The economics of botanical collections

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Introduction

Millions of plants are held in collections throughout the world. Some are alive, some dead; some are cared for, some left to decay. To obtain them, men have sometimes risked their lives (Smith 1932). Whether they were brave or merely foolish is the subject of this paper.

There are many different kinds of collections of living plants, with diverse functions and origins. Some focus on crop plants, such as the cereal, vegetable and fruit collections held by the John Innes Institute, Norwich, UK and Scottish Crops Research Institute (Wilkinson *et al.* 1993; Ambrose 1994), while others contain cultures of algae and protists (Thompson *et al.* 1988; Schlösser 1994). These special collections are recent inventions. Cultures of algae could not be established and maintained before the development of aseptic techniques and *in vitro* culture methods (e.g. see Pringsheim 1946). Collections of land races and cultivars of crop plants were mere curiosities before genetics provided a foundation for modern plant breeding.

Most governments accept that improved strains of crop plants are 'a Good Thing' (Sellar & Yeatman 1930) and make it a high priority to develop agricultural germplasm collections. Without such collections, breeding for higher yield, disease-resistance, better flavour or other desirable characteristics would be impossible. Collections of algae are esteemed less and are correspondingly insecure, judging by the history of the UK Culture Centre for Algae and Protozoa. This, though now recognized to be 'a unique biodiversity resource that must not be lost to biotechnology, research or science education' (Office of Science and Technology 1994), was once a major institute for systematics research (George 1976; Hibberd 1980). Clearly, there has been a change in the British government's valuation of this 'unique biodiversity resource' since 1976, and it would require a marvellous sophistry to claim that the valuation has increased.

The kinds of collections mentioned so far are important, but they represent the minority of living plant collections. The majority are held in botanic gardens and arboreta, of which there are over 1400 world-wide (Heywood *et al.* 1990), or in networks of smaller gardens, such as those taking part in the scheme run by the National Council for the Conservation of Plants and Gardens (NCCPG). In this, 600 collections have been established to conserve the rich diversity of cultivars and species (over 50 000 accessions so far) grown in British gardens (NCCPG 1994).

Gardens have been made and tended for thousands of years. The biblical book of Genesis records that God 'planted a garden in Eden, in the east' (chapter 2, v. 8) for the first man to keep. The layout and content of Roman gardens is being revealed by archaeological investigations at Pompeii and elsewhere (Jashemski 1992), and were also described in contemporary writings (e.g. *The letters of the Younger Pliny*, Book 2, letter 17: translated Radice 1963). The Romans and Egyptians brought back plants as spoil from military campaigns (Wilkinson 1990; Gleason 1994) and the elder Pliny recorded that Pompey the Great 'made proud boast and vaunted much, when hee said, That trees also by him were borne in triumph' (Holland 1634). He gave the specific example of ebony, considered the third richest tribute of all, after gold and ivory: 'Pompey the Great, in that solemnitie of triumph for the victorie and conquest of Mithridates [of Parthia: parts of modern Iraq and Iran], shewed one Ebene tree' (*ibid.*). Indeed, by Roman times there was extensive planting of exotic species, even where these had no food value. *Platanus orientalis*, a native of the Balkans and eastwards to the Himalayas (Tutin *et al.* 1964; Davis 1982), was widely planted by the Romans (e.g. Gleason 1994). However, these early gardens were not primarily plant **collections**. Their value lay in the shade, refreshment or entertainment they could supply; they were not meant as a means of gaining knowledge about plants.

Systematic collections of plants seem to have been an invention of the Middle Ages, by the Moors in Spain (Harvey 1981) and by the Aztecs in Mexico (Jellicoe *et al.* 1986). The oldest surviving botanic gardens, however, are the Renaissance gardens at Pisa and Padua (Pisa 1991; Terwen-Dionisius 1994), founded in the 1540s, and other gardens were soon established at Florence, Leipzig, Leiden and elsewhere (Jellicoe *et al.* 1986). Many began as physic gardens, supplying and investigating plants for use in medicine: the Royal Botanic Garden, Edinburgh, is one such, founded in 1670 (Fletcher & Brown 1970). Whatever their origins, however, the principal purposes of botanic gardens today are to furnish material for systematic research and to display plant diversity, for education and amenity.

Around the time Pisa and Padua re-invented systematic collections of living plants, collections of dead plants also began to be established. According to Arber (1986), Luca Ghini (?1490–1556) at Bologna 'seems to have been the sole initiator, in the renaissance period, of the art of herbarium making, which was then disseminated over Europe by his pupils', although the earliest extant herbarium is that of Gherardo Cibo, who began to collect *c.* 1532. The first institutional herbaria were founded in the latter half of the sixteenth century, the earliest being at Kassel in 1569 (Holmgren *et al.* 1990). As with botanic gardens, early herbaria were often associated with medicine, the collections being used during the preparation of printed herbals.

For over 450 years, governments, universities and private individuals have thought it worthwhile to make collections of plants. As a result, there are now well over 270 million herbarium specimens, in more than 2600 herbaria, and the number is increasing at a rate of around 3.5 million per year (Holmgren *et al.* 1990). Given that the total number of plant species is decreasing (since extinction is currently removing species at a much higher rate than they are being replaced through evolution: Systematics Agenda 2000 1994), and that the world has been scoured for specimens, dead or alive, for over 400 years, it would be surprising if questions did not arise from time to time, such as: haven't we collected enough and do we need to keep what we already have? As Davis & Heywood (1963) asked, in a textbook on flowering plant taxonomy: 'can governments be expected to go on expanding their herbaria indefinitely?' But these questions are in fact a distraction. Assembling and maintaining botanical collections are cheap, compared with most other scientific activities (and insignificant in relation to particle physics or molecular biology), while the benefits are demonstrable and great.

A personal perspective on accountability and accounting in systematics resesearch and collections management

The intellectual challenge of putting figures to the costs and benefits of botanical collections provides minor satisfaction, but is it necessary? It is certainly healthy for scientists to be reminded how much their activities cost and that they should have long-term goals, set short-term targets, work hard, be efficient, and publish. But current norms of public sector management go far beyond this. In the UK (and, I suspect, elsewhere), a generation of politicians and civil servants has brought words like **accountability** and **audit** to prominence. The people whose taxes pay for herbaria and botanic gardens have been encouraged to exert their right to bring public servants to account, to insist that they are told **how** 'their' money is spent, that it is being spent **wisely** and that it represents the **essential minimum** of spending. In order to improve efficiency and performance, there must be clearly defined objectives, and targets and criteria against which performance can be measured (HM Treasury 1992). These principles and practices are obviously good, as is the idea, embodied in the UK Citizen's Charter, that the public sector should aim to give a high quality service to the citizenry.

The central issues are: what is wise and what is essential? These questions are always difficult, but particularly so in relation to basic scientific research, where discovery cannot be planned and the significance of observations may not appear for many years. No-one has discovered a rational way to plan spending on basic scientific research, because there isn't one: it's a gamble, where the outcome and odds are unknown, but where benefits sometimes accrue. So, since no-one can determine in advance what is wise and essential, we hide our inadequacies by concentrating instead on things we think we can do well, which is to use auditing and accounting procedures to show how money is spent and that it is indeed a minimum. Unfortunately, many values cannot easily be turned into valuations.

At the Manchester conference and at a subsequent meeting in Leiden (*Systematics Agenda 2000 – the challenge for Europe: the action plan*, 14–17 May 1995), most participants were confident that systematics research, together with the natural science collections that underpin it, are vital, but that they are underfunded and in decline. Cotterill (1995) expresses a similar view. The response of many governments will probably not be dissimilar to the UK Government's (1993) view that: 'Whilst the Government is committed to supporting systematic biology, it has to consider its claims alongside other important branches of science and other claims on public funds' – the cake-server's dilemma. Those managing biological collections, believing in the value of what they do, work to persuade their sponsors that they deserve more funds. In the UK, however, they know that the emphasis of current science planning is on wealth creation and improvement in the quality of life (Chancellor of the Duchy of Lancaster 1993), and that any success they may have will likely be at the expense of colleagues in other scientific disciplines; but they are intelligent and inventive people, and in any case, systematists and biological collections have good data to support their claims (Systematics Agenda 2000, 1994). But perhaps the cake should be bigger? I finish this section with some quotes from an essay by Ruskin (1908), which though written to promote the cause of education, are relevant also to basic scientific research into biodiversity and our heritage of natural science collections.

> 'No nation ever made its bread either by its great arts, or its great wisdoms. By its minor arts or manufactures, by its practical knowledge, yes: but its noble scholarship, its noble philosophy, and its noble art, are always to be bought as a treasure, not sold for a livelihood. You do not learn that you may live - you live that you may learn ... But where is the money to come from? Yes, that is to be asked. Let us, as quite the first business in this ... look not only into our affairs, but into our accounts, and obtain some general notion how we annually spend our money, and what we are getting for it. Observe, I do not mean to enquire the public revenue only; of that some account is rendered already. But let us do the best we can to set down the items of the national private expenditure ... we spend eight hundred thousand, which is certainly a great deal of money, in making rough minds bright. I want to know how much we spend annually in making rough stones bright; that is to say, what may be the united annual sum, or near it, of our jewellers' bills ... Let us get those two items set down with some sincerity, and a few more of the same kind. Publicly set down. We must not be ashamed of the way we spend our money. If our right hand is not to know what our left does, it must not be because it would be ashamed if it did' (Ruskin 1908, v. 145, 147).

For eight hundred thousand, substitute some larger amount; for jewellery, substitute lotteries or some other national frippery. Polishing rough minds is just as important now as it was a century ago; it includes learning about the 10 or more million species that may share the world with us but which remain undiscovered, unnamed and unutilized by humankind (Systematics Agenda 2000, 1994).

The costs of acquiring and keeping herbarium specimens

Vascular plants

A basic model for the Sino-Himalaya. There are few published estimates of the costs of acquiring and keeping plant collections. Nielsen & West (1994) quote data by Armstrong to show that the cost of databasing herbarium specimens is low (just over £1 per specimen), compared to the cost of collecting, identifying and preparing them (£17), but such calculations are rare. The otherwise excellent herbarium handbook by Forman & Bridson (1989) does not deal with valuation and budgeting. I have, therefore, made some calculations of my own.

The herbarium of the Royal Botanic Garden Edinburgh (RBGE) has specimens from every continent, but its collections are particularly rich in material from Europe and SW Asia, parts of SE Asia and S America, and above all, the Himalayas and SW China. In the last five years, RBGE staff have undertaken about ten expeditions in the eastern Himalayas and SW China; for my calculations I have drawn upon their experience and the data contained in expedition reports (McBeath *et al.* 1991; Long *et al.* 1992, 1993; Noltie *et al.* 1994). Most of the expeditions have not one but several purposes, bringing back collections of dried and living plants, seed, bryophytes, and once, lichens. Each expedition member has had a different speciality, but all have shared tasks like planning (in Edinburgh), seed-cleaning, processing material destined for the herbarium, documenting the collections and writing the final report. It is difficult, therefore, to attribute costs to each activity.

However, based on data from real expeditions, let us construct an imaginary one:

- Four staff (a senior scientist as expedition leader, two experienced scientists and a postdoctoral trainee) go on an expedition to the Himalayas/SW China. They pay for help with trekking from a low-cost local firm, use cheap guesthouses or camp , and eat local food. The salaries of the four staff are £28 000, £20 000, £20 000 and £14 000 per annum, to which 25% has to be added to cover employers' pension contributions and National Insurance.

- The expedition lasts six weeks, including travel from and to Edinburgh, thus occupying 42 out of around 225 working days per annum (this allows for public holidays, annual leave and weekends). The direct costs (travel, food and accommodation, hire of porters, dispatch of specimens, etc) are £3000 per person. Planning and report-writing (*excluding* identification and preparation of specimens before incorporation in the herbarium) take a further two weeks.
- 1500 numbers of vascular plants are collected in triplicate (4500 specimens altogether). These include representatives of all major groups or families, since Edinburgh is conducting floristic studies in the region, but collection is not indiscriminate. Previously well-collected species are given low priority and collections are biased towards particular groups identified in the Acquisitions Policies of RBGE. Brief ecological and locality data, and information about plant habit, flower colour, bark, etc. are gathered, and photographs taken to augment the documentation of the collections.
- One of the three sets of 1500 specimens is deposited in a local herbarium; the other two are returned to Edinburgh. Here the specimens are identified, each taking 30 minutes on average by an experienced scientist (total salary costs £25 000 per annum).
- Of the two sets of specimens returned to Edinburgh, one is wholly used for exchange with other herbaria. The total gain to the herbarium of the expedition is thus 3000 specimens. Incoming exchange specimens will already have been identified, reducing the net cost of identification. However, Edinburgh staff spend a short time checking incoming material (5–6 minutes on average).
- The specimens are mounted on card and labelled. Assume that one mounter (total salary costs, including pensions and national insurance, £11 000 per annum) mounts 5000 specimens per year. Material costs of mounting (paper, glue) are small.
- Laying away in the herbarium takes an average of 5 minutes per specimen by an experienced herbarium assistant (total salary costs £16 000 per annum).
- On average, 750 specimens are accommodated in a metal herbarium cabinet costing £500. If anything, both figures are too high, the unit cost per specimen remaining the same. Cabinets should not, in general, be full, since in a growing herbarium space has to be left within them to reduce the frequency with which the collections have to be moved (this is very expensive). Assume further that 2 million specimens, together with essential working space and associated library, require a building costing £5 million (estimate from the Estates Department of RBGE; capital building costs are omitted from the overheads included below).
- Overheads on salaries: while the expedition members are away, they are making minimal demands on services in Edinburgh. Nevertheless, salaries have to be paid, offices must be maintained, and so on: assume an overhead of 10% of total salary costs. While the expedition is being planned, and afterwards, during the identification of specimens, laying away, and completion of the expedition report, higher overheads are applicable. A rate of 20% seems reasonable (allowing for library provision, administration costs and building maintenance, the expertise and advice of other herbarium staff, etc), except for mounting and laying away, for which the lower overhead figure (10%) seems more appropriate.

Table 1. *The cost (per specimen) of acquiring herbarium specimens of vascular plants, based on estimates for an expedition to the Himalayas or SW China (see text)*

	£	% total
Collection:		
salary costs	8.8	35
direct costs	4.0	16
Identification and management of exchange	5.5	22
Mounting	2.5	10
Laying away fixed costs	0.9	4
Housing		
herbarium cabinet	0.7	3
herbarium building	2.5	10
Total(£)	24.9	

On this basis, it will cost **£24.90** to collect, identify and mount each specimen and incorporate it into the herbarium (Table 1); not much to pay for a specimen that may have a useful life of several hundred years. Collection accounts for roughly half the total; the proportion attributable to the herbarium building and cabinets is quite small (13%). The striking feature of the data is the high proportion of the total attributable to salaries. Salary costs and associated overheads of expedition members, those engaged in identification and arranging the exchange of the 1500 duplicates, and the assistants responsible for mounting and laying away, together account for around 70% of the total. To those planning an expedition, the main problem must often seem to be: how will we find enough money to pay for the air fare, accommodation, food, hire of porters? – the direct costs of collection. These are the only costs one might hope to recover from a benefactor and the only ones that are easily identified in the annual accounts, but they represent only 16% of the total.

How robust are these estimates? Table 2 gives some alternative costings, based on different assumptions about the number of specimens and duplicates brought back.

Collecting outside the Himalayas and SW China. Table 1 shows that direct costs account for only 16% of the total; of this, travel to and from the UK makes up only a quarter to a third. For British botanists, there is often an inverse relationship between the cost of travel to and from an area and the cost of living in the area. Hence, acquisition costs for herbarium specimens will be only weakly related to differences in source locality, providing it is still possible to collect at the same rate.

The length of collecting trips. The relative insensitivity of acquisition costs to the price of long-distance travel, means that there is no particular virtue in expeditions that last several months, as opposed to a few weeks, unless the longer time is a prerequisite for getting particular material (because of the isolation of the area in which it grows). This was not so before air travel became widespread and (relatively) cheap. George Forrest's first expedition to China, beginning in 1904, lasted three years (bringing back several sets of nearly 4000 herbarium specimens, together with large amounts of seed: Diels 1912–1913)

Rates of collection and policy with respect to duplicates. Acquisition costs are very sensitive to the rate of collection and the number of duplicates taken. Many of the areas visited by recent RBGE expeditions to the Himalayas and SW China are species rich and a high collecting rate is possible. An even higher rate is possible in species-rich communities of shrubs and herbs in Mediterranean-type climates, where collection and drying are especially easy. If 1.5X as many specimens are collected as in the basic model (i.e. three sets of 2250 specimens, one of which is deposited in a local herbarium, one is used for exchange and one is retained), the cost of acquisition comes down, but only to £20.7 per specimen (Table 2, column A).

Table 2. *The costs (per specimen) of acquiring herbarium specimens of vascular plants: alternatives to the basic model (see Table 1)*

Model	A	B	C	D
Collection				
salary costs	5.9	7.1	11.8	8.8
direct costs	2.7	3.2	5.3	4.0
Identification, etc	5.5	5.0	9.0	9.0
Fixed costs: mounting, laying away, housing	6.6	6.6	6.6	6.6
Total (£)	20.7	21.9	32.7	28.4

A: 3 sets of 2250 specimens, one set available for exchange.
B: 6 sets of 750 specimens, four sets available for exchange.
C: 2 sets of 2250 specimens, no sets available for exchange.
D: 1 set of 3000 specimens.

In tall tropical forest, average collection rates of 40–100 or more numbers a day may be impossible, especially if it is the trees that are the focus of attention. On the other hand, since such hard-won specimens will be particularly welcome to other herbaria, the overall cost can be reduced by collecting large numbers of duplicates. Thus, if instead of collecting 3 sets of 1500 specimens, as assumed in the basic model, the expedition were to collect 6 sets of 750 specimens (again, leaving one set in a local herbarium), the acquisition cost might even be less than in the basic model (Table 2, column B).

There are drawbacks with exchange. It is unlikely (and undesirable) that other institutes will have similar acquisition policies, so that what they make available for exchange may not be of interest. To those whose background lies in experimental science (who today dominate science planning), exchange might appear to be a largely indiscriminate, philatelic activity, and hence something that is best avoided. However, Table 2 and common sense suggest that this is not so. First, assume (Table 2, column C) that 4500 specimens are collected as before, but that these represent 2250 numbers in duplicate, not 1500 in triplicate. One set is left behind in a local herbarium as before, leaving none for exchange. The unit cost of each herbarium specimen rises to £32.70. There would have to be considerable mismatch between the nature of incoming exchange material and the desiderata of an institute before the increased unit cost was worthwhile. The remedy for unsatisfactory exchange is not to abandon it, but to specify clearly and often what each institute is studying and seeking.

Alternatively, consider an institute that does act 'selfishly': an expedition collects 3000 specimens but no duplicates at all (Table 2, column D). The acquisition cost (£28.40) is still well above that in the basic model (£24.90). Though the institute might benefit from having amassed a collection fully in accordance with its acquisitions policy, the cost is not only an extra £3.50 per specimen but a reputation for 'rape and pillage' that will probably prevent further collection. Furthermore, it is unlikely that the expedition could gather and properly document 3000 different, informative specimens. It is much easier to collect three sets of 1000 specimens than one set of 3000. The distribution of species within and between different plant communities means that a significant proportion of an expedition is spent in searching and travel, which are, in themselves, non-productive. Thus, collecting in a particular locality quickly begins to obey the law of diminishing returns. And, regardless of whether the expedition collects many duplicates of a few plants or few duplicates of many plants, there are severe limits to the number of plants that can be collected per day, set by the logistics of specimen processing, transport, and so on.

Staffing. Since salary costs dominate the cost of acquiring herbarium specimens, it is desirable to use the least expensive staff for each activity, providing this does not adversely affect the quality of the collections and their processing. The staffing assumed in my basic model may seem generous. Remember, however, that the hypothetical, model expedition was not an unfocused collecting trip, but a deliberate attempt to collect material relevant to institutional research programmes. For this, a fairly high level of expertise is essential. It might be thought that costs could be reduced during the expedition by substituting technicians, to take over tasks that require no specialist knowledge, such as pressing specimens. This may sometimes be worthwhile, but often it will not, since processing material for the herbarium (and cleaning seed) can usually be done in the evening and early morning, when plant collecting is impossible.

In other words, it is very difficult to reduce the acquisition costs to £20 or less, unless specimens are collected near the herbarium and identified quickly by eye by a very junior member of staff – in which case, they probably aren't worth collecting. Specimens can be made as expensive as one cares to be inefficient, but clearly there will be some cases where acquisition will inevitably be costly, as a result of very difficult terrain, extreme isolation, or other special factors (irritant or spiny plants, tall trees, etc). Here, the price could be forced upwards, to £50 or more.

Bryophytes

Again using our Himalayan/SW China experience, it is possible to work out an approximate cost for the collection of bryophyte specimens and their incorporation into the herbarium. Bryophytes take up less space on an expedition than vascular plants, it is easier to collect duplicates, and exchange is often more efficient, since it takes place between people who generally know each other's interests and expertise very well.

Assume that a senior scientist on a Himalayan/SW China expedition collects four sets of 1500 specimens. The local herbarium has no bryologist and does not request a set of specimens; three sets are therefore available for exchange, bringing 6000 specimens in total. Identification is slower than for vascular plants (average 1 hour for each specimen) and requires the expertise of the senior scientist. Mounting is easier, since all that is generally needed is to stick paper capsules onto herbarium sheets. Although individual specimens are small, they are fairly bulky, so that the number of specimens per herbarium cabinet and the herbarium building cost are not much different than for vascular plants. On this basis, the acquisition cost of bryophytes is approximately £12.60 per specimen (Table 3). The number of duplicates is again critical. The extra difficulty of naming bryophytes, as opposed to vascular plants, coupled with a higher rate of collection in the field, means that the dominant cost element is identification. With vascular plants, as we have seen, it is extremely difficult to reduce the effective cost of the first phase of acquisition, namely collection. However, since the 'weakest link' in the acquisition of bryophytes is not collection but identification, it may often be best to maintain a high collection rate on the expedition, but to identify specimens only to genus, allowing them to be incorporated cheaply into the herbarium until they are required for study.

Table 3. *The costs (per specimen) of acquiring herbarium specimens of bryophytes, based on estimates for an expedition to the Himalayas or SW China collecting four sets of specimens (see text)*

	£
Collection	
salary costs	1.5
direct costs	0.5
Identification and management of exchange	6.0
Mounting	0.5
Laying away	0.9
Housing	
herbarium cabinet	0.7
herbarium building	2.5
Total (£)	12.6

Other plants

It is beyond the scope of this paper to consider every plant group in detail. The most expensive macroscopic plants to incorporate into herbaria are probably seaweeds. Collection and processing are much more tedious than for terrestrial plants, and identification often requires microscopical examination and considerable expertise. Fungi and lichens are easier to collect and process than seaweeds, but can be as difficult to identify; they are often bulky and may have high storage costs.

Few microscopic algae can be preserved effectively. The conspicuous exceptions are the diatoms, but the economics of collecting them are complicated by several factors: diatomists collect samples of whole communities, not specimens of individual species, and preparation is slow and expensive (involving chemical treatment). No identification of organisms is necessary before incorporation in the herbarium, since material can be indexed by source locality. Storage is cheap.

Gifts and purchases

At Edinburgh, we do not purchase many specimens and there is little market for herbarium collections, unless they have some special historical significance. Sale of collections was more common in the nineteenth century (e.g. Hooker 1842a, b), but even then, the financial returns were very modest. By contrast, fossils are widely collected for ornament (decor-fossils) as well as for their scientific interest; vertebrate remains can sell for over £100 000 in exceptional cases (Rolfe *et al.* 1988).

I suspect that a lucrative market could be created quite easily for herbarium specimens, since people will collect almost anything if they believe its value will appreciate. Some species exist now only as herbarium specimens. Examples are *Thuja sutchuensis*, collected once (with duplicates) in Chengkou County, Sichuan, China, but not seen since (Fu Li-kuo 1992), or *Trochetiopsis melanoxylon*, a species of a genus endemic to St Helena. *T. melanoxylon* became extinct *c.* 1780 and the only specimens remaining are five herbarium sheets, four of which are very old, dating from around 1700 (before the establishment of a standardized botanical nomenclature by Linnaeus; Q.C.B. Cronk, pers. comm.). Obviously, no new specimens of these species can be collected: the existing sets, dispersed through the herbaria of the world, form élite 'limited editions'. Suitably framed and protected from beetles and bright light, such material would have many of the qualities of a painting by an old master: rarity, aesthetic appeal, history and pedigree, and ease of display. Extra prices might be commanded by unusual plants, such as *Mellissia begonifolia*, which represents an extinct genus, formerly present on St Helena but not seen alive since 1880 (Q. C. B. Cronk, pers. comm.). It would be unfortunate for herbaria if a market did develop for their historical material, since thefts would increase and the availability of specimens for study would have to be curtailed.

Those selling specimens to herbaria such as Edinburgh rarely look for full financial recompense and may be satisfied with nothing more than a contribution towards their next expedition. We sometimes offer £1.50 per unmounted specimen for interesting material, but have heard of herbaria offering less than this for mounted, identified material from Asia. Recently, we paid £1500 for 7000 specimens. It is unlikely that anyone in the developed world could make a living as a professional collector!

Assuming a purchase price of £1.50 for unmounted material, and assuming that the specimens are only partially identified, the overall acquisition costs for such specimens might be £1.50 + £4.50 (for identification, assuming *c.* 15 minutes per specimen, on average) + £6.60 for mounting, laying away and the costs of housing – a total of £12.60.

Active herbaria also receive many gifts. Some are already mounted, in which case the acquisition cost reduces to £4.10 (for laying away and housing). If they are not mounted, the cost is £6.60, and if the identification is suspect, it will be £10 or more. Thus, although gifts are very welcome, they are not free. Last year, we received roughly 2000 specimens as gifts and 8000 through collections and exchange. Assuming £7 each for the gifts and £25 for the rest, the average acquisition cost for the year was £21. However, the proportion of specimens received as gifts varies considerably from year to year.

It is important to note that gifts are attracted by *active* research and curation. People do not like to think that their specimens are going to be put away and forgotten. Edinburgh has recently attracted several important bryophyte collections, such as E. W. Jones' African bryophytes and parts of the British Antarctic Survey collections (D. G. Long, pers. comm.). It is unlikely that these would have been given to Edinburgh if new research into bryophytes had not been initiated in the last 20 years.

Replacement costs

In one sense, the cost of acquisition is a valuation, since it indicates how much an institute has been prepared to pay to build up its herbarium. On the other hand, it is clearly an inadequate measure of value, since many historically or scientifically important specimens are gifts, costing much less to incorporate than a collected or exchanged specimen.

A better measure of value, though still unsatisfactory, is the replacement cost. For a well-documented Himalayan or SW Chinese specimen, acquired on an expedition and costing £24.90, the cost of replacing it is roughly the acquisition cost **minus** the costs of housing the specimen (presuming the specimen alone is lost or destroyed, rather than the whole herbarium and herbarium building), i.e. £21.70. However, this will be so **only** if the specimen is well documented. If the specimen has flowers or displays some other short-lived stage in the life cycle, and if the time and place of collection are recorded precisely, the replacement cost will be high; it may even be higher than the acquisition cost, since the uncertainties of climate dictate that a species that is flowering when collected on August 1 one year may not be when collectors attempt to replace it on August 1 twenty years later. But if the specimen is vegetative or if the time and place of collection are not precisely recorded, then the replacement cost will be substantially lower, since any specimen from within a wide area, and collected at more or less any time, may be an adequate or perhaps better replacement for the original. Indeed, the difference between the acquisition cost and the replacement cost is a measure of the quality of the specimen and the prudence of the investment the herbarium has made in acquiring it.

Gifts lower the cost of acquisition, but not of replacement. Thus, the specimens Edinburgh was given last year cost perhaps £7 each to incorporate into the herbarium, but would cost three times as much to replace.

Overall, then, we can suggest that the preserved collections of the Royal Botanic Garden Edinburgh, totalling close to 2 million specimens, would cost at least £40 million to replace. However, I cannot emphasize too strongly that this is not their true value. The primary function of herbarium collections is to support research into plant biodiversity and allow accurate identification, activities that are fundamental to almost every other aspect of plant biology. Estimates of replacement costs are useful for planning and give a rough idea of the long-term investment that a herbarium collection represents; they enforce a sense of responsibility in curatorial practices; and they give a rough yardstick by which one can judge the economic benefits herbaria bring (see below). But the Edinburgh herbarium is not just 'worth' £40 million.

Two further points must be made about replacement. First, exact replacement is impossible, because plant populations change. All one can hope to do is to replace one specimen with another that is of equal, though of different interest. Where a species or race has become extinct, the loss of herbarium specimens is irreparable and replacement costs are essentially meaningless, just as they would be for a Leonardo painting; would the London, National Gallery *The Virgin of the Rocks* be an adequate replacement for the Louvre version?

Second, replacement costs are largely fictional. If the collections of one of the major herbaria were to be destroyed (as happened in Berlin during the Second World War), the institute might survive, but full replacement would be out of the question, not only because no-one would pay for it, but because it would be impossible to achieve. This is not primarily because the source populations no longer exist, though this is increasingly true, but because we do not know what we have. For most specimens in most herbaria, the only true and complete record we have of their existence and nature is the specimen itself and the label it bears. Destroy the specimen and no-one will know what to replace. There are exceptions, especially among the smaller herbaria, where electronic databases of specimens are being constructed (Nielsen & West 1994), and in some cases printed catalogues exist for particular collections, such as for the specimens brought back to Edinburgh from China and Tibet by Forrest (Diels 1912–1913, the Staff of RBGE 1924, 1929–1930). In general, however, we can say that most herbarium specimens and the information on their labels are irreplaceable. Hence, a strong argument can be made for investing in full catalogues, with scanned images, of all the specimens in the major herbaria. This might cost £4 million for Edinburgh, but this is less than a tenth of the cumulative cost of acquisition and curation. Failing a full catalogue, it would be wise to make copies of all collecting books, correspondence and other documents associated with the herbarium, and store them in several distant locations, just in case the collections are destroyed and, by some miracle, there is after all some inclination to replace the loss.

Maintenance

Unlike living plants, herbarium specimens need little attention to keep them in good condition, if they are kept dry and safe from insects, at a fairly constant temperature (which can be a severe problem in the humid tropics: Forman & Bridson 1989). And few staff are needed to provide a 'skeleton curatorial service': receiving visitors, responding to correspondence, arranging loans, and writing guides to the more important collections. However, much more than this is needed to maintain a herbarium collection in full working order. For example, specimens need to be re-named in accordance with new monographs and nomenclature; type specimens need to be identified as such; the meaning of words and place-names on old labels need clarification.

Taking this broader view of the essential minimum of curation needed to maintain the quality of herbarium collections, I estimate (from Edinburgh expenditure on salaries and building maintenance, with due provision for the library, administration and other overheads) that the cost of keeping and curating each specimen is roughly £0.25 per annum – just 1% of the estimated acquisition cost. Clifford *et al.* (1990) argued that 'new specimens may be collected for new treatment' and hence that many herbarium specimens could be disposed of after study. Aside from any ethical or scientific objection to this (West *et al.* 1990), and the sheer impossibility of replacing some material, their policy makes no economic sense, unless specimens remain unused for many decades. Again, Walters (1993) considered that the cost of housing, protection and curation 'is potentially enormous' and asked 'should we not try harder to reduce by rational procedures this enormous burden"? But maintenance is actually cheap, **relative to** the cost of selecting specimens for disposal, which could exceed the average acquisition cost of £25 per specimen. One therefore has to ask how often weeding out 'useless' material will be worthwhile. The best way to apply quality control in a herbarium, or in living collections, is at the beginning: specimens should not be accessed unless they are of high quality, and complement the collections that already exist.

The costs of acquiring and keeping living collections

With herbarium specimens, acquisition starts with the planning of an expedition and ends when mounted, labelled specimens are put into herbarium cabinets – a well-defined process, whose different stages can be identified and costed. But there is no end-point with living collections. Does acquisition end with the arrival of seed or cuttings in Edinburgh, or when the plants are large enough to be planted out? Furthermore, exchange of surplus material of living plants or seed is often far less well regulated than the exchange of herbarium specimens. Typically, seed is distributed to many gardens and individuals, with the expectation, but no guarantee, that interesting material will one day be returned.

Our plant records suggest that, each year, between a quarter and a third of the accessions of plants of known wild origin are collected by Edinburgh staff; the remainder come through informal exchange. This suggests that, on average, each distribution of seed or other material brings two to three accessions in return. Expedition reports (McBeath *et al.* 1991; Long *et al.* 1992, 1993; Noltie *et al.* 1994) and my own experience show that expeditions that collect seed or cuttings as well as herbarium material cannot collect and process as many herbarium specimens as expeditions that bring back no living material. However, the reduction in the rate of collection of herbarium specimens caused by the collection of living material is lower than would be expected from a 1:1 substitution; these activities are partly complementary. Thus, we could postulate a second hypothetical expedition, in which the products are three sets of 1200 herbarium specimens and 500 packets of seed (each containing enough for distribution to several other gardens), instead of the three sets of 1500 herbarium specimens assumed in the basic model. Herbarium specimens have to be collected regardless of whether living plants are collected or not, since vouchers are required for the living material; I will assume, therefore, that the **collection** cost per herbarium specimen remains £12.80, as in the basic model. Then the cost of collecting seed or other living material can be estimated by subtracting the cost of collecting the 2400 herbarium specimens acquired by the expedition, from the total expenditure on salaries and direct costs. On this basis, if each living accession brings an average of 2.5 other accessions in exchange, the unit collection cost is £4.50. Identification is 'free', since this is included in the cost of the voucher specimens destined for the herbarium.

But the most expensive aspect of living plants is their cultivation. The Royal Botanic Garden Edinburgh currently maintains around 40 000 accessions of living plants, at a cost of around £2.5 million per annum (no ground rent is paid, since the Garden is on land owned by the State), which implies that each accession, on average, costs over £60 **every year**. In a botanic garden, many of the plants are on display, and are therefore managed in ways that would make no sense in a commercial nursery. But costs are inevitably high in a botanical collection, as opposed to a nursery or parks department, since each species has its own peculiarities and cultivation techniques often have to be worked out through trial and error. Botanic gardens, after all, are where most plants are brought into cultivation for the first time.

The benefits of botanical collections

Botanical collections bring many benefits, which are more than commensurate with the investment that has been made in acquiring and maintaining them. Let us first list the uses to which they are put.

The uses of herbarium specimens

Research into plant systematics. If we are to discover, catalogue and understand the million or more species of plants, algae and fungi that share this world with us, and gain insights into their relationships and evolution, herbaria are essential: 'For practical reasons, the classification of the world's flora is primarily based on herbarium material and the literatûre associated with it. Despite its limitations, a herbarium has certain advantages over living collections. It is usually only in the herbarium that we can compare all the related species of a genus in the same place, in the same state and at the same time' (Davis & Heywood 1963).

After they have been used for taxonomic research, herbarium specimens acquire significance as the essential material for checks and replication: taxonomic research must be open to test.

Identification. Almost all aspects of biology, from conservation to breeding and the search for new drugs and plant products, require the identification of biological material. Where good aids to identification exist, such as field guides or floras, they will be used before recourse to the herbarium. But even so, the identification of plants is ultimately dependent on the use of botanical collections. For many parts of the world and many plant groups, there are no published aids to identification and matching with herbarium specimens is the only sure way to accuracy.

Definition. The proper application of the names of species and other taxa is determined by types, which for many groups of plants are herbarium specimens. Definition is also the prime purpose of another group of herbarium specimens: the voucher specimens deposited to support identifications made during ecological, molecular genetic or other studies.

Biogeography and temporal changes in populations and distributions. A herbarium specimen documents the existence of a particular plant at a particular place and time.

Environmental monitoring. Changes in distribution demonstrated by herbarium material can be used to monitor environmental change. For example, van Dam & Mertens (1993) used diatoms on specimens of aquatic macrophytes held in the Rijksherbarium, Leiden, to detect deterioration in water quality over the last 50 years.

Ethnobotany. There is no necessary link between herbarium specimens and ethnobotany, only the accidental one that information about the uses of plants is sometimes recorded on herbarium labels; see Chaudhuri *et al.* (1977) and Altschul (1968).

History of exploration. Herbarium sheets are records not only of plants collected, but also of their collectors: they are sociological documents.

Professional education and training. The importance of herbarium specimens in taxonomic training is obvious, given the uses listed above.

The uses of living collections

Properly documented living collections have all the uses mentioned above, plus others:

Public education, amenity and display. One of the first botanic gardens, Padua, was designed like a theatre, 'where Nature herself was to be seen on the stage' (Terwen-Dionisius 1994). The display of plant diversity is one of the most important functions of living collections, to inform, educate and delight humankind.

Conservation. There is a general consensus that the first choice in conservation is to secure the future of species *in situ*, where they occur naturally. Even where this is possible, however, *ex situ* conservation is an important extra safeguard, in the form of seedbanks or collections of plants in gardens and arboreta. Numerous examples, demonstrating the importance of botanical collections to conservation, through preservation of germplasm but also through education and display, are given in *Botanic Gardens Conservation News*.

Research into plant growth, development, morphogenesis, physiology, biochemistry, genetics, molecular biology. Botanic gardens and other repositories of living plants rarely do such research themselves, but provide material to institutes that do.

Commercial horticulture and exploitation of plants. Throughout their history, botanic gardens have often been the conduits through which plants have been introduced to horticulture and many collecting expeditions have been sponsored by the horticultural industry. George Forrest's first expedition, for instance, was financed by the British entrepreneur A.K. Bulley, founder of the nursery and seed firm, Bees Ltd (Fletcher & Brown 1970). The contribution of the SW Chinese flora to British gardens, via collections by Forrest, Wilson, Kingdon-Ward and others is well known (Fletcher & Brown 1970), but the transfers would not have been possible without the link between the collectors and botanic gardens; here alone were the collections and expertise that allowed identification and the description of new species. The link between collectors, botanic gardens and horticultural introduction continues today.

Perhaps less well appreciated than the link between plant collections and horticulture is the extent to which botanic gardens and their collections have been instruments in transferring economically important plants between countries. This role is explored by Brockway (1979), who makes particular reference to the Royal Botanic Gardens, Kew. In the nineteenth and early twentieth centuries, with the encouragement of the British government, Kew used its taxonomic and horticultural expertise and status to act as a botanical entrepôt; indeed, Kew was established with this in mind (Brockway 1979, p. 80). Specimens of commercially valuable plants were acquired, not always ethically or even legally (Brocway 1979 pp. 115-116, 157), imported into Kew and grown, and then exported to parts of the British Empire, via a network of other gardens. Brockway's main examples are *Cinchona*, the source of the anti-malarial, quinine, and Para rubber, *Hevea brasiliensis*.

Plant breeding. Special collections have been made in many countries, as an essential basis for plant breeding (see Introduction). General collections, such as those in botanic gardens, are of lesser importance, but often contain relatives of crop plants, which may be useful as sources of novel genes.

Screening for pharmaceuticals, insecticides, nematicides, etc. The larger botanic gardens contain thousands of species (Kew and Edinburgh, for example, contain over 38 000 and 21 500 taxa, respectively), offering opportunities for industry to prospect for new, pharmacologically active compounds, etc. The germplasm being screened will often have been obtained for taxonomic purposes and any commercial exploitation must take full account of the rights of the 'donor' country.

Defining value for cost-benefit analysis

Earlier, I suggested that acquisition costs and replacement costs are not satisfactory as **valuations**. They measure investment. Nor are low purchase prices an indication of value, in spite of Samuel Butler's lines (*Oxford Dictionary of Quotations*, 1953), written over 300 years ago, but so expressive of contemporary thought:

> 'For what is Worth in anything
> But so much Money as 'twill bring.'

The uses of plant collections listed in the previous section indicate that there are returns on the investment made, which could in theory be quantified and turned into a valuation.

Thus, we could define the **residual value** of a specimen as the legitimate cost of the original scientific research, education, publication, nomenclatural definition, that a specimen can (and should) still support in an efficient, ideal world, together with the cost of all dependent research and development, and saleable products.

The **realized value** can be defined as the legitimate cost of such scientific research, education, etc., that a specimen has already actually supported, together with the cost of all dependent research and development, and saleable products.

These values can be very high, since the primary use of herbarium specimens is in taxonomic research, and taxonomy is essential (not merely desirable) for almost all other biological research and biological resource management, and for the commercial exploitation of plants. The realized value of the herbarium specimens used to circumscribe and define the Madagascan rosy periwinkle (*Catharanthus roseus*) would already run into millions of pounds, as a result of the discovery that two chemicals isolated from this plant are useful in the treatment of leukaemia (Natural Environment Research Council 1992, Systematics Agenda 2000, 1994); and that is to ignore the value of the discovery in terms of human lives.

It will quickly become obvious that to calculate the 'residual' or 'realized' value for any specimen is in practice impossible, but this does not mean that the concepts have no use. Thus, for example, they help clarify how specimens can depreciate or appreciate in value.

It is just conceivable that the residual value of a specimen could be reduced to zero, as a result of intense study and exploitation of the results: no more original research is possible and all the implications of previous research have been worked out. Does the specimen, then, have no value and can it therefore be thrown away? The answer is certainly 'no'. Firstly, the specimen is not only raw material for scientific research (and whatever flows from this), it is also part of the validation for that research. There is a sense, therefore, in which the realized value is **both** evidence of the **past** importance of a specimen **and** a valuation **now**. Secondly, even if the residual value were to be reduced to zero, it might not remain so. Advances in technology can open new lines of research and reopen others. This has happened over and over again in the last 200 years; recent examples include scanning electron microscopy and the development of molecular systematics.

The concept of residual value exposes a great folly: collections that are not used! In such cases, specimens may have no realized value. But not only that, the residual value depreciates inexorably, since some of the research, education and so on that a specimen might have supported will inevitably be done elsewhere, using other, similar specimens. To leave specimens in cupboards or glasshouses, preserved but not studied, is to throw away an investment. Note in passing that the acquisition cost of a herbarium specimen (£25) would be 'recouped' (i.e. £25 added to the realized value of the specimen) by just one or two hours of productive study by a taxonomist earning £20 000 per annum, once allowance is made for research costs and overheads. This shows how ludicrously cheap herbarium specimens often are – and the specimen remains available for further study and use for a century or more. Living collections are more expensive but also more versatile.

Botanical collections are good value for money

Botanical collections are the basis for a wide range of activities, some of which have obvious economic importance. Although I have suggested definitions of 'residual value' and 'realized value', I have not been able to quantify these even for one specimen. We should always remember that some benefits cannot be expressed in financial terms, e.g. the preservation of human life (although for the purpose of calculating the economic value of biodiversity, Pearce & Moran 1994 give the 'value of a statistical life' as US$ 4 million). Plants have sometimes have unexpected effects on life expectancy, such as the suppression of head hunting in Borneo by Para rubber (Dove 1994). But, restricting ourselves to things that can be quantified relatively simply, the benefits of botanical collections can still be quantified well enough to show that they amply justify their costs.

For a herbarium specimen, I have suggested that a reasonable figure for the average cost of acquisition is £25, while the annual cost of maintenance is £0.25. These are, I think, good 'ball-park' estimates and are unlikely to be wrong by more than a factor of two or three either way. If the figures had been worked out for a herbarium in a developing country, they would undoubtedly have been much lower, but they would then have been meaningless in a British context: there is no rational way to produce a globally valid average for the price of a herbarium specimen. Let us therefore use the 'British' figure as a basis for some comparisons. The acquisition cost of the 270 million pressed plants collected so far (Holmgren *et al.* 1990) would then be £6.75 billion, spread over the 450 years since herbaria began. 1% of this per annum might ensure active maintenance of existing collections. For living collections it is difficult even to guess at the cost per annum world-wide. Let us hazard that there are 10 million well-documented accessions in botanic gardens and arboreta, each costing £60 per annum to maintain, giving a total of £600 million per annum.

Small (1993) gives several examples where plant systematics research has contributed significantly to the development of new crops and plant products, including the discovery of *Zea diploperennis*, believed to be closely related to the ancestor of modern maize, *Z. mais*. *Z. diploperennis* possesses genes conferring resistance to drought and various diseases, which can be transferred to cultivated strains (this hackneyed but valuable example is also quoted by Systematics Agenda 2000, 1994 and others). Small estimates that the discovery may have a value of US$ 4.4 billion (currently £2.75 billion) **annually**. Earlier, the example was given of *Catharanthus roseus*, the source of the anticancer drugs vincristine and vinblastine; these are worth US$ 200 million per annum (Natural Environment Research Council 1992). Such examples may be rare (although Pearce & Moran 1994 estimate the prescription value of plant-based drugs to be US$ 11.7 billion per annum in the USA alone), but there need to be very few before the historical costs of acquisition and the maintenance of **all** existing herbarium collections become quite insignificant.

I have already mentioned the historical involvement of botanic gardens in the international transfer of economically important plants (Brockway 1979). This trade, illicit or not, was only possible because of the unique combination of horticultural facilities and expertise, and botanical knowledge (based on field, herbarium and garden studies), present in the larger botanic gardens. Thus, the development of the rubber industry of SE Asia can in many ways be credited to the work of the Royal Botanic Gardens, Kew, which 'were responsible for every phase of the development of cultivated Hevea rubber ... Kew supplied the plant and the basic botanical work. The colonial gardens functioned as agricultural experimental stations ...' (Brockway 1979). Add to this the involvement of this same botanic garden in the forced migration and exploitation of the plants yielding quinine, sisal, tobacco, tea, coffee, pineapples, almonds, derris and pyrethrum insecticides, and others (Anonymous 1941, Brockway 1979), and it should be easy for anyone to see the power and economic value of systematic and horticultural knowledge about plants (even if they object to the way the knowledge has been used in the past by colonial powers). This knowledge depends on botanical collections and the people who know how to use them. I conclude that both are cheap at the price.

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