Care and Conservation of Natural History Collections

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Vascular plants

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Introduction

An herbarium is a collection of preserved plant specimens and their accompanying documentation. The vast majority of herbarium specimens are dried, flattened whole plants or representative portions of plants, attached to a mounting sheet and/or enclosed in a paper folder which also holds a descriptive label that includes details of their collection. Other methods of preserving plant material for an herbarium include drying but not pressing (for bulky material such as fruit, seed, cones or wood samples) and preservation in spirit (see Chapter 5 on fluid preservation) and on microscope slides (see Chapter -1 on non-vascular plants and fungi).

Herbaria may contain specimens drawn from the whole range of plant material, from algae, mosses, liverworts and ferns, the so-called higher plants, the conifers and flowering plants. Several herbaria include fungi in their collection. Fungi and non-vascular plants, including all lower groups, are covered in the following chapter.

Historically, many different materials and methods have been used in the collection, preparation, preservation and treatment of herbarium specimens. There is no single historical sequence or development of approaches that would allow the compilation of a guide to the conservation needs of specimens prepared at different times. The approach has differed between countries, institutions and sometimes even individual workers and, therefore, a technique regarded as out of date at one place might still be in use at another. The quality of materials in particular varies with the budget of the preparator concerned. As most of these techniques and materials have not been documented or published, it is not possible to make definitive recommendations for all conservation procedures.

There are a variety of storage systems in use for herbarium collections around the world. Each system has its own advantages and disadvantages. The systems may be divided primarily into fixed shelving and movable compactor shelving, with secondary divisions into compartment or box storage systems, and further subdivisions into closed or open shelving systems.

Dried plant specimens can be kept indefinitely as long as they are properly protected from insect, fungal and physical damage (as discussed below). For example, specimens collected in the eighteenth century by Linnaeus or Banks and Solander are still excellently preserved (Plate 20).

When plants are correctly pressed, dried and stored they retain most of the characteristics essential for later study. These characteristics include their gross morphology and structure and, to a lesser extent, their microscopic level morphology, cellular construction, pollen structure and most of their secondary chemical constituents.

The vast majority of herbarium specimens are dried, flattened whole plants or representative portions of plants. As described at the beginning of the Introduction, such specimens are attached to mounting sheet and/or enclosed in a paper folder which also holds a descriptive label that includes details of their collection. The chemical composition of plant material varies with the group of plants but all plants (not including fungi) have some components in common which will include a high proportion of cellulose. Higher plants often contain lignin, secondary metabolites such as phenolic substances (e.g. flavonoids, resins) and other chemicals such as gums etc. Many of the lower plants, such as marine algae. contain large quantities of gelatinous polysaccharide materials such as alginate which can be quite water absorbent/deliquescent.

Some of these chemicals and compounds may be deleterious to the longevity of the specimen, changing with time, either by oxidation or by other natural decay. Whilst there is little published research on the long-term deterioration of the naturally occurring chemicals in plant specimens, Harborne (1967) covers flavonoids and Swaine (1963) discusses alkaloids and their deterioration.

Apart from the immediate changes of loss of water and desiccation of cell contents on drying, the most obvious short-term chemical changes for normally dried and stored specimens involve loss or change of colour. Little is known about long-term changes in the chemical composition of normally dried and stored plant material. The main physical changes are shape, loss of flexibility and embrittlement, and these changes appear to be primarily caused by loss of water from the specimen rather than significant chemical changes.

For herbarium specimens to be of scientific value both the plant material and its accompanying documentation must be preserved. The materials in which these are stored, i.e. the herbarium sheets etc., only serve to aid in their protection and conservation, and do not affect the botanical value of the collections. Whilst the preservation and conservation of these protective materials may not be a significant consideration for most herbarium collections, where the value accorded to the specimen rests heavily on its historical rather than its botanical value, the conservation of these materials must be considered. The emphasis in this chapter is on the conservation of the materials significant to the scientific value of herbarium specimens, i.e. plant material and documentation.

Collection and field preparation

Although not entirely relevant to this book, the initial collection of plant material directly affects its subsequent survival and therefore initial field preservation techniques are mentioned. A representative portion of the plant should be preserved to aid its recognition, and to ensure it is useful for as many purposes as are consistent with its long-term preservation. What can be preserved depends to a large extent on what was collected in the first place, and so the comments below apply to what should be included in the original collection, as well as what should be preserved once the material has been collected.

Specimen collection

Specimens should be as complete as possible, including flowers and/or fruits as well as a piece of stem bearing typical healthy leaves. In the absence of open flowers, buds should be included. If variation in leaf form is apparent, specimens should include different parts of the same plant to represent this variation. For some plants, in addition to a normal specimen, seeds are required for identification (e.g. plants in the families Caryophyllaceae, Chenopodiaceae, Cyperaceae and Geraniaceae).

Different parts of different plants and plant groups are critical for their identification. It follows that each group, and sometimes each species, has different requirements for what must be preserved for the specimen to be scientifically useful. Some variations from the norm are expanded on below.

Grasses and other plants of grass-like habit

These should be collected whole with the root-stock. A comment should be made on whether the plant was easy to pull up or not — the former usually indicating that it is an annual or the latter usually indicating that it is a perennial. Grass clumps may be divided into small tufts of leaves and flowering stalks, two or three of these tufts make a satisfactory specimen. Carefully knock off or wash away all dirt adhering to the roots. Grasses are best collected after the flowers have opened but before the fruits are ready to drop.

If the specimen is longer than the herbarium sheet, it should be bent once, twice or more, so as to form a V, N or M (according to its length), and pressed in this position. Attempts to bend it after it is dry will probably cause it to break. In the case of exceptionally tall grasses, the flowering parts, leaves and a piece of the basal parts should be collected, and a note made of the height and habit.

Woody plants (e.g. trees)

Different taxa have widely varying individual requirements for characteristics needed for identification and therefore preservation. Given the large number of species of flowering plants it is not feasible to cover them all here. Monographs and floras will give an indication of the range of critical characters for individual groups. In general, however, it should be noted that, in addition to mature leaves, specimens may need to include flower buds as well as flowers, fruits, seeds and, where relevant (e.g. *Eucalyptus)*, juvenile leaves which are often from suckers near the base of the trunk. In some species bark samples or accurate descriptions will also be needed.

Herbs

With small herbs, the entire plant should be collected. Critical collections of herbs with underground storage organs should be dug up complete with these parts. For less critical collections, a note on the characteristics of these parts should be made. The latter is preferable as it leaves the basal parts to shoot again the following year — this is especially important in the case of rare species. With larger herbs a normal sized specimen will suffice.

Water plants

Water plants should not be kept in water. The plant usually starts to decompose quickly in the warm, moist atmosphere of the container, making identification very difficult. Water plants should be carefully laid on a sheet of paper, excess water removed, and then the plants pressed and dried in the normal way. Very soft water plants may require special treatment such as preserving in alcohol or formalin solutions (see Chapter 5 on fluid preservation).

Succulents

Very succulent plants such as cacti, many species of *Ficus* (figs) and mistletoes drop their leaves (through abscission) entirely upon drying or remain alive for an excessively long period in the press. This is overcome by killing the plant before pressing, either by freezing the specimen for a few hours, clipping it in boiling water for a few minutes or by placing it in a microwave oven for about two minutes. A method commonly used, especially in the tropics, is to place the specimen in a polythyene bag with a few drops of 80⁰/6 methanol or ethanol. This will kill the specimen overnight or in a few hours and is especially good for succulents such as Euphorbiaceae or Cactaceae. Succulent material is ready for pressing when it has a flaccid, water-soaked appearance.

When the cell tissue has been killed (by freezing, alcohol poisoning, scalding or radiation) the specimen will still require attention until it has dried completely. The papers must be changed at least daily for the first few days, and complete drying in the case of cacti may take more than a month. An alternative technique is to collect succulent material in 70% alcohol which will preserve its original shape. For alcohol collections see Chapter 5 on fluid preservation.

Bulky specimens

Some very bulky objects (e.g. *Baizksia* spikes and thistle heads) may be cut or sawn lengthwise before pressing. Bulky fruits should be enclosed in wire or other strong netting bags before drying to retain the parts and their relationship. Wood blocks will need much longer drying and may need to retain bark on at least one face for identification. As the bark sometimes delaminates upon drying or with time these may also need to be enclosed in net bags before drying.

Ferns *(including fern allies, e.g. horse-tails)*

Specimens should include fertile (sporebearing) fronds and sterile fronds, as well as part of the rhizome (if present) or base of the stem (stipe). Tree ferns should include a portion of a fertile frond and the base of the frond stalk bearing scales or hairs.

Cycads

Whole fronds, including the bases, are needed with some species. Cycad fruits may be very large and bulky, and may need to be enclosed in a net bag prior to drying to retain the parts and their relationship.

Conifers

Conifer cones are often too bulky to be included on standard herbarium sheets and large examples should be enclosed in a net bag before drying (as for cycads) (Page, 1979).

Pressing

Techniques for pressing and drying specimens have been established for many years. There are minor variations in recommended methods, but they are essentially the same world-wide. The information given here is adapted from Bedford and James (1992). Bridson and Forman (1992) gives an equally informative account for the plant collector.

Specimens should be pressed as soon as possible after collection, before wilting and shrivelling can take place. In the seventeenth, eighteenth and nineteenth centuries a metal box called a 'vasculum' was used to keep the specimen fresh until ready for pressing, but today this has been replaced by plastic bags. Most plants can be kept sealed in containers such as plastic bags for up to a day if it is inconvenient to press immediately. However, some plants (e.g. begonias) show such rapid wilting, particularly the flowers, that delays must be avoided. Moreover, flowers with a lot of nectar may go mouldy very quickly if excess nectar is not shaken off before pressing.

Specimens are pressed flat and dried between sheets of special absorbent blotters available as White Buffered Blotter (Preservation Equipment) and Multisorb Wet Strength Paper (Conservation Resources), or semi-absorbent paper such as newspaper. Papers with a glossy surface should be avoided because they are not absorbent enough to aid drying. Specimens should be carefully laid out between the drying sheets, as their form at this stage largely determines their ultimate appearance. Wilted leaves should be straightened and unnecessary shoots of excessively twiggy shrubs cut away.

Sheets of thick, preferably smooth-sided, centre-corrugated cardboard or corrugated metal plates placed between the drying folders will assist air circulation through the press. These are particularly necessary when using a forced circulation of warm air. If such cardboard is not available, additional sheets of newspaper or wooden board (e.g. plywood) may be used to absorb moisture from succulent specimens.

When plants are uneven in thickness, for example where flowers are borne on thick twigs or arise from a thick bulbous base, sheets of spongy plastic foam (polyurethane or a similar substance) about 1 cm thick, placed between the newspaper folders, help to distribute pressure evenly across the specimen. If foam sheets are not available, several thicknesses of folded newspaper may be used. Care must be taken to ensure that 'damp spots' do not develop in the press. When using foam sheets it is advisable to circulate warm air around the press (e.g. from a light-box or sump heater).

Specimens are best pressed with moderate pressure, preferably in an arrangement which will permit as free a circulation of air as possible. This can be achieved by strapping the pile together in a press, i.e. between frames made, for example, from sheets of heavy (non-bending) cardboard, hardboard, plywood, pegboard or, best of all, a lattice of wood strips or metal frames (Fig. 3.1). Supplies of suitable materials can usually be obtained from packaging and cardboard manufacturers, who will cut materials to suitable sizes, or from hardware or building suppliers. The press frames should be the same size as or a little larger than the drying papers. (Amateur collectors often press small numbers of specimens in books or by placing weights on a pile of specimens, but this is not ideal because of factors such as slow drying and uneven pressure.)

Drying

When drying takes place unassisted or by natural air movement, the plant press should

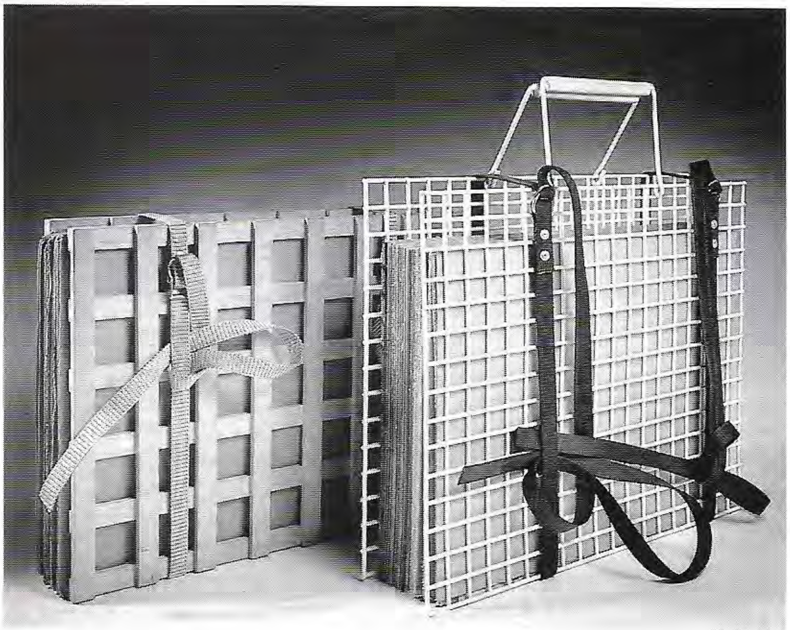

Figure 3.1 Two plant presses, one made up in a carpentry workshop from wood strips, the other supplied by a manufacturer of plastic-coated steel mesh.

be checked daily at first for dampness and damp papers replaced. Subsequent changes will depend on the original succulence/water content of the specimen as well as the weather conditions and relative humidity levels. Most plants should dry in less than two weeks. However, in tropical and wet conditions, daily changes will be necessary throughout the drying period, but in drier conditions the last one or two changes need only be given at intervals of three or four days.

Assisted air movement in reasonably dry climates can be aided by securing the presses to a car roof-rack whilst driving in dry daytime conditions. If available, a hot-air fan directing air around the press will also assist drying. Drying cabinets with a forced circulation of warm air are used in large herbaria to shorten drying time and to lessen the need to change drying papers (Fig. 3.2), but are not necessary for small quantities of specimens.

Under humid, tropical and coastal conditions special methods must be adopted to prevent rapid mould growth before the specimens can be placed in drying cabinets. Placing the entire bundle of drying papers and specimens in a plastic bag and adding a quantity of ethyl alcohol is a method commonly adopted. This is sometimes called the 'Schweinfurth method', after an Austrian botanist who collected extensively in tropical areas (Bridson and Forman, 1992; van Steenis, 1950). Such methods alter specimen colours and should be avoided unless conditions make them essential (see also de Vogel, 1987).

A few specimens regularly turn black on drying, but in general, brownish or blackish colours in the completed specimens or the growth of mould indicate that drying was too slow, often because the papers were not changed frequently enough in the early stages of drying.

Microwave ovens

Fuller and Barbe (1981), Hall (1981), Sauleda and Adams (1981) and Bacci *et al.* (1985) all refer to drying specimens in a microwave oven. However, as most microwave ovens are limited in size, and because of the limited penetration of microwaves, this technique is best used only on small collections. The microwave drying technique may be summarized as follows:

- Plants are prepared in the usual manner but, if possible, plain, unprinted blotters or absorbent paper (e.g. unprinted newspaper) should be used rather than printed newspaper as the chemicals in the ink on some newspapers may cause a fire in the

Figure 3.2 Drying cabinets with a forced circulation of warm air, as used in large herbaria to shorten drying time and to lessen the need to change drying papers.

microwave oven. Bacci *et al.* (1985) recommended 'babies napkins' but the details of this are not clear.

- The press should be of a microwave-safe material such as wood, acrylic or polycarbonate sheeting (e.g. plexiglass/perspex™).
- Drying time is determined by trial and error but, in general, drying is accomplished by irradiating at maximum power for one to two minutes.
- The number of specimens that can be treated at one time is limited by the dimensions of the oven and by the density of the material; in practice it is best to process no more than ten to twelve specimens of average thickness per batch.
- Specimens are usually dried after the moisture that characteristically appears on the glass door has disappeared.
- If the specimen is still damp when taken out of the oven, allow it to stand before reradiating the specimens, as moisture continues to evaporate from the specimen for some time.

- Care must be taken not to irradiate the specimens for too long or they may burn.

Note that mounted specimens should not be placed in microwave ovens — adhesives often melt, and tape may ignite.

Bacci *et al.* (1985) reported that microwave drying is a very effective method, but they noted that it adversely affects the structure of cytoplasmic membranes and organelles, which are preserved only if the specimen is dried at air temperature. Hill (1983) reported that the use of microwaves on specimens may cause damage to seeds, and Philbrick (1984) suggested other possible damage at the morphological and macromolecular level, thus reducing the long-term value of the specimens for some uses.

Alternative methods of drying

Alternative drying methods have been used for some time, but are mostly restricted to special purpose collections. The main alternatives are freeze-drying and drying in a desiccant powder such as desiccant silica gel. In general these techniques are used where it is essential to preserve the shape of a delicate plant or organ of the plant such as the flower. Specimens for which such techniques have been regarded as justified include delicate orchid flowers which are unrecognizable when dried by other methods (collection of these in preserving fluid is a more commonly used alternative), *Nepenthes* pitchers (Shivas, 1983) and other delicate parts of plants. Freezedrying has also been used to preserve the chemical composition of a plant as accurately as possible for later study and is commonly used for fungi (see Chapter 4 on non-vascular plants). Some aspects of freeze-drying are discussed by Romero-Sierra *et al.* (1986).

Disadvantages and special conservation problems of specimens dried by these techniques are that they are particularly susceptible to damage. The dried parts are fragile, lack support and often catch on packing materials. They must therefore be very carefully packed and stored in small boxes or tubes with some appropriate packing material that does not snag and break small projections. Drying in desiccant silica gel crystals or powder can also have the disadvantage that it is difficult to remove all traces of the silica gel after drying. Because the gel is hygroscopic, the remaining traces may attract moisture to the specimen.

Specialist techniques

There are many specialist techniques for specimen preparation for specific research projects, such as fixing specimens for leaf collections in desiccators for subsequent DNA extraction. These techniques involve small samples which are ultimately destroyed by the extraction techniques. DNA samples are sometimes stored in low temperature freezers (Karp *et al.,* 1998).

Mounting and labelling
(see also Appendix II)

Introduction

Croat (1978) surveyed herbarium problems, techniques and materials used in large herbaria in the USA during the 1970s. He reported that there was a considerable variety among the responses, indicative of some of the unevenness of problems facing the conservators of the future. There were, for example, numerous different methods for specimen mounting in use in the fifty large herbaria included in this survey. There was variation in: the types of method of primary attachment (whether cloth tape or adhesive); which adhesives were used for attaching specimens (fifteen types. including many proprietary products of unknown composition and others ranging from pastes and rubber contact adhesives to PVA) and for labels (eleven types, mostly proprietary products of unknown composition); the methods of application of the adhesive (from localized application, termed `strapping', through to more generalized 'brushing and atomizer' application and full coverage of the underside of the specimen — the `plate method'; and in methods of any additional, subsidiary attachment used, such as sewing with thread (including cotton, linen and string) or strapping with the same or a different adhesive or with cloth tape.

Herbarium sheets

The 'herbarium sheet' usually refers to the paper with the specimen mounted on it. The paper, its characteristics and life expectancy are of critical importance to the longevity of the specimens and their documentation. Plant specimens are mounted by attaching pressed, dried specimens to mounting sheets. This prevents fragile material from fragmenting.

Historically, herbarium sheets have often been selected on the basis of cost and availability rather than their longevity. Franks (1965) surveyed herbaria and recorded a range of paper sizes used, but no description of paper type. He did, however, include descriptions of folders including heavy white or brown paper, black and red coloured folders, and manilla folders.

Older specimens from the seventeenth, eighteenth and early nineteenth centuries tended to have rag-paper mounts and folders because it was commonly available at the time. However, more recent collections (i.e. the latter half of the nineteenth century onwards), especially those made this century, often have much poorer quality papers derived from wood pulp. These papers are now becoming discoloured, brittle and fragile (see also Clark, 1986).

The characteristics and life expectancy of the herbarium sheet is of critical importance to the longevity of the specimens and their documentation. The longevity of papers covers a wide range. At one end of the scale are the poorest types of paper which are highly bleached and contain many of the original raw components of the wood, such as lignin. These characteristics lead to increasing acidity and rapid deterioration. Examples include newspaper and the whitest and smoothest surfaced papers. The latter are extensively bleached and are then combined with fillers (mostly kaolin clays) to produce a smooth white surface. Medium quality papers include bond papers, such as photocopy bond, which are bleached papers without fillers and therefore have a slightly textured surface. Paper with the longest life expectancy is made from pure cellulose, either from cotton rag or delignified wood pulp. Different characteristics of papers include the fibre lengths of the cellulose compounds, giving different stiffness and folding characteristics, as well as different surface smoothness.

Various terms are used to denote paper that has a long life expectancy, including archival, permanent (sometimes also used for a type of plastic sheet which resembles paper), alkaline and acid-free, but none are completely satisfactory. For example, some archives are only retained for five years, so the term does not automatically denote longevity. Permanent is perhaps overstating the life expectancy of these materials and alkaline and acid-free mean only that the materials are not acid, but some alkaline papers can contain significant amounts of lignin or other impurities and degrade quite quickly. The word `archival' is used throughout this chapter because it seems to be the term most widely understood to denote long-life paper. The International Standards Organization has published Standard ISO 9706 Information and Documentation — Paper for Documents — Requirements for Permanence (see details at end of chapter).

The best papers are those that meet the highest archival standards, that is, they are papers with a life expectancy of 300 years and over, though papers with a life expectancy of 100 years may be acceptable in some situations. Papers that meet these standards are manufactured by a number of suppliers and are available through retailers around the world (see details at end of chapter).

Buffering of papers to prevent acidification and deterioration over time is achieved by incorporating stable alkaline compounds such as calcium carbonate, which work to resist acidification of paper. Buffered paper is recommended for herbarium use except for photographic materials, where it is believed that the alkalinity may adversely affect the images.

Disadvantages of archival paper include its cost and limited availability in many countries. It is often available only in set sheet sizes rather than in rolls, unless very large orders are placed (orders over two metric tonnes are required by some suppliers).

The possible interactions between plant compounds (which may be acidic) in dried plant specimens and the alkaline buffers in many archival papers have not been investigated to this author's knowledge. It is likely that such interactions/reactions would be minimal when specimens are kept in either the optimum relative humidity range of 45—60% RH or the slightly- wider recommended range of 35—60% RH. In high relative humidity conditions it is possible that some acid—alkali reactions may occur.

Many papers show considerable deterioration with age so that conservators need to be familiar with both the relevant concepts for conserving what is there and also the range of papers currently available. A detailed discussion of the myriad of different types of paper and their problems is a complex one and is not possible here, but some basic concepts relevant to herbarium (dried plant) collections should be considered. Longevity, strength and folding characteristics of the paper are of greater importance than colour and texture (smoothness), and the pH of papers should ideally be between pH 7 and 8 (i.e. neutral to somewhat alkaline).

Inherent problems in paper are caused by the presence of conditions and compounds that cause the decomposition of its colour, form, structure and strength. The main inherent problem is acidity, resulting mostly from the chlorine-bleaching process commonly used to whiten paper. Paper pH can be measured with an indicator-type dye (from a dropper or in pen form) or with an electronic pH meter. Acidity causes breakdown of the structure and strength of paper, leading to yellowing, brittleness and fragmentation. Other inherent causes of decomposition are some of the compounds in paper, either plant-derived, such as lignin and secondary plant metabolites such as flavonoids and resins, or introduced during the paper-making process, such as iron fragments from the rollers used to produce the sheets. With time these compounds cause discoloration and degradation of paper either through their own oxidation or through the encouragement of fungal attack. Such degradation often appears as brown or dark spots, often with radiating branches, commonly known as foxing. Other common causes of degradation in paper include exposure to light, moisture and fungal attack. The worst consequence is that the sheet ceases to provide support for the specimen, resulting in damage.

Herbarium sheet sizes and label placement

The size of the specimen is usually, as far as is sensible, governed by the size of the herbarium sheet. Samples about 30 cm long make suitable specimens of most species, as herbarium sheets are usually about 43 cm long by 28 cm wide. Smaller sheets (e.g. foolscap size, about 32 cm *X* 23 cm, are not recommended as they encourage the collection of small, inadequate specimens.

Full-size herbarium mounting sheets are usually about 43 cm long and 28 cm wide. Most herbaria have their own protocol for placement of labels and annotations, and the sheet size varies between institutions. Label position is usually consistent within the one collection. The plant name and notes are written ideally on a permanent paper label attached to one corner of the herbarium sheet (the bottom right hand corner is the common standard). Sometimes, annotations may be written directly on the sheet or card, though in some herbaria this is specifically forbidden.

Specimen mounting

Specimen mounting consists of various means of attaching pressed, dried specimens to sheets of heavyweight paper (herbarium mounting sheets). Specimens should be mounted on sheets of archival (permanent) cardboard or paper.

Specimens may be mounted with a range of different fixing media including adhesives, stitching, strapping/taping and wiring (Fig. 3.3). Only archival quality materials should be used.

A disadvantage of flat mounted specimens is that the reverse side is inaccessible for examination. This should be borne in mind when arranging and mounting the specimen. Ideally, easily reversible mounting media should be used, specimens should be strapped to the sheet rather than glued all over (see also Adhesives below), and the specimen should be carefully arranged before it is attached so that it shows all features. In the past, many herbaria used adhesives that were supposed to be reversible, but time has proved otherwise; these include animal glues and polyvinyl acetate (PVA) adhesives (Clark, 1986).

In some circumstances reversibility was not considered. Some specimens were mounted with adhesive on all surfaces in contact with the paper (often by coating a sheet of glass

Figure 3.3 A well mounted herbarium specimen using wire and long-life tape on archival paper.

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Figure 3.3 A well mounted herbarium specimen using wire and long-life tape on archival paper.

with adhesive, placing the specimen on the glass and then applying it to the paper) and are now virtually impossible to detach. This has significant disadvantages for the long-term usefulness of the specimen both because much of the specimen is inaccessible and because of possible changes in the specimen due to chemical migration from the adhesive.

Stitching

Stitching specimens to sheets using archival thread and needles effectively holds strong specimens in place without preventing access to the underside. The thread is looped over part of the specimen (such as the stem) and pushed through the mounting sheet on both sides of the part being retained. It is then tied off either behind the sheet or, less commonly, on top. A number of stems or parts of each specimen are sewed clown. Cotton thread and dental floss (unwaxed and unflavoured) are two recently favoured materials, but any thin archival thread can be used.

Advantages of this technique include that it is easily reversible and involves minimal chance of chemical contamination. Disadvantages include that the technique is timeconsuming and may not prevent fragile specimens from disintegration. The technique may have a useful role in providing extra support for bulky or woody specimens.

Wiring

Wiring is a stronger version of stitching. Instead of thread a metal wire is used. A nonrusting, corrosion-proof wire such as nickelplated copper wire is needed. This technique is useful for heavier specimens but is even more time-consuming than stitching. Also, care must be taken to cover the sharp, cut ends of the wire to prevent snagging of other specimens.

Strapping

Strapping involves attaching the specimen to the sheet at a number of points with narrow strips of archival paper, linen tape or adhesive straps. An alternative attachment technique is strapping with a clear, long-lasting 3M tape (Y8440 Scotch brand). This tape has been in use in some Australian herbaria for approximately twenty years with good success. The use of tape is faster than most adhesives and it is easier to remove if the specimen needs to be examined more thoroughly.

Different kinds of tape have been used to attach specimens to herbarium sheets, including linen tape with a variety of adhesives, preglued paper tapes and paper tapes with many different adhesives (Croat, 1978). The tape itself is unlikely to cause conservation problems with specimens, but long-term problems of individual adhesives are largely unknown. One exception is 'sticky tape' (Sellotape", Scotch Tape"' etc.). The adhesives of such tapes, and often the tapes themselves, disintegrate after only a few years. Some adhesives dry out and become hard, losing adhesion, others soften and spread. The only satisfactory way to treat such specimens is to remove them from their papers, scrape off as much adhesive and tape as possible and remount them with new, permanent materials (taking care to retain all labels, annotations and attachments).

Advantages of strapping are similar to those for stitching and include easy reversibility, minimal impact on the specimen and minimal obscuring of parts. It is also quicker than stitching. Disadvantages are that, unless tape is used, it can still be quite time-consuming, and that fragile specimens can still fragment.

Adhesives

Adhesives may be employed to attach the specimen to the sheet using spots or all-over gluing or with straps. In the past, many herbaria used adhesives that were supposed to be reversible, but time has proved otherwise. A wide range of adhesives have been used on herbarium specimens over the years, ranging from natural glues made from animal products (e.g. hoof and hide glue and rabbit skin glue), to gums, mucilages and synthetic adhesives such as polyvinyl acetate (commonly referred to as PVA). The adhesives in common use today are mainly PVA adhesives and methyl cellulose adhesives (Clark, 1986). Ageing of animal product glues may lead to hardening, shrinkage, cracking and gradual loss of adhesion. Such natural product glues are also susceptible to fungal and insect attack. Natural and synthetic gums and mucilages are something of an unknown quantity, though they seem to suffer from hardening and loss of adhesion with time. PVA emulsion-applied adhesives were expected to have a long life, but recent research (Clark, 1986; Horie, 1987) has indicated that they may also break down with time. The only significant problems of ageing with methyl cellulose adhesives occur before use (Tillett, 1979, 1989). Once dried, methyl cellulose adhesive seems to offer the greatest life expectancy (Baker, 1984; Clark, 1986). Walker and Hughes (1994) list details for additional adhesives.

In herbaria where specimens are handled frequently, curators concerned with fragmentation and loss of material have often opted for overall gluing of the specimens. This technique may have certain advantages in terms of keeping parts of specimens together, but has also been regarded as causing significant conservation problems. Egenberg and Moe (1991), in a survey of herbaria in Scandinavia, found that fully glued specimens showed serious deterioration while specimens mounted with paper straps were unaffected by changing temperature and relative humidity. For these reasons it is recommended that adhesives be used as straps or, at most, in selected spots only, rather than overall.

Bridson and Forman (1992) discuss mounting techniques in some detail. However, in most situations, their recommendation of 'overall gluing' is not supported for the reasons discussed above, and care should be taken concerning the reversibility and health risks of the adhesives mentioned therein.

Other techniques

Other fixing materials include pins and paper-clips used to attach items to the sheets. Metal components are prone to corrosion with time: in particular, steel and iron will rust and discolour the sheets. It is therefore important that any metals used are corrosion-resistant, such as nickel-plated brass pins and stainless steel staples, pins or clips. Of these, stainless steel or nickel-plated brass pins are the best method of attachment because they give a firm fit and yet are easily removable. Paper-clips, as well as corroding, can become accidentally dislodged, thus losing the attached item, or can inadvertently catch up foreign materials. Staples are difficult to remove, thus discouraging the use of the attached items, and the sharp points underneath may rub against the folders or other specimens.

Sundry attachments

Envelopes and bags are often attached to herbarium sheets to hold fragments or photographs. These are commonly made of paper, cellophane or plastic. Archival paper envelopes may last well, but are opaque and hide the contents. Cellophane bags were often used in the past to overcome this problem, but they become brittle and disintegrate with time and are best replaced with archival quality plastic bags. The major kinds of archival plastics are polypropylene and polyethylene. Both of these are degraded by ultraviolet light, but can have UV stabilizers incorporated to give protection. Polyethylene is soft and the most flexible, while polypropylene can be rigid or flexible.

Specimen labelling and documentation

(see also Appendices I and II)

Another important use of archival papers is for documentation of specimens and collections, especially specimen labels. Undocumented specimens are of little scientific use, so it is essential to preserve the specimen's documentation.

The documentation for plant collections includes field notes (usually included in a field book), annotated and numbered tags attached to specimens, photographs taken in the field or subsequently, and specimen labels prepared after the plant has been pressed and dried. Later documentation includes registers and electronic databases of specimen information that are usually stored on magnetic or optical media.

Field notes and tags often contain similar or complementary information about the specimen, which is transcribed on to the specimen label. Their preservation is important for historical and scientific reasons. Historically they include examples of the collector's handwriting, which can determine and confirm the validity of specimens with respect to particular collectors. Early collectors were commonly parsimonious with their annotations; after all, they knew when, where and who collected their own specimens. Today it is often only by careful examination of the original notes or field label(s) that one can determine the details attributable to a specimen. Scientifically the original notes provide a check of the validity of a modern label in case of transcription errors or mixed specimens (see also Chapter 9 on policies and procedures).

Collectors' notes were often written on the paper in which the plants were pressed. The paper used varied enormously; very early collections were usually pressed with blotting paper or brown paper but, for the last hundred years, newspaper has been the most commonly used. The use of the latter poses considerable conservation problems due to the poor life expectancy of this low quality paper. A photographic record or photocopy (on archival paper) of the note is a good way to preserve a copy of the information. The paper itself should be kept out of the light and may either be buffered against acidity and further degradation by attachment to, or wrapping in, a buffered archival paper or isolated from its surroundings by placing it in an archival plastic envelope. On the other hand, the use of high quality rag paper by some early collectors does not create any problems for the conservator, as this paper has excellent lasting properties. Although the conservation needs of this paper are significantly less than for newspaper, it should still be kept out of the light and away from physical damage.

Specimen labels are essential for scientifically validating specimens. They contain the collecting information, correct identification and specimen number. Today they are often computer generated and printed. Information on appropriate information content may be found in collection manuals such as Bridson and Forman (1992) or Bedford and James (1992). Labels are attached to specimen sheets with an adhesive. The type of adhesive chosen is critical, as it is essential that the labels do not become separated. An archival, permanent adhesive such as methyl cellulose should be used.

Storage

Most specimens fit on to standard herbarium sheets and within the standard storage systems discussed below. Specimens that, clue to their size or fragility, do not lend themselves to being mounted on herbarium sheets include both large and very small specimens. Large specimens include wood blocks, large woody fruits and plants where the smallest sample will not fit on to a standard herbarium sheet, such as palm leaves. Very small specimens unsuitable as dried, flattened herbarium specimens include orchid flowers, which are usually fixed in alcohol or formalin and then preserved in alcohol or other spirits (for further information see Chapter 5 on fluid preservation). Microscopic parts such as pollinia and pollen are mounted on microscope slides (see Chapter 4 on non-vascular plants).

Plants with very large leaves (e.g. Palmae, Araceae and Cycadales)

With plants such as palms, aroids and cycads, the smallest complete leaf is often many times larger than the standard herbarium sheet. There are at least two alternative collection and storage methods for such plants. One technique is to cut the leaf into numerous (carefully numbered) fragments which can then be placed on multiple sheets. This has the advantage of not requiring alternative storage areas. Disadvantages include the need for additional documentation, preferably including photographs, and the difficulty of relating the specimen to the living plant. The alternative technique is to collect the frond whole and to provide special separate storage for such material. The main disadvantages of this technique are that the material is difficult to handle (press, dry and store) and is often not in its correct sequence in the main specimen collection area, and therefore may be overlooked.

Many herbaria use large coffin-shaped boxes to store such items flat but, as a viable alternative, palm leaves can be kept whole in the main collection area, stored in specially constructed shelving which allows them to hang vertically.

Storage systems

There are a variety of storage systems in use for herbarium collections around the world. Each system has its own advantages and disadvantages. The systems may be classified primarily as either fixed shelving or movable

Figure 3.4 Detail of a rack storage system that holds the boxes illustrated in Fig. 3.4.

compactor shelving, with secondary classification into compartment or box storage systems, and further choices of closed or open shelving systems.

Cabinets

Franks (1965) and Croat (1978) discussed cabinet style in a number of herbaria around the world and noted that construction varied widely and included wooden and steel cabinets, the former with or without glass fronts. All such cabinets should be constructed so that insects and dust cannot enter them when closed.

Box storage

Box storage systems use the modern equivalent of Solander boxes to hold herbarium sheets (the original Solander boxes were rigid-sided flat boxes with a removable lid and drop-down front; modern equivalents usually lack the drop-front). They give very good protection to the specimens, at the cost of ease of access. Boxes are usually held on open shelving or compactors (Fig. 3.6), as doors or other covers for the shelves are less necessary. Boxes are usually about 470–500 mm long by 310–340 mm wide and 80–90 mm high. These

Figure 3.5 An archival, plastic Solander box used at the National Herbarium of New South W ales.

boxes have traditionally been made of cardboard or cardboard and wooden boards, usually reinforced with cloth tape and covered and lined with archival paper. The National Herbarium of New South Wales now uses an archival plastic box of similar dimensions (Anon, 1986b) (Fig. 3.5). Bedford (1992) described that storage system in some detail, and the fixed-position rack system that holds the boxes is illustrated in Fig. 3.4 and discussed below.

Plastic boxes

Plastic boxes have a well-fitting lid which gives good protection against insect invasion and water leaks such as from faulty water sprinklers in fire-control systems. Their main disadvantage is that the plastics are impervious to fumigants and in dry conditions plastic boxes may cause some static problems. Also consideration should be given to relative humidity with temperature cycling if there is inadequate air-conditioning.

Compartments

This method is a pigeon-hole arrangement which can be either open at the front or enclosed behind doors (Plate 20). Specimens are usually enclosed in paper, then species folders and then grouped in genus/family bundles in each compartment. Sometimes `groups' are tied with cotton tape to keep them together, but some institutions find tightly tied bundles can distort the specimens.

Figure 3.6 Compactor storage of cardboard herbarium boxes at the National Herbarium of New South Wales.

Open-shelved systems give easier access to specimens, but at the cost of poorer protection. However, compartment systems in fully enclosed cabinets with tightly fitting doors do give good protection, and may serve a double purpose by allowing fumigation of individual cabinets of specimens. These systems may be constructed in wood or metal; earlier systems favoured wood, new systems are usually made of metal. Wooden shelving can absorb and hold moisture, and can warp and give off vapours or resins, though some timbers are exceptionally stable (cedar, Californian redwood and mahogany have all been used with success). Bridson and Forman (1992) comment that wooden cabinets give better protection to specimens in a fire because of the insulating qualities of wood, whereas metal cabinets transmit the heat to the specimens, causing damage (see also Chapter 7 on the collection environment) Composition boards, such as reconstituted pine-chips or wood fibres (chipboard etc.), should be avoided as construction materials for specimen storage cabinets. Even when melamine-faced, these boards may give off formaldehyde and other damaging vapours from the adhesives in them. Wood also provides some environmental buffering because it absorbs moisture from the air and evens out temperature changes through its natural insulating properties.

Compactor systems

Shelving units may either be fixed in position, with aisles, or movable, as compactors. Compactor systems are the most space--efficient storage means for the collection but they restrict access to the collections, and require specimens to be mounted to prevent damage when the shelves are moved. Compactor units are usually open compartments that are closed only when the compactors are locked together, but compactors with each unit closed-in by sliding doors are also in use. Compactor systems can be manually, mechanically or electrically operated. Touw and Kores (1984) discuss `compactorization' of herbaria in some detail. They cover methodology, examples of installations and both the advantages and disadvantages of compactor storage. The advantages include cheaper, higher density storage, because more specimens can be accommodated in a given storage area. Disadvantages include making the collection less accessible and increasing the risk of physical damage to the specimens because of movement. These authors comment that the curator must weigh one factor against another, and that the ideal may be to use compactors only in less frequently accessed parts of the collection.

Restoration of specimens

Herbaria may have specimens in their own collections, or may acquire collections, that have been poorly prepared, poorly stored or have been damaged in some way. Such specimens require restoration and conservation.

The process of repairing specimens usually involves removing them from old sheets and papers and remounting them in archival papers with archival materials. It is critical that specimens be worked on individually so that there is no chance of losing the critical link between the specimen and its labels and annotations. As noted elsewhere, the papers themselves have no scientific value, but any labels and annotations must be preserved. Where these are on poor quality paper they should be photocopied on to archival paper, and the originals retained in an attachment. Historically important specimens may require the retention of the original papers. In this case the specimen should be removed and the papers conserved and de-acidified before the specimen is reattached.

Walker and Hughes (1994) report on the process used in the Royle Herbarium and give valuable advice for the restoration of specimens. In their case, specimens have been glued all over and must be humidified to be removed from the sheets. Where specimens are loose, strapped, stitched etc. humidification is not required and not desirable. Walker and Hughes also note that labels on the plant specimens themselves (e.g. on stems) are removed and stored separately. This can be dangerous and undesirable, as separated labels can be lost and thus information lost too. Some early collectors also had distinctive methods of attaching field collection labels and their removal destroys important information regarding provenance.

Where labels have been glued to the sheets the most effective dry removal technique is to place the label face down and peel and scrape the sheet from the back. This avoids bending and damaging the original label which may be fragile and brittle. Specimens should never be turned over as they may fragment and lose some of their parts.

Pests and their control

The most common pests attacking dried plant material are insects and fungi, though rodents and other large animals can cause damage in poor storage conditions. Further information on insect pests can be found in Chapter 8 on pest management, prevention and control).

Additional information useful to botanical collections can be found in Cowan (1980), Crisafulli (1980), Hall (1981, 1988), Retief and Nicholas (1988) and Robbins and Geraeu (1984).

Fungal attack

The primary risk factor for fungal attack is incomplete drying of specimens, caused either during the specimen preparation process or afterwards, or in collections that become wet later through flood, other water damage or improper storage conditions, especially in the tropics. Properly dried plant specimens will not suffer from fungal attack if stored in the correct conditions (see recommendations below). During the drying process specimens are particularly at risk if they dry slowly. This happens through poor drying conditions or specimens being wet before being pressed or having water-retaining or succulent parts. Specimens with sugary exudations or large quantities of nectar are also particularly attractive to fungi and need special care during drying to ensure that they dry fast enough to prevent mould growth.

If fungal growth occurs on specimens, it can be brushed with absolute or 95% ethanol or methylated spirits (denatured alcohol). However, this may alter the specimen unacceptably for chemical and other investigative research, and only kills the fungus present on the specimen; it does not prevent further problems of fungal growth. Specimens treated for fungal (mould) attack should be clearly annotated, including the date and treatment given. Clark (1986) discusses the conservation problems of specimens affected by water damage and fungus.

Other risks to herbarium material

Specimen handling

Very brittle material, such as older specimens or those stored in very low humidity regimes, require special care and steps should be taken to keep specimens fully supported. When moving bundles of specimens they should be kept in their boxes or wrapped and tied in their enclosing folders so that they are adequately supported until they are rested on a bench. Single specimens should be slid on to a stiff support such as a sheet of double-walled corrugated cardboard, or carried in a box during movement around the herbarium. Specimens must be kept face up and flat at all times, not carried or stored on edge, and very fragile specimens should never be turned over.

Transportation of specimens

The need for transportation of specimens most commonly arises when material is requested on loan for scientific study. It is critical that material be protected from damage and loss during transportation.

Loans of specimens between institutions should be securely packed in cardboard boxes. Double-walled boxes provide better protection than single-wall boxes. It is essential to ensure that the contents are tightly packed so that specimens do not move around or rub against each other. Each specimen should be placed in a folder, with additional padding such as foam being inserted where necessary.

It is essential that all the specimens he listed in some detail, and one copy of the list should be included with the specimens, one copy sent by separate post to advise of the impending delivery and one retained for the lending institution's records (see Chapter 9 on policies and procedures). For computerized collections the specimen record should be annotated to indicate that the specimen is on loan, to whom, and when it is due to be returned. For critical specimens such as types, registered post or freight is preferred.

Some herbaria treat the specimens to kill any possible insect pests before sending the material, especially if freight is expected to take some time. Most herbaria treat the specimens on arrival to prevent the possible introduction of any pests.

Collection environment

Plant material contains a proportion of water, even when outwardly dry (approx. 12—15%) and this helps it retain some flexibility. The withdrawal of more water from the material causes contraction and shrinking, and may lead to splitting and warping. Extremely dry material becomes brittle and therefore more susceptible to physical damage (plant products such as cellulose and paper are similar).

On the other hand, increasing the moisture content may cause enlargement and swelling, also leading to warping, but to a significantly lower degree than excessive dryness. The main problem from excessive moisture (more than 75% RH) is the increased risk of fungal (mould) attack. In addition, a rapid change from dry to wet can cause physical damage through warping and splitting.

There is clear evidence of the detrimental effect of extremes of relative humidity and temperature on dried plant material. However, within the ranges acceptable for human comfort, there has been no critical research on the effects of different relative humidities and temperature regimes on dried plant specimens. The basis of our knowledge is therefore largely empirical rather than absolute. It is also reasonable to extrapolate from the effects of extreme environments and from the much more complete evidence for the effects of different environments on museum and art collections. On this basis it is possible to say that optimum environmental conditions for the storage of dried plant materials are within the ranges for museum and art works. Thomson (1986) extensively discusses suitable environmental conditions for museum specimens, which apply equally to herbarium specimens. He states that humidity and temperature ranges of 45—60% RH (with a target of 55% RH) and 19-24°C, are optimal and gives guidelines for safe levels of exposure to light, including UV, and air pollution. However, herbarium specimens seem to be more resilient than many museum materials, and thus seem to survive quite well in less than optimum conditions within the range of 30-65% RH and 10—30°C but it is recommended that they be kept at an optimum of around 18—22°C as far as possible.

Herbaria have survived in conditions outside these ranges in certain places, with some herbaria operating as low as 10% RH and others up to and exceeding *75%* RH; but their specimens are at significant risk, and many will almost certainly not survive in the long term. Relative humidity levels are much more critical than temperature. When operating outside the optimum and recommended ranges special precautions will need to be taken. For example, if operating in extremely dry climates, specimens will need to be more securely mounted than normal, and should be physically better protected than they are normally, for example by being stored in fixed shelving rather than compactors, to reduce damage by movement and vibration. Fluctuating relative humidity is the most damaging scenario (see Chapter 7 on the collection environment).

Disaster recovery

Because unforeseen disasters can occur at any time it is important that herbarium staff have a well organized disaster plan and the necessary supplies to cope with disaster and to recover from it. Disaster recovery planning and materials are similar for herbaria, museums and libraries, and are well covered in other publications (Upton and Pearson, 1978; anon., 1980; Anderson and McIntyre, 1985; Barton and Wellheiser, 1985; anon., 1986a). See also Appendix III on disaster planning and Appendix IV considering a case study.

Little can be done with burnt specimens and fragmented specimens (such as in a bomb blast) except to preserve and protect what is left intact. The damage most likely to occur, and from which there is the best chance of recovery, is water damage. This can occur through flooding or other inundation (natural or man-made, such as roof leakage or collapse or fire-sprinkler malfunction). The technique of particular importance for water-damaged specimens is that of snap-freezing all damaged and waterlogged material (see Appendix IV). This delays deterioration and prevents fungal attack, which gives curators time to evaluate the situation and decide how best to approach the problem. It also keeps labels and other documentation in place (or wherever they are when the material is sent to be frozen), which is one of the greatest problems with water-damaged specimens. Bulk freezing facilities are available commercially in most countries as they are used in food preservation. In some places the facilities may be in the form of mobile trucks, but usually the specimens will need to be transported to the freezing facilities. They will need to be carefully wrapped or boxed, and labelled before freezing so that specimens can be retrieved in small enough quantities to be conserved. If possible, individual specimens should be isolated from each other with plastic sheets to avoid sticking together; the plastics available for wrapping food for the freezer will serve this purpose well.

Disasters in herbaria are fortunately rare. When they do occur, preparation beforehand will minimize the long-term effects. In the worst cases some specimens will remain for restoration, and the return of duplicate specimens previously distributed to other herbaria could be sought. Off-site storage of database back-ups, copies of documentation, contact lists and instructions for recovery will greatly assist the recovery process.

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Suppliers

Drying papers

Preservation Equipment Ltd. Shelfanger, Diss, Norfolk IP22 2DG, UK.

Conservation Resources (UK) Ltd. Unit 1. Pony Road, Horspath Industrial Estate, Cowley, Oxfordshire OX4 2RD. UK.

Herbarium mounting papers

Enclosing folders/genus covers: c. 120—160 g.s.m., e.g. Archive Cartridge' or `Archival quality Manila

Species folders and type specimen folders: c. 120 g.sm.. e.g. 'Archive Cartridge' or `Teton text'.

Specimen folder `flimsies': 60—85 g.s.m., e.g. 'Archive text wove 85 g.s.m. or Archivart lining paper' 60 g.s.m.

Suitable papers are available from a range of manufacturers, including those listed here. In the UK: **Coultergard, Bridge and Co.** (the Archive range) and **Wiggins Teape Pty Ltd** provide archival papers to a number of the larger herbaria. French manufacturers include **Canson** and **Montgolfier.** In the USA: The Teton range (manufactured by the **Simpson Paper Company)** is used by some herbaria, while other suitable papers are available from a list of US manufacturers making only alkaline paper including **Finch, Pruyn and Co., P.H. Glatfelter Co., Grays Harbor Paper Co., Miami Paper Corp., Mohawk Paper Mills, Newton Falls Paper Mills, Potlatch Paper Co., Potsdam Paper Mills, SimpsonPlainwell paper Co., Ward Paper Co., S.D. Warren Co. and Geo. A. Whiting Paper Co.** (Anon, 1988b). Other US manufacturers with archival paper as part of their range include the **Rising Paper Co.** and **Strathmore Paper Co.** In Australia: **APPM** manufacture a small range of archival papers.

Mounting cards. c. 200 g.s.m. e.g. `Teton cover', `Teton cover plus' or Bristol board. Mounting cards for macroscopic marine algae are usually a heavyweight, long-fibre paper with wet-strength about 245 g.s.m.

International Standard ISO 9706 Information and Documentation Paper (1984)

The standards cover tear resistance, alkaline reserve (2%) resistance to oxidation (kappa number less than 5.0) and pH 7.5—10.0 for both inner and outer layers of the paper (by aqueous extract, or manufacturers' certification). The *Alkaline Paper Advocate* and *Abbey Newsletter,* both published by Abbey Publications. USA, provide up-to-date information on paper standards.

Plate 20 Specimens in the general herbarium of The Natural History Museum, London. The open cupboards show how dried plant specimens are stored dry in paper folders; red indicates critical material (i.e. type specimens). The specimen in the foreground *(Banksia (Ientata)* was collected by Banks and Solander in Australia on Captain Cook's first voyage on the Endeavour. (reproduced with kind permission of the National Geographic Society. Photographer: Cary Wolinsky.)

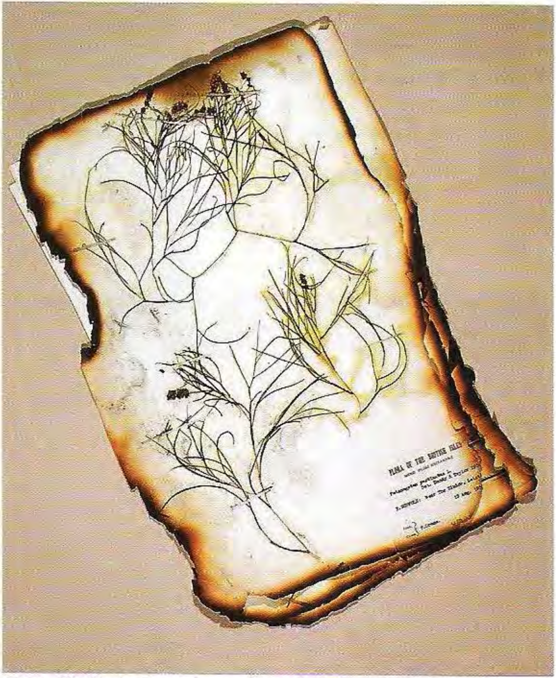

Plate 23 Herbarium sheets from the Natural History Museum, London, damaged by fire during the Second World War. Note charring, smoke damage and subsequent water damage (The Natural History Museum).