it that herbaria do not become simple reference collections but maintain their role in preserving the record of biodiversity.

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PRELIMINARY ANALYSIS OF THE EFFECTS OF COLD STORAGE ON FUR GARMENTS AND MAMMAL SKINS

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Abstract.—Cold storage has been adopted from the commercial fur storage industry by museums to control insects and microbial pests in fur garment and mammal skin collections. A pilot experiment was conducted to determine the effects of cold storage and chill-thaw cycles on these collections. The results showed that as the skin samples were cycled in and out of refrigerated conditions, they exhibited a loss of moisture regain and possibly a loss of hysteresis over time. The apparent loss of hysteresis may have been caused by the migration of salts out of the interfibular areas of the skins. It is recommended that cold storage temperatures be raised to within 10°C of room temperature, and that fur garments and skins be bagged and acclimated to room temperature when taken in and out of cold storage.

Cold store rooms are used today by many museums for long-term preservation and storage of mammal skins and fur garments. The rationale for the technique is that chilled temperatures minimize the risk of insect infestation in addition to reducing rates of chemical reactions involved in the degradation of materials. Museums adopted cold storage from the commercial fur storage industry, which began using the technique as a temporary seasonal solution for the protection of fur garments from infestation by household insect pests. Museums, however, adopted cold storage as a permanent year-round storage environment for their fur garment and skin collections. One conservator of natural history collections notes, "Adopting empirical, nonscientifically based methods is not the answer to problems in the preservation of natural history collections, nor does the answer lie totally in the direct transfer of techniques from other disciplines" (Rose, 1991). Museums did adopt cold storage without scientifically assessing the process and its impact on the collections.

Commercial fur storage developed after the 1890s (Anon., 1940; Anderson, 1953). According to Howard (1896), cold storage for fur garments became the sole source of revenue for some firms, but until that year, no research had been conducted to determine the most appropriate temperature. Howard, an entomologist for the U.S. Department of Agriculture, arranged to oversee experiments, which tested the effect of low temperatures on several common household insects. Based on the results, Howard (1896) concluded that temperatures from 4–5°C (40–42°F) would protect materials from insect damage. These temperatures did not kill the insects, but put them in a state of inactivity, or diapause, where they did not feed, breed or move. His continued research showed that the larvae of the clothes moth and black carpet beetle could withstand a constant temperature of 0°C (18°F), but that fluctuating temperatures would kill them (Howard, 1897).

Contemporary research has shown that the survival of insects exposed to low temperatures is dependent on the temperature; time of exposure; the species of insect; its state of development; its gender; the relative humidity (RH) and the insect's cold tolerance level, or acclimation ability (Mullen and Arbogast, 1984; Fields, 1992). Temperature affects insect development, slowing or stopping it at the suboptimum zone, 13–25°C (55–77°F); and the lethal zone, 5 to −25°C (41

Table 1. Suboptimum and lethal low temperatures for skin and fur loving insects (Schrock, 1988; Strang, 1992; Brokerhof *et. al.*, 1993).

Scientific name	Common name	Sub optimum temperatures °C	100% lethal low time/temp. °C
Coleoptera: Dermestidae			
Anthrenus flavipes LeConte	Furniture carpet beetle	n/a	−18
Anthrenus museorum (L.)	Museum beetle	4	<−20
Anthrenus scrophulariae (L.)	Carpet beetle	4	n/a
Anthrenus verbasci (L.)	Varied carpet beetle	14	−20
Attagenus pellio (L.)	Black carpet/Furriers beetle	n/a	−18
Attagenus unicolor (Brahm)	Black carpet beetle	10	−24
Dermestes lardarius (L.)	Larder beetle	15	<−2
Dermestes maculatus (De G.)	Hide beetle	8	−23
Lepidoptera: Tineidae			
Tineola bisselliella (Hummel)	Webbing clothes moth	9	−20 (16–30 hrs)
Tineola pellionella (L.)	Casemaking clothes moth	n/a	−20 (13–16 hrs)

to −13°F), the insect dies in a matter of time. Variations among species and other characteristics will influence the specific ranges (Fields, 1992). Table 1 shows a selection of insects that infest animal tissues and their corresponding suboptimum and lethal low temperature ranges. The suboptimum temperatures, which range from 4° to 15°C (39–59°F) for skin pests, are the basis for cold storage of these materials.

Jackson (1926) was the first author to recommend that museums use cold rooms as an alternative to chemical controls, to permanently store skins in order to control insects. He recommended a 10°C(50°F) temperature for cold storage. In the definitive work by Hawks *et al.* (1984) on the preservation of tanned skins in mammal research collections, the authors recommended the use of cold storage but at a higher temperature level. Based on the argument that it took below freezing temperatures to kill insects, and temperatures above 30–40°C (86–104°F) combined with a high RH to seriously damage leathers, they recommended a fur vault environment of 20–22°C (68–72°F) with a RH of 50–60% with good air circulation and back-up climate control systems. The authors also believed that cold storage alone was not an effective pest control process and recommended fumigation as well.

In order to describe current practices and to identify any common problems, an informal survey was conducted of two commercial fur storage companies and several Canadian museums that use cold storage for their skin and/or fur garment collections (Table 2). Of those surveyed, only the Royal Ontario Museum (ROM) had had an insect problem with cold storage (Burbank and Elliott, 1996; personal communication, Elliott, 1997). The constant among those surveyed was the difficulty controlling RH. Immediate consequences from the rapid elevation in RH can be condensation on the collections and mold activation. For example, the cold storage in the National Museum of Man, now the Canadian Museum of Civilization, broke down in 1976 and caused a major mold outbreak (Florian, 1976).

Table 2. Results from an informal survey of commercial fur storage companies and museums that use cold storage for fur garment and/or mammal skin collections.

Museum or company	Temperature range	Relative humidity	Acclimation	Special considerations
Victoria Furs	13-16°C	45%	N/A	
Eatons Fur Storage	13-16°C	55-58%	N/A	
Provincial Museum of Alberta	Room temp.	Room RH	No	Due to problems controlling RH; not operational.
Royal Ontario Museum,				Monitored with datalogger and security alarm system.
Ethnology/textiles	4-5°C	50-55%	Yes	
Natural history	5°C	30-35%	No	
McCord Museum, Quebec	12°C	50%	No	Not regularly monitored. Intake air dehumidified. Objects stored in coroplast containers in the vault.
Canadian Museum of Civilization, Quebec	4-6°C	50%	N/A	Computer regulated and monitored with alarm system.
Royal British Columbia Museum	4-6°C	32-39%	No	Monitored with security alarm system.

Table 3. Physical characteristics of the skin samples before testing.

Characteristics	Sample #1	Sample #2	Sample #3	Sample #4
Type	Canidae family, possibly Coyote	Gray wolf, adult male, rear leg skin	Ursidae family, likely black bear	Mustelid family, likely mink
Skin thickness	1.0 mm medium thin	0.65 mm thin	2.0 mm medium	0.45 mm very thin
Skin color	White to pale yellow	White to pale yellow	White to pale yellow	White to pale yellow
Skin texture/ Flexibility	soft, spongy, moderate flex	soft, high flexibility	rough, compact, moderate flex	compact, high flexibility
Follicle size	fine	fine to coarser guard hair	thick, coarse	very fine
Hair length	30 mm; guard hairs are 60 mm	40 mm; guard hairs are 80 mm	80 mm, fairly uniform	7 mm; guard hairs are 10 mm
Hair color	lt. brown with dark tips	pale grey at roots to fawn	dark brown, uniform	gray to brown, dk. brown guard
Hair density/ Grain	dense, evenly spaced	dense, evenly spaced	open, in clumps of threes	Very dense, evenly spaced
Crystallinity/ Birefringence	Hair: high Skin: low	Hair: high Skin: none	Hair: high Skin: moderate	Hair: moderate Skin: low

In another case, there was a mold outbreak in the cold storage of a museum in Yellowknife, Yukon, when the power failed and the generator broke down (Pouliot, 1997, personal communication). Thus, the potential for mechanical failure and the ensuing fluctuating RH can make cold storage an unreliable preservation technique.

Wellheiser (1992) provides a list of criteria for the assessment of nonchemical pest control treatment processes. These criteria include the effectiveness and reliability of the process and the effect on the materials of the objects. Of these, only the effectiveness of the process as an insect control has been analyzed in the literature. For this reason, a pilot experiment was conducted on a small number of skin samples, to examine the effects of a cold storage environment on the material, and in particular, the moisture relationships and regain ability.

Materials and Methods

Skin samples from four different mammals were selected for testing (Table 3). One piece of each skin was selected as the control and kept at room temperature. Another piece of each skin was selected for chill testing. Because of resource constraints, the species identification and tanning history of three of the four samples were unknown. Skin sample #2 was preserved with a formic acid pickle and potassium aluminum sulfate tawing in the fall of 1996. Hairs and skin sections from the samples were viewed with a compound microscope with a polarizing filter. A key for mammal hair (Mayer, 1952) was used to aid in identification. Vegetable tan spot tests, elemental analysis (EDSX) and scanning electron microscopy (SEM) were also conducted to aid in the identification of species and tannage.

Four other tests: pH, conductivity, shrinkage temperature, and moisture content, were conducted to assess the chemical stability of the samples. Moisture regain tests were conducted to determine whether refrigeration altered the regainability of the samples. Regain ability is the ability of a material to lose or gain moisture at various levels of RH and temperature (Florian, 1994). After the regain tests, the chilled samples were observed for changes in physical characteristics and were analyzed for pH, conductivity, shrinkage temperature and moisture content. These results were compared with those from the original control samples. Articles by van Soest *et al.* (1984), Young (1987), Calnan (1991), and Hallebeek (1992) were used as guides for these experiments. Because of the small number of samples, these tests were conducted to illustrate trends, not to generate statistically significant figures. The tests were conducted as follows:

Vegetable Tan Spot Test

Two small samples, approximately 2 mm^2, were prepared and placed on a single glass slide, each with its own coverslip. A drop of 2% ferric sulphate was deposited with a pipette at the edge of the coverslip of one of the pair, and the sample was observed for any color change. A positive test results in the formation of iron tannate, which has a dark purplish color, and indicates the presence of tannins.

Elemental Analysis (EDX) and Scanning Electron Microscopy (SEM)

These analyses were conducted at the Department of Metals and Materials Engineering at the University of British Columbia in Vancouver. Combined SEM and EDX tests indicate which elements are present in the samples and aid in the identification of tannage. SEM photos of hairs aid in taxonomic identification. The following is a list of procedures (Mager, 1997, personal communication).

1. A sample of skin approximately 5 mm by 5 mm was cut and stuck onto a carbon-impregnated, double-sided sticky tab on an SEM stub, fur side down.
2. The skin samples were put into a carbon evaporator and pumped to a vacuum of 5×10^{-5} torr. Approximately 25 nm of carbon were evaporated onto the skin samples by direct current heating the carbon. The samples were rotated during coating to get an even coat. The carbon coating is used because the EDX cannot detect elements with an atomic number lower than 11 (Na).
3 These samples were tested in the SEM at 20 kV accelerating voltage with the Energy Dispersive X-ray Spectrometer (EDX). A 0 to 10 keV x-ray spectrum was gathered from each sample and the element peaks identified. The area under each peak, above the background, is roughly proportional to the percentage of that element in the material, outside of the organic elements that are not detected.
4. For the hair photographs, a separate SEM stub with conductive double-sided adhesive was prepared for each sample. A small number of hairs was cut from each skin and pressed into the adhesive. These SEM stubs were coated with approximately 10 nm of a gold-palladium alloy in a sputter coater. The sputter coater works at rough vacuum (1×10^{-1} torr) and uses an active Ar+ plasma to distribute the Au-Pd alloy evenly over a rough sample surface. This method is superior for micrographs where EDX is not required.

pH Tests

A 0.5 g of sample was minced into fine pieces with a scalpel and placed in a beaker containing 20 ml distilled water, pH = 6.5. A magnet was placed in the beaker. The sample was stirred for two hours on a magnetic stirring plate. After sitting overnight, the liquid was poured through filter paper into test tubes and measured for pH with a Fisher Accumet™ electronic pH meter.

Conductivity

A Hanna Instruments™ digital conductivity meter was used on the same samples prepared for testing pH. This test measures the salinity levels of the samples.

Shrinkage Temperature

A small strip, approximately 5 mm long, was cut from each sample and placed inside a 0.02×6 cm glass test tube to which distilled water was added. The length of each sample was marked with indelible ink on the test tube exterior. Each sample was placed in a Rinco™ "Glasapparatefabrik" machine and submerged into a glass vessel filled with clear oil. A thermometer was inserted into the vessel for monitoring the temperature of the oil. A magnifying glass in front of the oil reservoir allowed for excellent viewing of the sample and the thermometer. The temperature was increased from room temperature at a rate of 2–3°C per minute until sample shrinkage was observed and the temperature recorded. The oil was allowed to return to room temperature after testing each sample.

Moisture Content

One gram of each sample was finely minced with a scalpel and placed in a tared 100 ml beaker. The beaker was placed in a lab oven at 100°C for nine hours and reweighed. The total moisture content of the sample was calculated from the difference in before and after drying weights. For the testing of the chilled samples, skin and fur were combined in proportion to the control samples.

Moisture Regain

A sample was cut from each of the skin types, and allowed to sit uncovered overnight at a room temperature of 22°C (72°F) and a RH of 45%. The sample was weighed on a Mettler® electronic scale for dry weight, then placed in an open enameled metal pan in the lab refrigerator. A calibrated ACR® datalogger was placed on the wall next to the samples to measure the temperature and RH. The temperature and RH were also spot monitored with a small thermohygrometer. From readings off the thermohygrometer, the refrigerator thermostat was adjusted to a range of 4–6°C (40–43°F) to simulate the temperature of the cold storage vault used for the natural history specimens.

The samples were measured weekly for three weeks. Each sample was quickly placed in a pre-weighed clear Ziploc® brand plastic bag, sealed and weighed for wet weight. The difference between the dry and wet weights is the amount of moisture sorbed by the sample. Each sample was then removed from its bag and weighed again at increments of 15 minutes and then 30 minutes until the weight stabilized. This generally took about five hours. The difference between the new dry weight and the wet weight was the amount of moisture desorbed by the sample. The percentage moisture gained was calculated by dividing the moisture adsorbed by the last dry weight measured. The percentage moisture lost was calculated by dividing the moisture desorbed by the last wet weight measured. The samples were then returned to the refrigerator for two more weekly cycles.

After the third week of refrigeration and weighing, the samples were shaved with a scalpel. The hair was retained in separate petri dishes. New dry weights were measured for the shaved skins and hair samples, and the refrigeration and weight measurement cycle was continued for another three weeks. In this case each skin and each hair sample was bagged and weighed separately. The hair was removed in order to determine how each would react to the chill-thaw cycle and if there were differences in their reactions.

RESULTS

Results of Chemical Analyses

The results of the tests (see Table 4) indicate that all the samples may have been alum tawed, which is a semi-tanning process using aluminum sulphate. The vegetable tan tests and elemental analysis show that samples 1, 3 and 4 do not differ significantly from sample 2, which is known to be alum tawed. However, because sample 3 denatured more quickly in water than the others, it may have been treated with little or no preservatives beyond high concentrations of sodium chloride. The pH levels are normal for skin, indicating there is not a high level of deterioration in the samples. The conductivity tests show that the relative salt levels of the samples are high. The shrinkage temperatures are also within levels expected for alum tawed skins, which are generally 10°C below that of raw collagen. The moisture content levels for sample 1 and 2 are slightly high, perhaps due to their longer and thicker hair. The normal level for skins is approximately 15% (Raphael, 1993).

Results of Chemical Analyses (Chilled Samples)

There was a slight rise in pH in all the samples except sample 2, which decreased slightly (Table 4). This result and the lower shrinkage temperatures may be related to the large increases in conductivity, which indicates that a greater amount of salts migrated out of the skins into solution after chill testing. There was also a decrease in the moisture content in all of the samples.

Table 4. Results of chemical analyses of skin samples, before and after chill-thaw treatments.

Test	Sample #1		Sample #2		Sample #3		Sample #4	
	Control	Chilled	Control	Chilled	Control	Chilled	Control	Chilled
Vegetable tan	Negative		Negative		Negative		Negative	
EDX	C, O, Na, A1, Si, S, C1		C, O, Na, A1, Si, S, C1, K		C, O, Na, A1, Si, S, C1, Ca		C, O, Na, A1, Si, S, C1, K, Ca	
pH	3.5	3.7	3.8	3.6	4.1	4.2	3.6	3.9
Conductivity	4,890 μS	6,500 μS	1,870 μS	2,710 μS	3,050 μS	9,200 μS	3,550 μS	4,300 μS
Shrinkage Temp.	48°C	45°C	50°C	49°C	53°C	48°C	48°C	42°C
Moisture Content	19%	17%	20%	16%	13.5%	12.4%	15%	13%

Moisture Relationships and Regain Ability

Figure 1 shows the measurements of the actual weight fluctuations due to alternating treatments of one week cycles between the room environment of 22°C (72°F) and 45% RH and the refrigerated environment of 4–6°C and 25–35% RH for all of the samples tested during weeks 1–3. Figure 2 shows the same measurements for weeks 4–6, after the samples were shaved. Table 5 shows the calculations used to determine the percentage moisture change of all of the samples over the six week period.

Figure 3 shows the change in percentage equilibrium moisture content (EMC) for all of the samples tested during weeks 1–3. The percentage moisture gained and lost were added and subtracted sequentially to and from the initial moisture content measured from the control samples. The same relationships cannot be shown for the skin and fur samples tested between weeks 4 and 6, because there was not enough sample available to measure the EMC at the beginning of week 4. Because there was only one set of samples tested, the final moisture content measurement was made on a combination of skin and fur.

Physical Changes

There were no observed physical changes in the samples. The tested samples were compared to the control samples in terms of skin thickness, skin color, skin texture and flexibility, and degree of birefringence.

Discussion

The observation and testing of physical and chemical characteristics of the samples did aid in identifying the specimens' taxonomy to the family level and in assessing their present condition. Results from the vegetable tan spot tests, elemental analysis and shrinkage temperature tests helped to narrow the range of possible techniques used for the preservation of the samples.

The moisture relationships of skin in cold storage can be explained in terms of the water vapor in the air (RH) with the moisture in the material [quantified as the equilibrium moisture content (EMC), or by the water activity (a_w) (Florian, 1994)]. The following are definitions of the factors used to explain moisture relationships using the water activity model. The moisture content is the percentage of moisture per dry weight of the material. The EMC is the moisture content in equilibrium with the environmental RH (Mannheim, 1994). The a_w is a thermodynamic equilibrium parameter and is defined by the equation (Karel, 1975):

$$a_w = p/p_o$$

where:

p = partial pressure of the water held in the material
p_o = vapor pressure of pure water at a given RH and temperature

A moisture isotherm defines the relationship between the a_w and EMC where a change in temperature will affect the vapor pressure, so that at any given moisture content the a_w decreases with a decrease in temperature (Kapsalis, 1987). Hysteresis is the effect where the isotherms for adsorption and desorption differ, because a lower vapor pressure is required to reach a certain moisture content by desorption than by adsorption. In a given material, the capillary pores become elastic

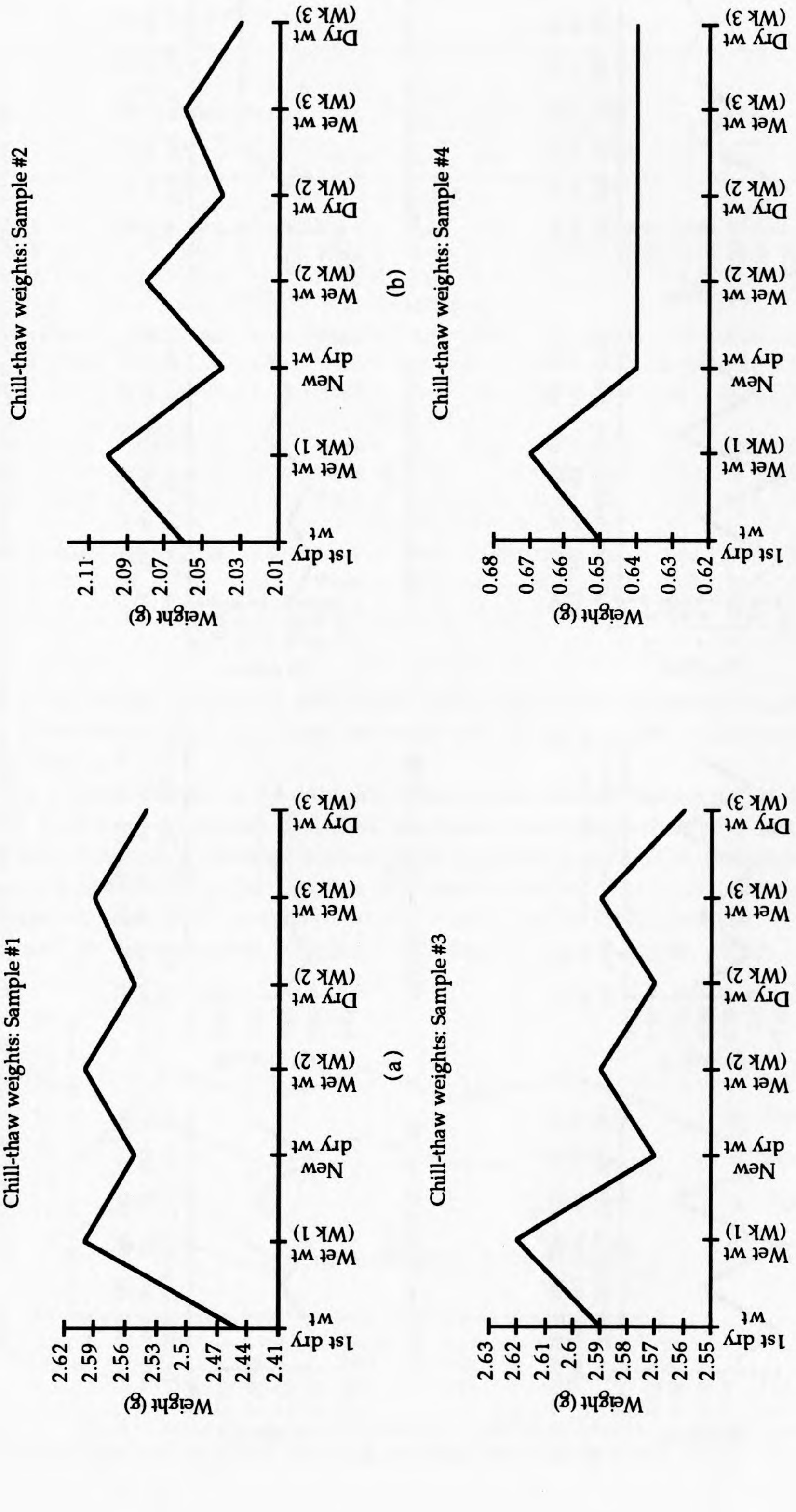

Figure 1. Graphs showing weights of the four skin samples measured during alternating chill-thaw treatments over time, weeks 1–3.

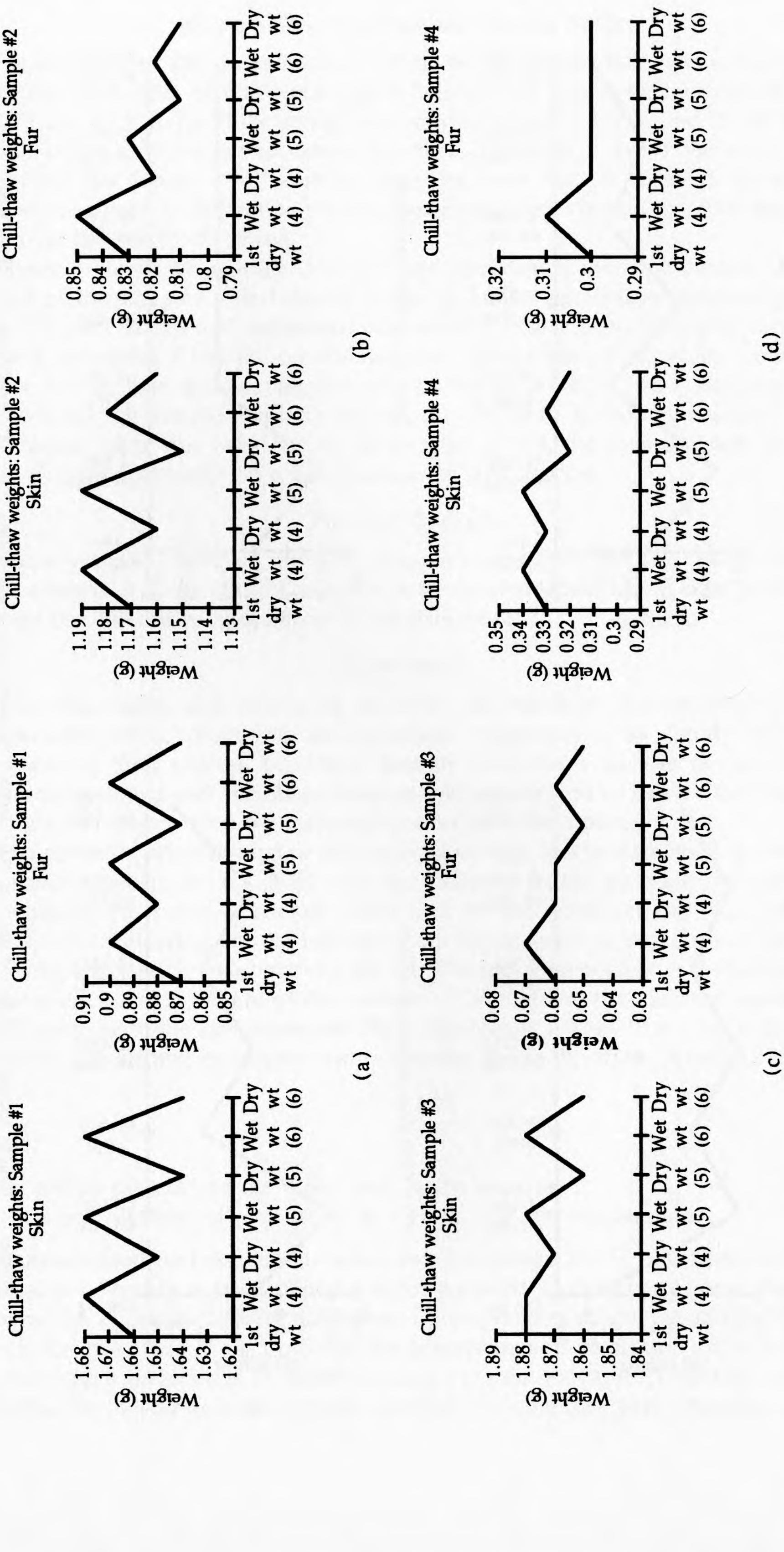

Figure 2. Graphs showing weights of the four skin and fur samples measured during alternating chill-thaw treatments over time, weeks 4–6.

Table 5. Calculations of moisture gain and loss used to determine % equilibrium moisture content (EMC), from chill-thaw treatments, weeks 1–6.

Time	Moisture adsorbed (g)	Moisture desorbed (g)	% Moisture gain	% Moisture loss	Time	Moist. adsorbed (g)		Moist. desorbed (g)		% Moist. gain		% Moist. loss	
						Skin	Fur	Skin	Fur	Skin	Fur	Skin	Fur
SAMPLE #1													
Week 1	0.15	0.05	6.12	1.92	Week 4	0.02	0.03	0.03	0.02	1.20	3.45	1.79	2.22
Week 2	0.05	0.05	1.96	1.92	Week 5	0.03	0.02	0.04	0.03	1.82	2.27	2.38	3.33
Week 3	0.04	0.05	1.57	1.93	Week 6	0.04	0.03	0.04	0.03	2.44	3.45	2.38	3.33
SAMPLE #2													
Week 1	0.04	0.06	1.94	2.86	Week 4	0.02	0.02	0.03	0.03	1.71	2.41	2.52	3.53
Week 2	0.04	0.04	1.96	1.92	Week 5	0.03	0.01	0.04	0.02	2.58	1.22	3.36	2.41
Week 3	0.02	0.03	0.99	1.46	Week 6	0.03	0.01	0.02	0.01	2.61	1.23	1.69	1.22
SAMPLE #3													
Week 1	0.03	0.05	1.16	1.93	Week 4	0	0.01	0.01	0.01	0	1.52	0.53	1.49
Week 2	0.02	0.02	0.78	0.78	Week 5	0.01	0	0.02	0.01	0.53	0	1.06	1.52
Week 3	0.02	0.03	0.78	1.17	Week 6	0.02	0.01	0.02	0.01	1.08	1.54	1.06	1.52
SAMPLE #4													
Week 1	0.02	0.03	3.08	4.48	Week 4	0.01	0.01	0.01	0.01	3.03	3.33	2.94	3.23
Week 2	0	0	0	0	Week 5	0.01	0	0.02	0	3.03	0	5.88	0
Week 3	0	0	0	0	Week 6	0.01	0	0.01	0	3.03	0	3.03	0

and swell during adsorption and shrink and collapse during desorption, due to the loss of moisture. This structural alteration will result in a loss of hysteresis (Kapsalis, 1987).

The weight change in the samples tested is due to loss and regain of the EMC. After each chill treatment the EMC increased. Sample 1 showed a net increase in EMC, because it never desorbed to its original weight. The presence of hysteresis is indicated by the obvious differential between moisture adsorption and desorption. The other samples showed a net loss in EMC, because they never regained to their original weights, indicating a loss of regain ability. Also the

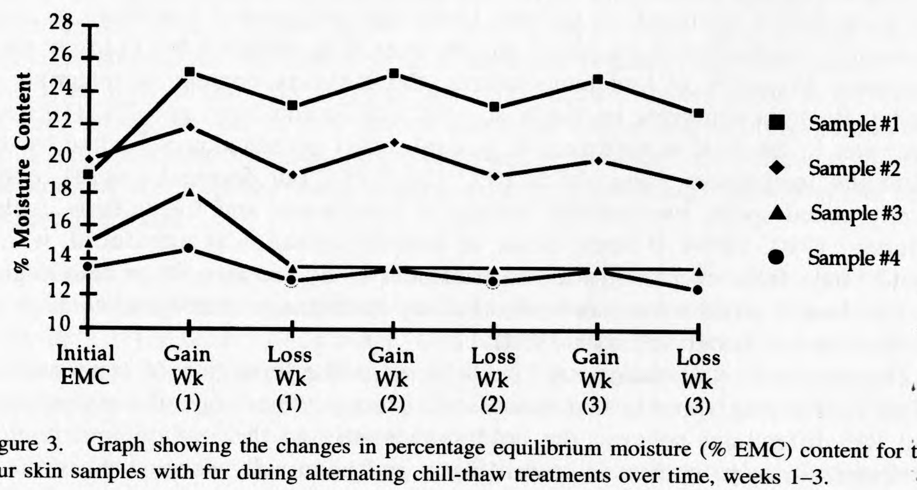

Figure 3. Graph showing the changes in percentage equilibrium moisture (% EMC) content for the four skin samples with fur during alternating chill-thaw treatments over time, weeks 1–3.

amount of moisture regained by the samples decreased with each successive week. The difference between the amount of moisture adsorbed and desorbed by the samples flattened out over time, indicating a possible loss of hysteresis.

In weeks 4–6, when the fur and skin were tested separately, all the skins continued to show a loss of regain ability. The fur of samples 1 and 4 did regain to their original weights. The fur from sample 4, however, showed a lack of ability to adsorb or desorb any moisture after the fourth week. This is the same pattern exhibited by sample 4 during the first three weeks of testing. Because the shaved skin showed a different pattern of regain in this case and in sample 3, it is well worth testing shaved skins. It is also advised to have two separate sets of samples for testing, one shaved and one unshaved throughout the entire testing period. Samples 1 and 2 furs responded similarly to their skins.

The a_w of a material will determine whether it will absorb or desorb moisture when exposed to a certain RH (Mannheim, 1994). The a_w can be reduced for preserving a material by adding solutes such as salts or sugars to the solution. The solute will lower the a_w, but normally will not lower the EMC. This is the basis of the preservation of skins by tanning with salts. The salts alter the vapor pressure of the water in the skin as well as deposit salts between the collagen fibers, acting to reduce the amount of moisture the hide will sorb, reducing swelling, and keeping the capillaries from collapsing (Haines, 1991). Untanned skin sorbs the most moisture, followed by chrome tanned, then vegetable tanned skin, reflecting different moisture isotherms for skins with different tannages (Abaji and Abaji, 1989).

The chemical analyses of the chilled samples indicate that there was a migration of tanning salts, which may have contributed to the reduction in shrinkage temperatures. According to Haines (1987), high salt concentrations generally increase shrinkage temperatures. Salt migration can cause capillary collapse and loss of flexibility, leaving the skin more prone to chemical degradation (Raphael, 1993; Williams, 1997, personal communication). For skins preserved with pseudo tannages, which are not moisture resistant, it is critical that moisture relationships are stable.

Another reason water relationships are important is the higher the level of a_w, the higher the chemical reactivity in the system, which leads to an environment more conducive to microbial growth. Under the refrigerated conditions of cold storage we might expect microbial growth rates to be reduced due to lower temperatures. However, at low temperatures, the moisture content of materials is higher. Bacteria can grow on foods at −5°C (23°F) and fungi at −7°C (19°F) if the water in the food is unfrozen. In general, fungi germination is limited by the minimum temperature range of 0–10°C (32–50°F), but dormant conidia, commonly called spore, can survive storage in cold water and freeze-thaw cycles (Florian, 1990, 1994). If some factor of conidia activation is introduced, which could range from chemicals used in treatment to by-products of protein degradation, fungal germination can be induced by fluctuations in RH and by high a_w levels in the substrate (Florian, 1994).

The moisture relationships are also a factor in the formation of condensation when transferring skins in and out of cold storage. The larger the temperature and RH differential between the cold store vault and the rest of the museum environment, more condensation will form and potentially damage the skin. in addition, the more often and longer the cold storage door is opened, the more likely extreme fluctuations will occur. Michalski (n.d.) recommends placing the objects in plastic bags for 24 hours until room temperature is reached, in order to alleviate the condensation problems.

The transfer of skins in and out of cold storage raises another concern with the use of suboptimum temperatures for the control of insects. Many insects have the ability to become cold tolerant through the process of acclimatization (Mellanby, 1954; Mullen and Arbogast, 1984; Florian, 1986; Fields, 1992; Strang, 1992). In order to insure insect mortality, all objects brought in and out of cold storage should be acclimated to room temperatures prior to freezing for eradication. It has been shown that the practice of freezing insects for eradication is quite effective (Mullen and Arbogast, 1979, 1984; Florian, 1986, 1990, 1994; Brokerhof *et al.,* 1992, 1993; Fields, 1992; Strang, 1992; Wellheiser, 1992).

Conclusions

In this analysis of the effects of cold storage on skin, the following concerns have been raised. The moisture relationships in the cold storage environment can be conducive to microbial growth, especially in the event of mechanical failure. The transfer of unprotected skin in and out of cold storage can cause damaging condensation. Insects can acclimate to cold storage temperatures thus avoiding death at lower temperatures. Finally, as the results of the pilot experiment show, as mammal skins are cycled in and out of refrigerated conditions, they exhibit a loss of moisture regain and possibly a loss of hysteresis over time. The apparent loss of hysteresis may be caused by the migration of salts out of the interfibular areas of the skins and indicates capillary collapse. With pseudo tannage techniques such as alum tawing and salt pickling, extensive salt migration could reverse the tannage and lead to accelerated degradation of the skin.

These results cannot be generalized because of the small number of samples tested and the many unknowns of the sample histories, such as genus, gender, age, history of preparation, treatment and storage. The intent of these experiments, however, was to assess whether changes were taking place that could warrant further study. In order to gather results that can be generalized, similar but more extensive studies need to be conducted with larger numbers of samples of known histories and over a longer period of time. Samples with different and known tannages should also be tested, such as different vegetable, oil and mineral tannages, as well as rawhide. Another area that requires investigation is the effect of cold storage on oils in skin and fur garments with regard to oil migration and lipid oxidation. Until further information can be gathered, the following recommendations are proposed for managing existing cold storage units used for museum collections:

- *Consider raising the temperature of the cold storage unit to within 10°C below the room temperature outside the unit.* As the temperature is raised the moisture content of the skins will decrease. This higher temperature level will also reduce the risk of condensation problems resulting from transferring objects in and out of cold storage. It is easier to maintain a more stable and desirable relative humidity level with the higher temperature.
- *Consider bagging objects before moving them in and out of cold storage to*

reduce the formation of condensation. Keep objects in bags until they acclimate, as one would when using freezing temperature treatments.

- ***Implement an integrated pest management approach for the pests of skin and fur garment collections.*** **Skin and fur garment collections should be regularly inspected. If integrated pest management is practiced correctly, cold storage will basically become unnecessary as an insect control technique.**
- ***Monitor the RH and the temperature of the cold storage unit and install security alarms.***

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NOTES

The Contribution of In-State Depositories to the Natural History of Their States.

In 1940 (Grobman, 1941) I studied the geographic variation in scalation of the Smooth Green Snake, *Liochlorophis (Ophrodrys) vernalis.* In pursuing that study I attempted to examine all available specimens in United States and Canadian collections.

In 1990 (Grobman, 1992) I restudied the species and examined extant specimens from the same collections.

A substantial increase in the amount of study material had become available in the 50 year interval between the two investigations. In the twelve states selected for this report, specimens were available for examination from 112 counties in 1940. In 1990 specimens were available from 206 counties in those same states. Table 1 shows the number of counties, in each of twelve states, from which specimens were available for examination when the two studies were conducted. Also indicated are the active natural history depositories known to me in each of those states when the studies were made. Increases in those states without active depositories during the 50 year period were primarily the result of increases in the number of specimens housed in major national collections outside of the states in question, such as the United States National Museum and the American Museum of Natural History.

Consolidation of the data from Table 1 is presented in Table 2. Inspection of that table suggests that an increase in the knowledge of the natural history of a state is enhanced by the presence of an active depository in that state.—*Arnold Grobman, Adjunct Curator, Florida Museum of Natural History, Gainesville, Florida 32611.*

Table 1. Number of counties (in selected states) represented by specimens of *Liochlorophis* (*Opheodrys*) *vernalis* in natural history museum collections in twelve states.

State	1940	1987	Active natural history collection in the state
CO	6	15	University of Colorado Museum
IL	9	19	Field Museum of Natural History; Chicago Academy of Sciences; University of Illinois Museum of Natural History; Illinois Natural History Survey
IN	3	8	
IA	13	19	
MI	34	53	University of Michigan Museum; Michigan State University Museum
MN	6	18	University of Minnesota Museum
NE	3	7	University of Nebraska Museum
NM	6	10	University of New Mexico Museum
ND	4	7	
OH	12	12	
WI	14	32	Milwaukee Public Museum; University of Wisconsin Zoology Museum
WY	2	6	University of Wyoming

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Table 2. Increases in states with, and without, active in-state depositories.

With/without active depositories	Counties represented 1940	Counties represented 1987	Percent increase
With (CO, IL, MI, MN, NE, NM, WI, WY)	80	160	100
Without (IN, IA, ND, OH)	32	46	44

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BOOK REVIEWS

LEARNING FROM THINGS: METHOD AND THEORY OF MATERIAL CULTURE STUDIES, 1996, W. David Kingery, ed. (Smithsonian Institution, Washington and London, 262 pp.) This collection of essays grew out of a 1993 Smithsonian conference on material culture and represents editor W. David Kingery's commitment to interdisciplinary collaboration and dialogue among material culturists and others. Thirteen contributors examine the ways in which they and their profession use the study of material culture—that is, any kind of object—to recreate, record, and understand the past. Widely varied disciplines, outlooks, and partialities are represented by distinguished scholars.

Jules D. Prown colorfully characterizes scholars interested in material culture as different in kind, being either "farmers," hard systematic thinkers occupied with object attributes that are consciously part of the makers intention, or "cowboys," soft humanists interested in objects as the embodiment of cultural belief systems and as metaphors able to transfer information to the viewers unconsciously. Truth or reality, according to Prown, is likely to be best served through collaboration between hard and soft material culturists. Prown's thinking and challenge are supported by the balance of the essays.

Steven Lubar, Joseph Corn, and Ruth Oldenziel, all historians of technology, examine how objects are studied. As material culturists, these scholars look at utilitarian tools because machines and devices represent technological knowledge. Lubar regards the understanding of how a machine works as only a preamble to confronting the larger issues of American history—for example, issues of cultural and social change, and issues pertaining to ethnicity and gender. For Lubar an object is an encoded text, which the technological historian reads or decodes. Corn's analysis of the methodology of a great many historians of technology presents a strong case for collaboration with more object-centered culturists. Because Corn believes that society privileges knowledge based upon abstract, theoretical study, his research—and apparently that of several of his colleagues—is quite distanced from actual things. By comparison intuitive knowledge, which has a long, honorable history, appears to lack intellectual rigor despite being intimately dependent upon the object itself. Oldenziel argues for the multivalent nature of material artifacts, holding that while a technological object may remain materially stable, the object means different things to its various users. To acknowledge this is to understand that the meaning of objects is shaped by human activity. Oldenziel muses about what may come in our electronic age with the changing shape, or indeed immateriality, of technology, arguing that the methods by which material culture is studied need to be examined, if emerging challenges are to be met.

The formation process, or assembling of collections of and records pertaining to material culture, is the subject of several essays introduced by Michael Brian Schiffer. Schiffer reminds the reader that the past does not exist and that understanding the past is at best a science dependent upon inference. Such inferences are based only upon those material objects and records that survive. Schiffer's amusing study of shirt pocket radios and the subminiature tubes that drove their early production utilizes several kinds of surviving evidence, thus supporting

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Schiffer's precept that researchers look beyond traditional lines of evidence. Marjorie Akin analyzes the private collector with the objective of developing a research strategy that includes access to the vast amount of material and information in private hands. Several insightful essays speak to broadening one's view of the evidence to include, for example, how collections came to be and the presentation context.

Essays by W. David Kingery, David Killick, and Michael S. Tite emphasize the consequential nature of materials science data to the study of material culture. Kingery, Killick, and Tite cite examples of science's maturing ability to measure and analyze, such as radioactive carbon dating and high level magnification, which demand attention from the material culturist. Interdisciplinary efforts are called for by the three contributors to this section. For example, the structure of a material helps define how the craftsperson, artist, or industry will use the material, and a scientific method such as high level magnification may reveal, with *hard* data, an internal structure otherwise unavailable. Thus a *soft* analysis or interpretation may be strengthened. Also, insular specialization that characterizes many disciplines today leads to fragmentation of evidence, which may be offset by interdisciplinary dialogue and collaboration.

Learning From Things, as a collection of articles, hits a theoretical bull's eye. Editor Kingery's viewpoint that those of us who undertake the study of material culture might engage in dialogue and collaboration that crosses the boundaries of specialization in order to enrich our work and get closer to the truth of objects is validated by the content, scope, and depth of the various discourses. It is easy to imagine that the conference, which preceded the publication of these essays, sparked energetic conversation. Prown reports of those assembled at the conference that, "we gather together because we want to be together, to find common ground, and we bend over backward, as we should, to be polite."

While several of the contributors demonstrate the productive results of following diverse lines of evidence and consulting with unconventional sources, the essays stand alone, interrelated primarily by virtue of Kingery's vision and the given subject categories. One cannot but wish to hear Steve Lubar, who holds that objects are encoded texts, discuss the potential meaning within things with Catherine Fowler and Don Fowler who write that "ethnographic collections, sans documentation, have no knowledge value." Although the contributors to this volume have provided a solid basis for teaching research methods and for discussing complex notions central to material culture studies, one hopes that the next conference and publication will have a format within which dialogue and collaboration between specialists may be presented. That hope, which gradually comes into focus upon the reading of the articles, gives force to Kingery's purpose.—*Linda Foss Nichols, Museum of Fine Arts, Boston, 465 Huntington Avenue, Boston, Massachusetts 02115.*

DEVELOPING STAFF RESOURCES FOR MANAGING COLLECTIONS, 1996, P. S. Cato, R. R. Waller, L. S. Sharp, J. Simmons, and S. L. Williams, eds. (An Initiative Cosponsored by the Canadian Museum of Nature and the Virginia Museum of Natural History, Virginia Museum of Natural History Special Publication Number 4, Martinsville, Virginia, 71 pp.) This unique contribution to the museum literature fills a void and addresses a need recognized in that literature. In 1993 *"Preserving Natural Science Collections: Chronicle of Our Environmental Heritage,"* (W. D. Duckworth, H. H. Genoways, and C. L. Rose, eds., National Institute for the Conservation of Cultural Property, Inc.) cited education and training initiatives for museum staff as one of its keystone recommendations. Needs in the areas of formal in-service education, informal professional exchanges and pre-service education were stressed. In 1994 a workshop was held at the Canadian Museum of Nature to further explore the topic of professionalism in museums and trends in the natural sciences that impact collecting institutions.

The present work is basically a report summarizing the conclusions of the workshop's thirty participants (all of whom are listed in it). The study resulted in a suggested process and a set of analytical tools with which museums can assess their personnel resources for managing collections. In articulating these, *"Developing Staff Resources"* characterizes staff as "the most important resource an institution has to manage its collection." It then suggests guidelines for museums to use when planning professional development agenda that are specific to institutional needs and goals.

An excellent feature of the book is the tabular organization of most of its salient points. In a well-planned series of twenty-two tables the book summarizes such useful information as museum pressures and trends originating both within and outside the museum community, knowledge and skills required to implement effective collection management systems, potential clients and possible products of collection management systems, and relationships between clients and products. These graphic summaries are often presented as multi-unit grids that span double-faced pages rendering the material easy to read and highly accessible. These information-rich tables are distributed throughout the book and essentially provide comparative baselines with which museums can assess their specific professional development needs.

A thesis central to the book is that in determining priorities for professional development a museum should rank the importance of products and services they deliver relative to how these relate to collection management; also, the frequency of delivery of these products and services should also be considered. Finally, in a thirteen point protocol organized as an appendix, the book outlines specific steps (including worksheets) museums can follow in planning professional development programs consistent with their needs, mission, and goals. A four page resource list provides a bibliography of relevant literature and a number of curricula and training program opportunities. A glossary of museological terms is also included.

This book is recommended for all individuals responsible for museum administration, especially for those involved with human resources and long-range planning issues. It is also recommended as superb supplemental reading for museum studies courses. The publication of this book underscores the growing profes-

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sionalism and standards of excellence that have characterized collection management over the last decade and is an important contribution to its literature.—*Marilyn R. Massaro, Museum of Natural History, Roger Williams Park, Providence, Rhode Island 02905.*

GUIDELINES FOR INSTITUTIONAL POLICIES AND PLANNING IN NATURAL HISTORY COLLECTIONS, 1994, K. E. Hoagland, ed. (Association of Systematics Collections, Washington, D.C., 120 pp.). Museums and other collecting organizations are facing increasing levels of accountability for standards and service, often from outside sources. Consequently, they are appreciating the efficacy of internal planning and policy documents. Each repository needs to have planning and procedural documents; these are most functional when they specifically address each organization's situation, and thus best when drawn up in house. This ASC publication will guide museums, universities and other collecting bodies through the process of developing appropriate, individualized policies and plans. Help is here and in a usable form. It is not a template aid where one fills in the blanks. It does outline, in a comprehensive manner, the many factors to be considered when drawing up or revising these important documents.

Sixteen topics are addressed followed by an appendix consisting of the SPNHC Guidelines for the Care of Natural History Collections. A general bibliography precedes the references listed for each chapter. A brief summary of the topics covered is as follows:

1. The planning section begins with coverage of the *Mission Statement* which describes the organization's fundamental purpose, hence its goals. Two "styles" are recognized: one being a brief quotable statement which can also be an external marketing tool, and is often supplemented by a more lengthy declaration; the other is a longer document asserting the operating philosophy of the institution. Several sample mission statements are included.
2. *Strategic Planning* implements the mission statement in order to achieve the institutions's goals, and is a continuous process.
3. *Acquisitions and Accessions* begins the section on policies and procedures with collections origins, i.e., their acquisition and formalization of ownership.
4. *Management and Care of Collections* policies articulate the commitment to manage the collections, the basic resource for the organization, as accountability is a legal as well as an ethical issue.
5. *Access and Use* offers far-ranging considerations in regard to physical access at the home institution and through outgoing loans.
6. *Destructive Sampling* is treated separately from access and use issues as it is unlike other transactions in that it involves a relationship between the institution and the individual user, preferably formalized in a signed contract format that aims to minimize the effects of sampling.
7. The *Deaccessions* entry does not provide much innovative advice for those familiar with this process. However, the specifics provided for natural history collections are uniquely relevant, such as coverage of (botanical) duplicate exchange and the (entomological) practice of transferring specimens for identification.
8. *Documentation and Databases* describes a broad array of materials and data to be provided for in policies to develop, safeguard and use collection based information.

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9. A program for *Archives and Records* complements other efforts to manage and care for collections. It would seem, though, that it might work best under the guidance of a professional archivist.
10. The issue of *Ethics* is one of importance to staff, board and volunteers. A properly designed Code of Ethics helps individuals avoid questionable as well as clearly improper conduct. Policy elements are provided as well as excerpts from a museum employee handbook. Comments regarding "conflict of interest" include more than the expected restrictions against personal collections.
11. The *Field Research and Collecting* section emphasizes a "follow the rules" approach, and recognizes that a permit confers a privilege. The Collecting Etiquette portion and Foreign Field Research coverage contain much trouble-shooting wisdom.
12. A *Repatriation* policy need not concern itself solely with transfer of materials, but should be part of developing a "positive long-term relationship" with affected groups. Issues surrounding Repatriation straddle legal, ethical and social concerns when the organization enters the murky waters of competing claims, intellectual property rights, among other issues, to determine what can or should be returned.
13. A *Health and Safety* program protects staff and visitors. The policy needs to be both proactive and remedial.
14. The unit on *Hazardous Wastes* provides guidelines for small to mid-size institutions lacking Health and Safety personnel.
15. *Emergency Preparedness* planning encompasses: risk management to identify potential emergency situations, establishment of avoidance strategies, as well as strategies for dealing with these situations.
16. *Disposition of Orphaned Collections* deals with planning measures that can be taken by both institutions, and private individuals who amass research-quality collections.

The publication is what it says it is and is what one expects it to be. It is bare bones in many ways, yet more fleshed out and helpful in a practical sense than other recent efforts. All essential issues are covered, with the possible exception of a Conservation Plan which lays out strategies for addressing conservation problems in a logical, feasible manner. There is brief mention of the need for a policy on preventive conservation, and some concerns (e.g., Integrated Pest Management, collections-specific standards) are presented. However, omission of conservation planning as a distinct policy/planning item, on a par with the others, diminishes its importance as a management focus.

Some topic coverage applies to collection management in general, while others such as destructive sampling and field collecting, are most welcome because they are specific to natural history situations. Most importantly, all of it is natural history, appropriate whether for a whole institution devoted to natural history or to natural history department(s) within a larger organizational context.—*Ann Pinzl, Nevada State Museum, 600 North Carson Street, Carson City, Nevada 89701.*

MANUAL OF NATURAL HISTORY CURATORSHIP, 1994, G. Stansfield, J. Mathias, and G. Reid, eds. (Museums & Galleries Commission, HMSO Publications Center, London, 306 pp.) This title fills a void in the curatorial literature for a how-to manual covering all aspects of natural history collection management. It is the only text available to date that provides an overview of subjects relevant to curators, collection managers, and students in museum studies programs. With the support and assistance of the Museums & Galleries Commission, the editors, as members of the Biology Curators' Group, state their aim "to provide a basic work reference for. . .anyone concerned with natural history collections," and that it "represents a first attempt to produce a comprehensive work of reference relating only to natural history museums." In this objective they have succeeded with excellence and have set an important standard for its categorical successors.

In clear, concise, non-technical language organized into fourteen chapters further subdivided by well-defined headings and sub-headings, the book outlines curatorial methods, maintenance, and uses of natural history collections. Only a very brief (eight pages of text, two of references) chapter introduces theoretical aspects of the organization and functions of natural history museums proper; the balance of the text adheres to its mission as a curatorial procedures manual. Beginning logically with collecting methods and acquisition policies, subsequent chapters are devoted to such topics as preparation and preservation, documentation, storage, collection uses, health and safety issues, and the interpretation and exhibition of natural history specimens. One chapter deals with live animals and plants in natural history museum environments including ethical and conservation issues. The book's last few chapters cover broader topics in the realm of natural history museums proper, including how they relate to schools and curricula, information services, publications, as well as to other organizations and agencies.

It is important to note that many of the cited examples, case studies, and applications have a decidedly though not exclusively British orientation as should be expected with all eleven contributors being from the United Kingdom. This is especially apparent in the chapter dealing with education and its reference to the National Curriculum; sections of the book dealing with the legal aspects of collecting and nationally standardized documentation practices also bear a British emphasis. The introduction clearly states that the book's contributors are natural history curators in the UK and what is to follow will reflect largely British experience. However it also correctly notes that reference is also made to museum practice in other countries where it was deemed desirable to place the British experience in context. Indeed this is correct, for throughout the book case studies, examples, and chapter bibliographies include references from the United States and Canada and to a lesser extent Europe, Africa, and Australia. Indeed the comprehensive reference lists at the end of each of the fourteen topical chapters are alone worth the price of the book.

This work in no way pretends to be a primer on collection conservation; in fact only a three page section bears this heading in the chapter devoted to storage and maintenance. A section on pest control, also in this chapter, is equally brief. Similarly those interested in expanded discussion of computerized collection documentation issues will have to look elsewhere, as only two pages of text are allocated to this subject. Only a single page deals with tissue and molecular

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samples as museum specimens. Collections related to physical anthropology, archaeology, paleontology, geology, and others sometimes found in natural history museums are not treated as the scope of this manual is limited to biological collections, both botanical and zoological. About a page of text deals with archival material pertinent to these collections.

The book presents a balanced introduction to the essentials of natural history museum collections curatorship and their potential applications for research, biodiversity management, education, and exhibition. As such it stands as the only textbook/manual of its kind in the literature to date. With its clarity, conciseness, and avoidance of technical jargon, its organizational excellence and comprehensive scope, this work will undoubtedly set the standard for future publications of its kind for many years to come. It is the hope of this reviewer that it will encourage the publication of a complementary volume whose emphasis will reflect North American experience and practices.—*Marilyn R. Massaro, Museum of Natural History, Roger Williams Park, Providence, Rhode Island 02905.*

Museum Collection Resources Display Available for Loan

The Resources Subcommittee of the Conservation Committee (SPNHC) maintains a display of supplies and materials that are preferred by many museums for the storage and perservation of natural history collections. Examples of items included in the display are: materials used in the construction of storage containers and specimen supports; equipment for monitoring storage environments (e.g., Humidity, temperature, insects); and a variety of containers for the storage of collections and documentation. Some of the products are discipline-specific (e.g., pH neutral glassine for interleaving between herbarium sheets) but most can be used in multidisciplinary collections (e.g., ethafoam™ for lining shelves; Tyvek™ tape for box and tray construction). The exhibit is available for loan to interested parties for meetings, conferences, and other museum-related activities. Shipping costs to and from the requested venue are the responsibility of the borrower. There is no loan fee but SPNHC invites borrowers to make a voluntary contribution to cover the costs of routine maintenance. For additional information, or to borrow the display, contact:

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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.

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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?

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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.

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