WCMC Biodiversity Series No. 7

Industrial Reliance on Biodiversity

T. M. Swanson and R. A. Luxmoore

DARWIN INITIATIVE

WORLD CONSERVATION MONITORING CENTRE

WCMC Biodiversity Series No. 7

Industrial Reliance on Biodiversity

A Darwin Initiative Project

T. M. Swanson
Faculty of Economics and Politics
Cambridge University

R. A. Luxmoore
World Conservation Monitoring Centre

WORLD CONSERVATION MONITORING CENTRE

DARWIN INITIATIVE

World Conservation Press

1997

The World Conservation Monitoring Centre, based in Cambridge, UK, is a joint venture between the three partners in the World Conservation Strategy and its successor Caring For The Earth: IUCN - The World Conservation Union, UNEP - United Nations Environment Programme, and WWF - World Wide Fund for Nature. WCMC provides information services on conservation and sustainable use of species and ecosystems and supports others in te development of their own information systems.

Prepared for publication by the World Conservation Monitoring Centre with generous funding from the Darwin Initiative.

WORLD CONSERVATION
MONITORING CENTRE

DARWIN INITIATIVE

Published by: World Conservation Press, WCMC, Cambridge, UK.

ISBN: 1 899628 06 1

Citation: Swanson, T. M. and Luxmoore, R. A.. 1997. *Industrial Reliance on Biodiversity*. World Conservation Press, WCMC, Cambridge, UK. 98pp.

Cover design by: Michael Edwards

Printed by: Victoire Press Ltd, Cambridge

Available from: World Conservation Monitoring Centre
219 Huntingdon Road, Cambridge CB3 0DL, UK
Tel: +44 1223 277314; Fax: +44 1223 277136
Email: info@wcmc.org.uk; URL: http://www.wcmc.org.uk

CONTENTS

TABLES

FIGURES

PREFACE

This report presents the results of industrial surveys undertaken under the auspices of the U.K. Department of Environment's Darwin Initiative between 1994 and 1996. The project was entitled "Sustainable Utilisation for Global, National, and Community Benefit: An Analysis of Utilisation and Biodiversity Conservation". It was conducted jointly by the World Conservation Monitoring Centre (Dr Richard Luxmoore, principal investigator) and the Faculty of Economics, Cambridge University (Dr Timothy Swanson, principal investigator). The investigator who conducted most of the surveys and wrote up the majority of the reports under this portion of the project was Nathalie Olsen, now of the Food and Agricultural Organisation, Beijing, China. Also contributing to this portion of the project were Jose Carlos Fernandez (Department of Applied Economics, Cambridge University) and Harriet Gillett (WCMC). Dr Caroline Harcourt assisted with the final editing. We would also like to acknowledge the time and assistance received from the numerous members of industry who participated in the survey. The views expressed in this report are those of the authors only and do not necessarily reflect the views of the Darwin Initiative nor those of the Department of the Environment of the UK.

1. INDUSTRIAL RELIANCE ON BIODIVERSITY: A SUMMARY

Timothy M. Swanson

1.1 INTRODUCTION: THE INDUSTRIAL USEFULNESS OF BIODIVERSITY

Biodiversity, a contraction of 'biological diversity', is the term used to describe the total variety of living organisms. Biological diversity is customarily addressed by biologists at three different hierarchical levels: genes, species and ecosystems, but, for general usage, the term is most often used as a collective noun meaning nature or all life on earth (WCMC, 1996). Biodiversity is of clear importance. It is, for instance, the primary source of foods and medicines for most societies. It is also the source of many forms of "non-use values" e.g. the value which many western societies would give in order to "save the tropical forest" or the "ecological value" of diverse eco-systems. These values are very important, but they are the subjects of other enquiries (Prescott-Allen and Prescott-Allen, 1986; Perrings *et al.*, 1995; Barbier, Burgess and Folke, 1994; Pearce, 1991) and are not dealt with here.

Instead, the object of this study is to ascertain the extent of industrial reliance on biological diversity; we are attempting to determine the extent to which biodiversity feeds directly into western industries, and the extent to which they rely upon it. There is a general consensus among environmental scientists that biological diversity plays a very important role in the activities of some of our industries. However, there is very little direct evidence of the degree to which the industries depend on this biodiversity. There has been some work in the past which has attempted to set out the case for the role of biological diversity as an input into standard western industry (Wilson, 1986), but much of this previous work has been anecdotal in nature. For example, there have been reports of the "serendipitous" discovery of "weedy tomatoes" or the fortuitous discovery of a remnant patch of "perennial maize". These finds are undoubtedly useful (the tomato variety alone is estimated to be worth millions of US dollars), but the process by which they are identified and the way they are used by western industries are too haphazard to ascertain their real importance.

This report attempts to provide clearer and more concrete evidence of the industrial use of biodiversity. The study looked at two different ways in which industry used the world's biological diversity. Firstly, in Chapter 2, the use of *biodiversity as a commodity* is studied. This chapter presents data on the direct trade in various diverse biological products as commodities for manufacture and sale. Secondly, in Chapters 3 and 4, data on the use of *biodiversity as information* is presented. In these chapters, information obtained in response to questionnaires sent to pharmaceutical companies and plant breeders/seed companies is presented. The object of the questionnaires was to get some precise information on the degree to which these industries relied on biological diversity in the production of their products and, thereby, obtain data on the use of diverse organisms to inform research and development processes in these industries.

1.2 BIODIVERSITY AS A COMMODITY: DIRECT USE OF DIVERSE WILDLIFE RESOURCES

The two most significant industries which deal in commodities from natural habitats are forestry and fisheries. The value of wood products exported worldwide in 1991 amounted to around US$65 billion (FAO, 1993). Exports of fish at about the same time (1989) raised some US$32.8 billion (FAO, 1991). In addition, many forest products and fish are consumed within their country of origin, thereby raising the value of these commodities immensely. Although much less significant than forestry and fisheries, there is also a considerable trade by other industries which rely upon biodiversity. These include, for example, those that trade in: furs; reptile skins; game meat; live animals, for the pet trade in particular; crude shells; corals; natural pearls; ivory and plants. Altogether these other industries trade in diverse biological commodities worth, perhaps, $1-5b. per annum. Almost the entire trade flows from less developed countries to Europe, the USA and Japan. Table 2.33, showing the estimated minimum value of wildlife imports to these areas, is certainly an underestimate of the overall value of the trade in biodiversity as a commodity, but it gives a clear idea of the relative magnitudes of the trade in these various industries.

It is evident from the extensive data presented on direct use of wildlife resources that it is extremely difficult to obtain an accurate figure for the value of the trade in these products and even more difficult, almost impossible, to quote a figure for their total value, as use by local communities goes more or less unrecorded. It is clear, though, that the conservation of the world's wildlife resources is essential for human well-being. Sustainable wildlife management has to be practised to allow the continued use of these resources.

1.3 BIODIVERSITY AS AN INFORMATIONAL INPUT INTO BIO-INDUSTRY

The pharmaceutical and agricultural industries are concentrated on in this publication as the activities of these businesses are most closely linked to the biological-industrial interface. In these industries, biodiversity functions primarily as an informational input to their research and development processes, and is essential to this purpose.

Some areas within agriculture and medicine can be conceived of as living defence systems rather than static technologies. That is, rather like the sea defence systems of a low-lying country, these fields of human activity consist of continuing efforts to combat the erosion of human-erected defences against a hostile biological world. In agriculture, we constantly attempt to keep at bay the always-evolving pests and predators of our food crops. In medicine, we continue in our efforts to defend ourselves against diseases caused by many different organisms, as these have an even more direct impact on human beings. In both cases, the defences are neither absolute nor perpetual - as with the Dutch dykes - they are constantly eroding under the pressure of the forces of nature.

The fight against malaria is an excellent paradigm for the nature of the front-line battle between the human species and its potential biological invaders. It illustrates that any gains in terms of development of new drugs or strategies to counter the parasite, must be perpetually defended against the ability of the parasite to evolve resistance. The nature of the biological world assures that these gains are always under assault. This is generally true throughout society; wherever humans have successfully appropriated some portion of the world's bounty for themselves (cultivated crops, domesticated species), there are forces within the biosphere that will place these holdings perpetually under assault.

In short, having a large proportion of the biosphere invested in a small number of species (namely, humans and their associated domesticated/cultivated species) results in an inherently instable system. This situation represents an opportunity for exploitation by other biological organisms: successful invasion confers massive gains in fitness. Evolution will constantly and perpetually introduce new variants of pests and parasites for the invasion of this niche.

Humans continue to expand the niche which must be protected - with approximately 5 billion individuals and 40% of the terrestrial biosphere used by them (Vitousek *et al.*, 1984) and they have to be ever vigilant in the protection of their gains. If they are not, these gains will be eroded by the forces within the biological world. This is the task - a dynamic contest between humans and nature - that society has set for the biosphere-focused industries (or `bio-industries'): the medical/pharmaceutical industry and the plant breeder/agricultural industry.

Biological diversity is an essential component in the defence of the human niche simply because it contains ingredients which have been generated within the relevant crucible. That is, it is not biological diversity *per se* that is the most useful input into important human industries, but rather it is the information to be gained from the characteristics which have evolved within a living environment that is most likely to make a contribution. Biodiversity is useful to our industries because of the manner in which the existing set of life forms have been selected (within a living, contested system similar to our own), provides us with an already-vetted library of successful strategies.

Any life form may be of some use to humans, either in terms of the explicit information it represents (the observed characteristic or phenotype) or for the implicit, biological coding of that information (its genotype). We can take note of the explicit information and make use of those observed characteristics for whatever ends we might wish, or we can make use of the coded (genetic) material that produces the effect and transplant it to achieve the desired result.

Pharmaceutical industries most often pursue the former strategy (making use of observed characteristics in biological material), while agricultural industries most often pursue the latter (Swanson, 1995). Pharmaceutical companies frequently screen plants (and other life forms) in order to discover chemicals with biological activity; e.g. `alkaloids' in plants (Fellows, 1995). However, if these chemicals appear to serve some useful purpose, then the pharmaceutical industry will usually focus on the synthesis of that chemical within a laboratory environment from its basic chemical constituents. In contrast, agricultural and plant breeding companies tend to operate by identifying a useful trait within a organism that is closely-related to one that they are interested in, and then use selective breeding to transport that trait (genotype) into the plant or animal they wish to change. Although the two industries are following the same basic pursuit (i.e. the incorporation of successful strategies into the human economic system), they use different techniques to effect this endeavour. One (the agricultural industry) is transporting successful strategies between near relatives using genetic material, while the other (the pharmaceutical industry) is transporting successful strategies across vast biological distances through chemical replication of the strategy.

The importance of biodiversity to human industries is that it is a living system containing a library of successful strategies. The ability of humans to use the information contained in the rest of natural world has been constrained by the lack of techniques available and this has limited the transfer of biodiversity's information. However, our knowledge about such matters is increasing rapidly and it is already possible to transfer strategies between organisms and living systems in ways that were not imaginable a few years ago. Hence, the advance of the technological frontier in the area of the bio-industries should dramatically increase, rather than reduce, the value of biodiversity.

The purpose of our surveys of the pharmaceutical and plant breeder/agricultural industries was to ascertain the extent to which they currently rely on biodiversity for their research strategies, and how the movement of the technological frontier is affecting their reliance on biodiversity.

1.4 THE PROJECT ENVIRONMENT (INDUSTRIAL AND NATURAL) PROPERTY RIGHTS ISSUES

The difficulty of the task undertaken here cannot be overemphasised, as the industries concerned feel under assault on this issue, and they do not see it as being in their own best interests to contribute voluntarily to an exercise of this nature for two reasons. Firstly, commercial concerns do not, in general, benefit from revealing information in their possession, because they rely on informational advantages to compete within their industries; for this reason, this summary and the reports from which it derives make every attempt to conceal the identities of the firms involved (actual names are used only when the information is taken from sources available to the general public).

Secondly, and more importantly, the industries involved (pharmaceutical and plant breeding/seed companies) have been engaged in a long debate concerning the property rights to the products they manufacture (see, e.g., Juma, 1989). For example, developing countries have long claimed that the ingredients of the "green revolution" are simply recycled varieties of their own making, and they have agitated in various fora for a share of the proceeds from these activities. This has led to a FAO resolution for the creation of a regime of "Farmer's Rights" analogous to the existing "Plant Breeder's Rights". As a result, western industries perceive that they have good reason to feel threatened by movements for the conservation of biological diversity. They perceive these to be attempts to redefine their rights to their own products. In consequence, for example, the USA qualified its accession to the Biodiversity Convention by refusing to accept or enforce any parts of that convention which infringed its claims to property rights within its industries.

The problem with this stance is that it ignores the importance of property right institutions in the creation of incentives for the investment in important resources (Swanson *et al.*, 1994). If property rights performed no role other than to distribute the proceeds from existing products, then there would be no conflict between the USA's official position and biodiversity conservation. However, since property rights are crucially important determinants of investment activity, this stance poses a threat to biodiversity and any industries which rely upon it.

Economists perceive property rights regimes as institutions which play a very important and specific role within the economy. They view all the assets on which society depends (natural and human-made) as belonging to all people. Property rights merely determine the sets of hands through which the benefits from certain assets are first channelled; whoever is the "owner" of a particular asset is merely the first person to receive any benefits which it produces, after which its benefits continue to flow throughout society. For example, most people would be able to conceive of farmers as managers whose efforts result in a flow of farm produce to the rest of society, with compensation returned to the farmers for their managerial efforts. This means that property rights are perceived as institutions for the delegation of management authority to an individual for one of society's assets.

Why does the distribution of property rights matter? It matters because not everyone is equally well-situated to be an efficient manager of a given asset. The best managers of an asset are the people who have the most direct control over its continued survival and prosperity; in the case of a natural resource, this is usually those people who live on and with the resource (Swanson and Barbier, 1992). Otherwise, people who live with a resource, but who fail to acquire control over its flow of benefits, will fail to perceive the advantage of maintaining the resource, rather than exploiting or converting it. In the economist's framework, natural resources disappear because those individuals who make decisions about them do not perceive sufficient benefit to their maintenance.

Biodiversity is disappearing for precisely this reason. The vast majority of remaining diversity exists in the developing world, where there are tremendous forces arrayed against its continuing survival (Brown *et al.*, 1993). The forces for the conversion of land, while at a virtual standstill in the developed world, continue unabated in developing countries. For example, between 1960 and 1980, the developing world increased the amount of land dedicated to western-style agriculture by 37.5%, while in the developed world the area remained constant (Holdgate *et al.*, 1982). The ongoing threat to terrestrial biodiversity comes primarily from land-use conversion (WCMC, 1992) and the fundamental criterion determining the rate of this conversion must be the perception of relative rates of profitability from alternative uses of the land (Swanson, 1993).

If the biodiversity that still exists in large swathes in the developing world is to be preserved, it will require a fundamental change in the perception of the value of its retention in the minds of those peoples who are presently making the decisions to convert these lands. This is precisely the role of a property rights institution. Its function is to channel the benefits from an important resource through the hands of the individuals most able to make the decisions concerning its retention; otherwise, those same individuals will replace the asset with something over which they are able to exercise control. For such reasons, across the developing world, "unowned" diverse resources are cleared and burned and replaced by "ownable" ones such as cattle or crops (there are now 1.3 billion cattle on earth).

If biodiversity is to be conserved, it will be necessary for property rights institutions to be defined in order to encourage investment in its preservation. This is not a position that is against the interests of any sector of any of the industries concerned; in fact, it is necessary to ensure the medium term survival of the resource and hence the industries which rely upon it. Property rights institutions are one of the primary mechanisms for ensuring that utilisation translates into resource conservation - the overarching objective of this project.

In summary, the objective of these surveys has been to determine whether there are important western industries which rely upon biodiversity and, if so, to acquire some concrete indicators of the extent of this reliance. One of the primary obstacles to the satisfactory completion of this task has been the perceptions of the industries themselves, who have been practising a theory of own interest which includes a defence of the status quo. One of the subsidiary objectives of this exercise has been to demonstrate to these industries that this is a myopic view of their own self interest, and that cooperation in the recognition and conservation of the contributions of biological diversity to their own industries would be important for the medium term sustainability of their enterprises. If there are industries reliant on biological diversity, then a revamping of the property rights systems will be necessary in order to channel the benefits of biodiversity to those who are best able to conserve it. We saw the preparation of this survey, the involvement of the industry, and the presentation of these results as one part of a long process of demonstrating to industry the rational (rather than confrontational) approach to biodiversity conservation.

1.5 CONCLUSIONS

The objective of this project has been to ascertain the nature and the extent to which important Northern industries are reliant upon the diverse biological resources which exist in the South. The findings of the project demonstrate that biodiversity functions in two fashions, as a basic commodity and as informational input. As a commodity, biodiversity is most important in the forestry and fisheries sectors, but there are a large number of secondary sectors (furs, reptile skins, etc.) in which it also figures. Fisheries amount to around $35b. per annum in traded commodities, forests $3.5b. and other commodities about the same as the forestry sector.

By far the more important contribution biodiversity makes to Northern industries must be its role as an informational input in specific industries. Western society is built upon a biological foundation and two of our most important industries (agriculture and medicine) are in fact defence systems for the maintenance of this bio-foundation. The biological world provides forces for the continual erosion of these systems, and so we must conceive of these bio-industries as dynamic contests for the maintenance of our foundation in the face of these hostile forces.

If these bio-industries represent the defence systems around human society, then biological diversity represents the basic building blocks upon which these systems are based. In the face of the forces eroding these systems, it is necessary constantly to acquire new information, develop new strategies and access new biological material for maintenance purposes. Biological diversity provides all of these, partly because it is biological in nature but primarily because the diversity that it represents was formed within the same crucible that is the subject of our concern.

The survey of the pharmaceutical industry indicates that it recognises its reliance upon nature as the original designer of all useful chemical substances. Biological diversity provides this industry primarily with informational inputs: strategies for combatting new pests and parasites. Although biological diversity also factors directly (in the form of biological materials incorporated directly into pharmaceuticals), the far more important contribution is the demonstration of chemical structures that conduct biological activity. The evidence suggests that all, or almost all, useful pharmaceutical products being developed are based on some natural chemical template (although the chemical template may have been known for a very long time).

The survey of the plant breeder/seed industries provides a far more concrete portrait of the extent to which this reliance exists. Plant breeding companies face biological forces that render their products (cultivated crops) obsolescent within approximately five years, and they invest the majority of their R&D funds in the solution of this problem. They are continually researching the stock of germplasm that is associated most closely with the currently utilised species, but this existing stock must also be continually supplemented with infusions of new, more diverse germplasm. The survey indicates that on average about 7-8% of the stock of germplasm must be renewed each year at current rates of depreciation. This means that wild varieties and landraces are being accessed at a rate that completely renews the stock of germplasm every 10-15 years. Without this stock of diversity, the current system for maintaining agriculture could not be sustained.

Therefore, this study indicates that modern economies are heavily reliant upon biodiversity, not merely for abstract sustainability or for the occasional anecdotal genetic jackpot, but for the simple and continual maintenance of two of our most important industries. Without these resources, and hence without these industries, the human niche (and human society as we know it) would be altered beyond recognition. Biodiversity conservation is a simple matter of providing the essential foundations upon which these vital industries are built.

1.6 REFERENCES

Barbier, E, B., Burgess, J. C. and Folke, C. 1994. *Paradise Lost? The Ecologicial Economics of Biodiversity*. Earthscan Publications, London.

Brown, K., Pearce, D., Perrings, C. and Swanson, T. 1993. *The Conservation of Global Biological Diversity*, Global Environmental Facility: Washington,D.C.

FAO 1991. *FAO yearbook: Fishery statistics, commodities 1989*. FAO, Italy.

FAO 1993. *FAO yearbook: Forest Products 1980-1991*. FAO, Italy.

Fellows, L., 1995 Evolution and the production of useful chemical substances. In: Swanson, T. (ed.) *Intellectual Property Rights and Biodiversity Conservation.* Cambridge University Press, Cambridge.

Holdgate, M., Kassas, M., White, G. (eds.) 1982. *The World Environment 1972 - 1982.* United Nations Environment Programme, Nairobi. Tycooly International.

Juma, C. 1989. *The Gene Hunters*: biotechnology and the scramble for seeds. Research Series/African Centre for Technology Studies No. 1. Zed Books, London.

Pearce, D. 1991. An Economic Approach to Conserving the Amazon Forest. In: Helm, D., *Economic Policy Toward the Environment.* Blackwell, Oxford.

Perrings, C., Maler, K. G., Folke, C.,Holling, C.S. and Janssen, B.O.(eds) 1995. *Biodiversity Loss: Economic and Ecological Issues.* Cambridge University Press, Cambridge.

Prescott-Allen and Prescott-Allan, 1986. *The First Resource: Wild Species in the North American Economy.* published in cooperation with the World Wildlife Fund for Nature, Yale University Press, USA.

Swanson, T. 1993. *The International Regulation of Extinction.* MacMillan, London.

Swanson, T. (ed.) 1995. *Intellectual Property Rights and Biodiversity Conservation.* Cambridge University Press, Cambridge.

Swanson, T. and Barbier, E. (eds) 1992. *Economics for the Wilds.* Earthscan, London.

Swanson, T., Pearce, D. and Cervigni, R. 1994. *The Appropriation of the Value of Plant Genetic Resources for Agriculture.* Commission for Plant Genetic Resources, Washington

WCMC 1992. *Global Biodiversity : status of the earth's living resources.* Chapman & Hall, London

WCMC 1996 *Assessing Biodiversity Status and Sustainability.* Groombridge,B. and Jenkins, M.D. (Eds), World Conservation Press, Cambridge, UK. 104pp

Wilson, E.O. (ed.) 1986. *Biodiversity.* National Academy of Sciences, Washington, D.C.

2. THE VALUE OF THE WILDLIFE TRADE

Carlos Fernandez and Richard Luxmoore

2.1 INTRODUCTION

Humans have always depended on a wide range of wildlife resources; the composition and relative importance of specific resources have, however, changed over time. Although reduced in importance, diverse wildlife resources (DWR) are still playing an important role in human life, either directly, as sources of food, clothing, utensils and medicines, or indirectly, supporting the environment in which other products valuable to human well-being grow, controlling pests and diseases, providing a genetic pool that enables future improvements of existing crops, or providing clues for the development of medicines. The development of agriculture represented a gradual move towards increasing dependency on domesticated plants and animals for food (Robinson and Redford, 1991), leaving a narrower range of wild species contributing significantly to human food requirements. For instance, at present, the four big carbohydrate crops (wheat, rice, maize and potatoes) feed more people than the following 26 crops combined (Swanson *et al.,* 1993).

The very process of domesticating and improving crops relies to varying degrees on the wild genetic resources available for cross-breeding programmes. Modern genetic science has further increased the potential use of these wild gene pools. The impact of these genetic resources on agriculture has been most impressive. For instance, in the period 1930-75, yield per hectare of wheat in the USA rose by 115%, rice yields rose 117%, maize 320% and potatoes 311%, to mention just a few examples (Prescott-Allen, 1988). Likewise, other wildlife resources have found new and diverse applications in industries from fashion to pharmaceuticals.

In some areas, wildlife, in the form of game meat, is a key item in the diet of local people. In parts of the Peruvian Amazon, for instance, wildlife provided all the animal protein consumed by colonists. Overall, this dependence on wildlife for food in South America is greater among Indian groups than in settlers of European origin and is often deeply rooted in local traditions (Redford and Robinson, 1987). In such cases, ensuring a sustainable use of wildlife resources has the added advantage of helping to maintain traditional Indian cultures. Evidence suggests that meat consumed locally is generally more important than the fraction that is exported. However, exports have the added benefit of providing a source of foreign currency (Luxmoore, 1989). The number of animals taken by subsistence hunters can be very large. Over a period of less than a year, people from three Waorani villages in Ecuador killed 3165 mammals, birds and reptiles (Robinson and Redford, 1991). The high level of subsistence hunting can often result in major population declines of the target species. Wildlife resources are also used locally in the production of utensils, medicines, clothing and various types of craftwork both for local consumption and export. At the international level, the Convention on International Trade of Endangered Species (CITES) enables explicit monitoring of trade in endangered wildlife (for species listed in one of the Appendices of the Convention). Customs statistics provide further information on international trade, though not in such detail.

Many of the goods and services provided by diverse wildlife resources do not have formal markets, and most are consumed locally. This makes it difficult to ascertain the magnitude and value of their use. Although both CITES and Customs records provide an estimate of the volume of trade in some products originating from DWR, only Customs provide the declared value and this may not correspond to the market value. In fact, detailed studies have found that, in many cases, reported values are biassed downwards. Global services of wildlife, such as CO_2 absorption and existence values, are even more difficult to evaluate and are not reflected in the limited data that are available. Thus, trade in DWR as portrayed by existing data and other sources provide only one dimension of the value of wildlife for human well-being, and should be taken only as an indication of the minimum value of wildlife for consumptive purposes.

Within the limitations described above, this chapter assesses the international trade in the main categories of DWR in terms of volume and declared value. Initial consideration is paid to the two single biggest markets for wildlife: forestry (section 2.2) and fisheries (2.3). Trade in wild animals (other than fish) for non-edible products and human consumption (including fur and skin trade, live animal trade, shells, ivory and game meat), is covered in Section 2.4. Section 2.5 deals with plant resources: ornamental use, food sources and genetic value. This last item is minor as it is studied in depth in the following two chapters on the pharmaceutical industry and in agriculture.

2.2 FOREST RESOURCES

Wood is the single most important marketed commodity produced from the wild. Although some tree species have been domesticated (i.e. are produced in plantations), the vast majority of the wood traded has been harvested in the wild. The value of wood products exports amounted to US$65 billion worldwide in 1991 (FAO, 1993), making it the largest wildlife industry in terms of value, followed by fisheries with some $32.8 billion in exports in 1989 (FAO, 1991). Table 2.1 shows how the total value of trade in timber has increased over the period 1980-91.

The USA is one of the main traders in wood products, for both exports and imports. Annual USA exports of forest products between 1989 and 1991 averaged US$12.4 billion (slightly more than 10% of world exports), whereas imports over the same period were US$14.5 billion. Most of the US imports were from Canada (97% of lumber and 50% of hardwood veneer), followed by the tropical rain forest region of South East Asia (Indonesia, Malaysia, Philippines and Thailand) and Brazil. Europe is also a major exporter and importer of wood products. In 1991, imports of forest products to Europe amounted to US$56 billion, while exports from the region reached US$47.6 billion.

While world markets are dominated by trade in softwoods (coniferous), hardwood (non-coniferous) trade, comprising mainly the valuable tropical timber, generally commands higher prices in international markets and is more significant in terms of the environmental impacts of unsustained harvests. High value, low volume traded tropical woods are generally for specific uses such as veneer and plywood in cabinetwork, panelling, etc (see Table 2.2). The majority of other tropical woods do not reach international markets because of their low value, although technological advances are making them more suitable for use in pulpwood, and they could eventually have a greater share in exports.

Despite its potential, the majority of all tropical wood consumed is used locally as fuelwood or simply burnt away, together with the rest of the habitat it helps to maintain. In this respect, developments in the management of, and market opportunities for, tropical woods are crucial for the provision of sustainable management alternatives to the clearing of tropical forest that is now effectively reducing some of the richest areas of DWR in the world.

Table 2.1 World timber trade: roundwood, sawnwood and other forest products 1980-1991

Year	Total Roundwood				Total Sawnwood				Other forest products (1)	
	Volume		Value		Volume		Value		Value	
	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports
	'000m³		US$ million		'000m³		US$ million		US$ million	
1991	47382	31823	3491	1943	33537	23878	9305	6305	43168	39319
1990	45554	28256	3685	1891	38424	23319	10443	6308	43843	39743
1989	48447	28726	3301	1644	37178	25388	9064	5490	39488	36072
1988	46661	26589	3136	1502	37321	25800	8590	5246	36256	33938
1987	45610	26737	2927	1506	35674	24950	7823	4543	30380	28886
1986	41735	26557	2462	1237	33849	24355	6101	3967	23562	21835
1985	41499	26694	1977	1035	31188	24633	4866	3315	18404	17606
1984	40063	24500	1918	938	31481	26058	5277	3719	18359	17237
1983	36314	20587	1899	881	32148	25948	5502	3776	16949	15536
1982	36109	21206	2222	1031	30464	23447	5869	3590	17761	15736
1981	39943	23570	2723	1245	29709	22474	6005	3988	19008	17068
1980	41884	23809	3390	1387	34637	25482	8238	5058	20170	18161

(1) Including: Veneerlogs, pulpwood, plywood and paper.

Note: Discrepancies in export and import figures may be due to under reporting and illegal trade.

Source: FAO, 1993.

Table 2.2 World timber prices: sawlog and veneer log prices of coniferous and non-coniferous 1980-1991

	Sawlog and veneerlog prices				Proportion of Non-coniferous in Sawnwood trade	
	Non-coniferous		Coniferous			
Year	Imports	Exports	Imports	Exports	Imports	Exports
	US$/m³		US$/m³		(by volume)	
1991	178	124	74	73	0.20	0.13
1990	196	139	84	84	0.19	0.13
1989	176	112	78	73	0.19	0.12
1988	176	109	78	70	0.19	0.12
1987	184	122	71	77	0.19	0.13
1986	164	104	63	67	0.17	0.11
1985	137	85	48	54	0.18	0.11
1984	131	84	52	57	0.18	0.12
1983	136	96	53	61	0.17	0.10
1982	156	98	62	72	0.17	0.11
1981	168	109	70	76	0.18	0.12
1980	202	133	78	78	0.18	0.12

Note: Discrepancies in export and import figures may be due to under reporting and illegal trade.
Source: FAO, 1993.

As a result of concern over their status, several tropical timber species are now listed in Appendix II of CITES. Some trade data are available but, unfortunately, there is also a significant illegal trade. Callister (1992) found that illegal trade takes place on a massive scale: "hundreds of thousands of hectares of forest, containing millions of cubic meters of timber, have been logged annually either illegally, or to supply illegal trade". Myers (1984) estimated that 6000 km^2 of tropical forest are illegally logged annually worldwide, but the proportion of that clearance attributable to the timber trade is unknown.

Callister (1992) also produced evidence of illegal trade reflected in discrepancies between timber exports and imports. In the case of imports to Japan from the Philippines, the differences in volume amounted to more than 3 million cubic meters under-reported by the Philippine authority. In Thailand, confiscations of teak in 1988 amounted to 39,200 m^3 (Callister, 1992), whereas reported teak trade represented only 24,117 m^3 (Oldfield, 1991).

2.3 FISHERIES

The global volume of landings of fish exceeds production of cattle, sheep, poultry or eggs and is the largest source of either wild or domestic animal protein (Norse, 1992). This is particularly important in many developing countries. Daily per capita consumption of animal protein from fish and seafood represented around half of total protein intake from animal origin in countries such as Indonesia, Thailand, Malaysia, Sierra Leone and Zaire (Groombridge, 1992, Ch. 26).

The fisheries industry has experienced a constant expansion over recent decades. Annual world landings of aquatic resources have increased more than four fold in the last 40 years, from 21.9 million tonnes per year between 1948 and 1952 to 99.5 million tonnes in 1989 (Groombridge, 1992, Ch. 26 and FAO, 1991). In 1989, US$32,787 million of fish products were traded internationally, representing about a third of world production. Table 2.3 shows the trends in fishery products and trade. Most of the catches and landings take place in marine fisheries (86.2% of total landings in 1989), while the rest originate in aquaculture and capture fisheries. World production is largely destined for human consumption. During the period 1986-88, 65.8 out of the 95.1 million tonnes caught annually on average were destined for human food use and the rest went to animal feed, fertilizer, etc.

The increase in production over the 1980s has been largely associated with increase in catches of pelagic species. In fact, catches of only four species (Peruvian anchovy, South American sardine, Japanese sardine and Alaska pollock) accounted for more than 50% of the increase in total world landings over the 1980s (FAO, 1990).In terms of species being harvested, the vast majority of the catch (92.1%) comprises fish, while mollusca, crustacea and other animals are relatively unimportant in terms of global landings. Analogous to the tropical timber trade, these low volume products generally command high prices in world markets and have a disproportionately high economic value.

In their study on the importance of wildlife for the US economy, Prescott-Allen and Prescott-Allen (1986) estimated that annual imports into the USA between 1976 and 1980 amounted to 2.5 million tonnes of fishery products worth US$2.3 billion, largely for human consumption. A small group of species accounted for a large proportion of total imports: shrimp (US$562m), gadids (cod, haddock, pollock) (US$474m), scombrids (tuna, mackerel) (US$328m), lobster (US$277m) and flounder (US$121m).

Table 2.3 Estimated total international trade in fishery commodities

Year	World Catch	International Trade(*)	% World Catch	Value of trade	
				Imports	Exports
	million tonnes			US$ million	
1989	99.5	38.3	38.54	35896	32787
1988	98.8	35.4	35.89	35325	32370
1987	94.3	34.2	36.29	30537	28223
1986	92.8	33.2	35.78	24255	23069
1985	86.4	31	35.88	18621	17365
1984	83.9	27.7	32.98	17186	16240
1983	77.5	25.2	32.56	17111	15920
1982	76.8	26.1	33.96	16909	15581
1981	74.7	23.5	31.54	16638	16073
1980	72.1	24	33.4	16034	15494

(*) 128 countries. Source: FAO, 1991.

2.4 WILD ANIMAL TRADE

Although meat is one of the most important animal products used by humans, it is often other products that have greater importance in international trade. Apart from fish, commodities such as furskins, leather, fibres, decorative items, medicinal products and live animals have a much greater share of international trade in wildlife resources than does meat. This section will overview the state of trade in these commodities.

2.4.1 Fur Trade

The high demand for some animal products has greatly exceeded the supply from the wild and, as a result, farming operations have emerged, for example, for chinchilla and mink. A fur coat from South American chinchilla in the 1920s and early 1930s cost $100,000, creating a high incentive to harvest the animals. By 1943, only isolated wild populations of chinchilla were left. High prices in international markets, combined with the ease of keeping chinchilla in captivity, encouraged the development of farming operations. This had the effect of increasing the supply which, together with a decline in demand caused by changing fashion, brought the price down. The chinchilla fur market is now well established and supplied entirely from captive breeding. Mink farming operations have been so successful that almost 96% of all production is derived from farmed animals (Prescott-Allen and Prescott-Allen, 1986).

Unfortunately, most wildlife is unable to reproduce rapidly enough under intense consumer demand and, if it cannot be bred in captivity commercially, it is necessary to lower the demand for wild products or otherwise restrict the trade.

Table 2.4 European imports of whole, raw furskins from 1986 to 1989

Year	Species	Quantity (tonnes)	Value ('000 ECUs)	Price (ECU/kg)
1989	Mink	2,320	409,138	176.35
	Rabbit, hare	4,897	4,732	0.97
	Beaver	63	3,382	53.68
	Muskrat, marmot	127	4,569	35.98
	Fox	1,523	113,595	74.59
	Seal	8	370	46.25
	Sea otter, nutria	34	908	26.71
	Wild feline	9	2,814	312.67
	Other	395	31,690	80.23
	TOTAL	9,376	571,198	60.92
1988	Mink	3,136	508,221	162.06
	Rabbit, hare	4,520	4,616	1.02
	Beaver	105	4,725	45.00
	Muskrat, marmot	377	17,907	47.50
	Fox	1,951	167,558	85.88
	Seal	50	704	14.08
	Sea otter, nutria	111	3,178	28.63
	Wild feline	14	4,028	287.71
	Other	805	61,663	76.60
	TOTAL	11,069	772,600	69.80
1987	Mink	2,158	539,582	250.04
	Rabbit, hare	6,544	9,515	1.45
	Seal	26	185	7.12
	Sea otter, nutria	349	15,980	45.79
	Muskrat, marmot	635	33,945	53.46
	Wild feline	40	10,004	250.10
	Other	3,557	345,223	97.01
	TOTAL	13,309	954,434	71.71
1986	Mink	2,700	545,550	202.06
	Rabbit, hare	5,306	8,518	1.61
	Seal	90	774	8.60
	Sea otter, nutria	2	14,519	7,259.50
	Muskrat, marmot	1,403	25,890	18.45
	Wild feline	32	9,999	312.47
	Other	3,292	280,725	85.27
	TOTAL	12,825	885,975	69.08

Source: Eurostat/nimexe series 4B. European Community, external trade statistics.

The fur trade has been implicated in over-exploitation of several species and only a few have been successfully domesticated. The increased difficulty in obtaining specimens from the wild, and the subsequent restrictions on trade brought about by international regulations have led to substitutions for other species. This and the changes in demand brought about by the fashion industry, have the greatest influence on the pattern of trade in most fur-bearers. Public opinion is of greater importance in the case of seals (Prescott-Allen and Prescott-Allen, 1986).

In Europe, fur skin imports still represent a lucrative market, with more than ECU571 million imported in 1989 alone (see Table 2. 4). However, a significant proportion of this trade involves domesticated animals, such as mink. Approximately equal numbers of animals are trapped and farmed worldwide for their pelts. The main producers of wild furs are the USA, Canada, South America, Asia and Australia (Sleeper, 1988). On the demand side, the USA, Japan, Italy, Germany and Spain are the largest consumers.

2.4.2 Reptile Skin Trade

International trade in reptile skins is a significant market, involving millions of crocodilian, lizard and snake skins annually. Over the past decades, international trade in reptile skins has increased significantly. It has been estimated that, from 1983 to 1989, an average of 2.94 million skins were imported annually to the EC alone (Jenkins and Broad, 1994), with a total of 10 million skins worth $150 million traded annually worldwide.

Over the same period, the EC, Japan and the USA together account for between 75% and 85% of all net trade reported to CITES. France and Italy are the largest importers within the EC, followed by Spain and Germany. The USA is the world's main importer of reptile skins. Each year, between 1984 and 1990, the USA imported around 2.5 million skins per year, valued at almost US$49 million, and 27.3 million manufactured products, valued at US$257 million (Jenkins and Board, 1994). Table 2.5 shows the main sources of imports to the USA of raw and processed reptile skins and manufactured products. It is evident that, although many countries with reptile populations do have a significant tanning and processing industry (e.g. Argentina, Philippines, Indonesia), their level of production is small, compared with other manufacturing countries supplying the USA, notably Taiwan, Hong Kong, Italy and Spain.

European importers of raw skins are France and Italy, which are also the main processing countries within the EC. Precise trade routes vary greatly depending on the species. Table 2.6a gives the main source countries of *Caiman crocodilus* skins imported to the EC. The EC is the single largest importer of a number of reptile species including *Caiman crocodilus*, *Varanus niloticus*, *Alligator mississippiensis*, *Boa constrictor*, *Python sebae*, *P. molurus* and *P. reticulatus* (Jenkins and Broad, 1994).

Caiman imports to Europe appear to have remained relatively stable over the last eight years, while snake skins have experienced a greater fashion cycle. Table 2.6b shows the major products manufactured from skins of *Caiman crocodilus*. Many of these are re-exported to the USA, Japan, France and Switzerland.

The only reptiles which are farmed in significant numbers are crocodilians, producing around 100,000 skins annually; the remainder of the skins are from wild-caught animals. As with other wild species, despite the relatively large number of reptile species being used (over 40 listed in CITES) a fraction of them (11 species) represent a high proportion of world trade (85%). Of these 11 species, one is a crocodilian, four are lizards and six are snakes.

Table 2.5 Major countries of origin of trade in reptile skins (>10,000 skins/year) and items (>100,000) to the USA (1984-1990)

	Country	Export Raw (Skins)	Re-export Raw (Skins)	Export manufactured (Items)
Origin only				
	Venezuela	36,500		
Origin/re-exporter				
	Japan	12,700	96,300	
	Singapore	12,500	107,900	
Re-exporter only				
	UK		197,800	
Origin/re-exporter/manufacturer				
	Taiwan	103,264	86,700	6,233,949
	Argentina	908,175		215,877
	Thailand	274,276		737,388
	Philippines	37,800		528,675
	Indonesia	20,900		224,232
Re-exporter/manufacturer				
	Germany		107,900	503,036
	Spain		86,800	2,564,093
	Italy		101,900	2,517,633
	France		105,400	344,979
Manufacturer only				
	Hong Kong			9,841,872
	China			706,495
	Switzerland			506,259
	Canada			467,693
	Austria			313,019
	Mexico			119,837

Note: Some countries appear as manufacturers only although they have wild populations due to the small size of their raw skin exports.
Source: Jenkins and Broard, 1994.

Long-term trends in reptile skin trade are complex. There has been a general broadening of the market from the traditional high-value skins, such as crocodile, turtle and python, to those of the smaller and cheaper species, such as caiman, lizards and small snakes. Part of this has been due to a reduction in supply (over-harvesting), part to trade restriction (all turtles and many crocodiles are on CITES Appendix I), but mostly it has been due to greater market penetration and a demand for cheap, high volume, skins, notably the small snakes. Fashion also plays a role, and has affected the relative proportions of snake and lizard skins.

Trade in reptile skins usually consists of a two stage process in which producers of raw skins export them to countries with tanning and manufacturing industries, where they serve both the local market and re-exports to international markets in final goods. In recent years, however, countries of origin have tried to integrate vertically and export more processed goods (Jenkins and Broad, 1994).

Table 2.6a Major countries of origin and importing countries of skins of *Caiman crocodilus* (1990-1)

	Country	Skins	
		1990	1991
Origin			
	Venezuela	204,206	150,138
	Colombia	91,386	130,405
	Nicaragua	15,050	29,283
	Guyana	10,503	6,632
	Bolivia	11,039	2,768
	El Salvador	938	2,106
	Argentina	3,831	105
	Guatemala	2513	12
	Other	3,456	1,507
Total		342,922	322,956
Importer			
	Italy	100,206	59,966
	France	22,359	54,237
	Spain	5,582	6,557
	Germany	1	9,653
	UK	16,280	0
Total EC		146,601	130,563
Source: Luxmoore and Collins, 1994.			

Table 2.6b Major countries of origin of *Caiman crocodilus* manufactured products exported by Italy and France (1990-1)

Country of origin of raw skin	Italian exports by final product				French exports by final product			
	Shoes	Watch straps	Items	Belts	Shoes	Watch straps	Items	Belts
Venezuela	71,569	11,495	28,743	15,861	62	173,286	3,717	1,427
Colombia	10,348	48,652	18,164	8,356	25	41,889	6,036	439
Nicaragua								
Guyana	27,748	5,170	15,714	4,793	76	372,788	3,278	2,134
Bolivia	39	60	1,006	1,227		1,456	155	2
El Salvador	3,267	8,907	450	2		24		
Argentina	64	100				9,985	16	
Guatemala	1,034	31,766	272	14		82		254
Other	395	1,100	1,050	425	3	15,488	2,099	542
Total	114,464	107,250	65,399	30,678	166	614,998	15,301	4,798

Source: Luxmoore and Collins, 1994.

Table 2.7 Japanese Testudinata skin imports by region (kg)

Year	Latin America	Asia	Europe	Total
1990	18,325	-	12	18,337
1989	5,784	-	12	5,796
1988	4,045	25	-	4,070
1987	18,350	1,901	-	20,251
1986	37,537	2,025	-	39,562
1985	13,961	13,349	-	27,310
1984	17,099	13,959	-	31,058
1983	8,180	17,773	-	25,953
1982	11,383	25,328	-	36,711
1981	25,688	10,254	-	35,942
1980	42,765	22,824	-	65,589

Source: Japanese Customs Statistics, 1980-1990.

All species of crocodile, larger snakes and lizards used for the skin trade are included in Appendices I or II of CITES, and so good data are available on the size of trade. However, many of the smaller snakes are not listed in CITES, and are, therefore, difficult to monitor accurately.

Turtles

Large scale use of turtle leather started in the 1960s, with skins originating in Mexico, Ecuador, Pakistan and Indonesia and being processed in Italy, France and Japan. Most of the trade was in *Lepidochelys olivacea*, with lesser quantities of *Chelonia mydas*. All species were listed on CITES Appendix I in 1975, although the three main importers maintained reservations and continued trading. By 1984, Italy and France withdrew their reservations, leaving Japan as the main importer. Table 2.7 shows the level of imports to Japan between 1976 and 1990. Japan withdrew its reservation on *Chelonia mydas* in 1988 which explains the drop in that year and the previous peaks showing opportunistic high harvest before the ban. A similar trend may be showing with the withdrawal of the reservation on *Lepidochelys olivacea* in 1991 (Jenkins and Broad, 1994).

Table 2.8 Minimum net trade in classic crocodilian skins detailed in CITES annual reports

	1984	1985	1986	1987	1988	1989	1990	1991	Total
A. mississippiensis *	21519	20718	33278	45184	51838	77810	125483	146829	522,659
C. acutus	106	573	27	4	1	59	0	0	770
C. cataphractus	2030			149	1193	570	554	459	4,955
C. intermedius								0	0
C. johnsoni	157			824	1274	794	988	884	4,921
C. niloticus	6115	9378	18480	22974	27526	41097	39701	48445	213,716
C. novaeguineae	29156	43027	33938	37890	34728	42993	47674	32165	301,571
C. palustris				3			3	0	6
C. porosus	5358	6497	5752	7166	10042	15928	13036	14900	78,679
C. moreletii	4	1	1	244	18	4	1	0	273
C. rhombifer							0	0	0
C. siamensis	800	351	605	981	2050	1713	2808	1400	10,708
C. gangeticus							0	0	0
T. schlegelii							0	0	0
Total	65,245	80,545	92,081	115,419	128,670	180,968	230,248	245,082	1,138,258

* Gross exports from the USA.

Source: Table 32 in Luxmoore and Collins, 1994.

Table 2.9 Japanese imports of reptile skins and leather (1983-90)

Year	Product	Quantity (kg)	Value ('000 yen)
1990	Lizard skin	64,700	849,443
	Lizard leather	6,988	229,190
	Alligator and crocodile skin	106,253	2,334,646
	Alligator and crocodile leather	2,720	241,556
	Snake skin	14,170	240,793
1989	Lizard skin	92,632	1,019,423
	Lizard leather	18,132	308,138
	Alligator and crocodile skin	120,599	1,892,000
	Alligator and crocodile leather	1,211	89,448
	Snake skin	34,760	664,172
1988	Lizard skin	54,818	575,496
	Lizard leather	4,288	74,096
	Alligator and crocodile skin	125,782	1,388,000
	Alligator and crocodile leather	2,077	135,220
	Snake skin	33,019	701,780
1987	Lizard skin	59,363	581,367
	Lizard leather	5,069	93,497
	Alligator and crocodile skin	128,554	1,259,000
	Alligator and crocodile leather	14,754	307,823
	Snake skin	40,155	696,657
1986	Lizard skin	54,208	462,132
	Lizard leather	878	18,700
	Alligator and crocodile skin	149,321	1,232,000
	Alligator and crocodile leather	9,499	248,941
	Snake skin	25,880	440,980
1985	Lizard skin	72,849	790,950
	Lizard leather	2,933	53,467
	Alligator and crocodile skin	220,782	2,296,000
	Alligator and crocodile leather	13,816	518,781
	Snake skin	44,617	980,156
1984	Lizard skin	83,055	922,670
	Lizard leather	726	13,659
	Alligator and crocodile skin	201,116	1,545,542
	Alligator and crocodile leather	7,141	374,175
	Snake skin	48,790	1,088,380
1983	Lizard skin	75,238	900,710
	Lizard leather	5,860	20,464
	Alligator and crocodile skin	233,533	1,468,594
	Alligator and crocodile leather	2,979	146,598
	Snake skin	20,058	387,352
1982	Lizard skin	82,560	1,287,654
	Lizard leather	8,333	19,589
	Alligator and crocodile skin	203,531	1,766,912
	Alligator and crocodile leather	4,836	228,912
	Snake skin	14,583	343,156
1981	Lizard skin	100,775	1,518,099
	Lizard leather	3,588	30,156
	Alligator and crocodile skin	105,416	1,236,000
	Alligator and crocodile leather	13,179	523,108
	Snake skin	35,439	723,794
1980	Lizard skin	108,181	1,393,190
	Lizard leather	3,193	39,712
	Alligator and crocodile skin	91,194	1,230,427
	Alligator and crocodile leather	11,574	506,424
	Snake skin	28,216	528,185

Source: Japanese Customs Statistics, 1980-1990.

Crocodilians

Crocodile leather varies in quality depending on, among other factors, the amount of bony structures (called osteoderms) in the ventral area. This species-specific characteristic has meant that some "classic" species are preferred to others, and explains why trade was slow to move from the preferred crocodiles to the lower quality caimans.

Farming operations have resulted in an increase in the availability of the high quality classic crocodilian leather. Legal world net trade in the four main species of classic crocodilian rose from around 60,000 in 1984 to around 165,000 in 1989 and 240,000 in 1991 (Table 2.8). Of the skins traded in 1991, 146,829 were of *Alligator mississippiensis* exported from the USA, both a range state and a major consumer. Around 60% of exports were destined for Europe, where France was the main importer, with almost 64% of the European share. Japan was the second most important importer, with 26% of world trade reported to CITES. A proportion of the trade is not reported to CITES, but it is difficult to obtain solid evidence for it (Luxmoore and Collins, 1994).

Documented trade in caiman skins was around 800,000 skins in 1988, supplying mainly the European tanning industry. France and Italy are the chief European countries with a significant tanning industry. Japan is the third major consumer of reptile skins after the EC and the USA. Table 2.9 shows the quantity and value of imports of various reptiles for Japan.

Lizards

Only the genera *Tupinambis* and *Varanus* feature significantly in the international skin trade. With regard to *Tupinambis*, the USA is the largest consumer, with over one million skins per year between 1984 and 1989 and over half of world trade, followed by the EC with 23% of total imports over the same period. Japan accounts for 34% of world imports of *Varanus* skins (1983-89) followed by the EC (27%) and the USA (9%). Table 2.9 shows the level of Japanese lizard skin imports.

As mentioned before, the increased difficulty in obtaining sufficient 'classic' crocodilian skins at a low cost has served as an incentive to turn to other reptile species, such as lizards. Swanson (1991a), showed that demand for *Varanus salvator* was lower with higher income, indicating that the species was normally purchased as a cheaper substitute to the preferred but more expensive crocodilian skins.

Snakes

As mentioned previously, a significant number of snake species are not included in the CITIES Appendices and, as a result, estimation of total trade is made difficult. Apart from three species from Latin America and one from Africa, all significant trade in skins is in snakes of Asian origin (Jenkins and Broad, 1994). Table 2.9 shows the level of snake skin imports into Japan as reported by the Japanese Customs Statistics.

2.4.3 Live Animal Trade

Although of smaller volume than the skin and fur trade, the trade in live wild animals, involves a much broader range of species (Table 2.10). According to some estimates, hundreds of millions of fish, reptiles and amphibians are traded each year. In 1980, for instance, more than 400,000 live reptiles entered the USA for the pet market, and in 1978, 260 million tropical fish, valued at more than US$17 million, were imported (Oldfield, 1989). It has been estimated that, between 1976 and 1980, the USA imported US$346 million worth of ornamental and pet species each year, of which at least US$90 million came unequivocally from wild sources (Prescott-Allen and Prescott-Allen, 1986). The value of trade in wildlife is often concentrated on a small number of species. It has been estimated that between 1967 and 1968, 38% of species (the rarest) comprised 90% of the value of trade (Oldfield, 1989).

Table 2.10 Minimum number of CITES Appendix II species traded (1983-1988) as live animals, parts and derivatives or both

Taxon	Type of traded specimens		
	Only live	Both live & other	Not live
Mammals	55	117	39
Reptiles	98	115	19
Amphibians	13	7	2
Fish	1	2	3
Invertebrates	2	8	62

Source: Calculated from Anon., 1991a.

Worldwide, trade in live animals is worth many millions of dollars. Japanese imports of live animals in 1990, for instance, were valued at more than £10 million while declared European imports of live animals were almost ECU90 million in the same year.

Among the main reasons for concern about the live animal trade are the conditions of transport. The supply of just a few individuals to the zoo market is estimated to involve the loss of many others during the inadequate capture and transport conditions (Anon, 1993).

Most live animals traded internationally, apart from primates (see below), are either for the pet market or for zoos. The level of trade is not known since there are no statistics available other than from CITES, which covers only those species listed in one of the CITES appendices. However, these provide the best information available and for some groups, for example primates, boas and crocodiles, are fairly complete.

Live Reptiles

Reptiles are traded internationally not only as skins, but also as live specimens. The live animals are primarily for the pet market, but are also used in oriental medicines. For some species, such as the small land tortoise, the pet trade represents the only significant form of international trade. The number of specimens involved in the reptile live trade has increased significantly over the period 1988-92, from under 400,000 to nearly 1,000,000 specimens per year, mostly due to increases in snakes and lizards being traded or added to CITES appendices. Table 2.11 shows the net imports in live reptiles and amphibians in CITES-listed species.

Snakes

Trade in live snakes showed a very significant increase in 1990, from 88,329 specimens in 1989 to 421,668 in 1990, declining to 290,805 in 1992. This change can largely be explained by three species which were moved from Appendix III to Appendix II in January 1990: *Ptyas mucosus* (rat snake), *Naja naja* (Asian cobra) and *Ophiophagus hannah* (king cobra), resulting in a significant increase in reported trade in these three species. Although this sharp increase could be due partly to a genuine increase in number of animals, it is more likely a spurious increase due to better reporting. In particular, trade reported from China showed a marked increase in 1990 in all three species, with a subsequent drop in reporting in 1992. Table 2.12 shows the trends in reported trade from China between 1988 and 1992. Unlike the larger boids, it is likely that these three species are traded mainly for oriental medicine and not as pets.

Between 1989 and 1990, reported trade in live snakes grew by 331,339, an increase of almost 200%. However, 214,540 of that rise was due to increased reported trade in *P. mucosus*, which was also the most important snake in trade over the period 1988-90. Reported trade in *Naja naja*, the third most important snake in trade after the *Python regius*, showed an increase of 75,271 in 1989-90, and numbers of *O. hannah*, the seventh most important snake in reported trade, increased by 13,162 in the same years.

The vast majority of trade in these three snakes was for commercial purposes, with the exception of 63 specimens for zoos, 61 for circuses and travelling exhibitions, and 55 for other purposes such as education and science. With regard to other snakes, the fourth most important snake in trade was *Boa constrictor*, with just over 15,000 specimens traded annually, followed by *Python reticulatus* and *Python molurus bivittatus*. These are all widely kept as pets.

Land tortoises

Tortoises are very popular as pets, particularly the small land tortoises. More than 90% of all tortoises recorded in CITES statistics, traded between 1988 and 1992, were land tortoises. Nearly half of them were one species, *Testudo horsfieldii*, a small tortoise occurring east of the Caspian Sea, in Afghanistan, eastern Iran and northwest Pakistan, and possibly in extreme western China. At present, the major threats to this species are both the heavy collection for the pet trade and the loss of habitat (Swingland and Klemens, 1989). The second most important species in trade was *Kinixys belliana*, with an average of 6523 specimens per year over the period. The three sub-species of this small tortoise, with a carapace length of up to 20cm, range from Senegal and Cameroon eastward to western Kenya and from Tanzania to Natal in South Africa and into Madagascar. Apart from the pet trade, the species is also eaten locally. Prior to 1984, the major species in trade were three European tortoises. The introduction of restrictive legislation in the European Community resulted in a shift to the Asian and African species (Luxmoore and Joseph, 1986).

Freshwater turtles

Red-eared terrapins (*Pseudemys scripta-elegans*) are probably the most common species kept in captivity, but they are not included in the CITES Appendices. During a study on turtle-associated salmonellosis in Puerto Rico, it was found that *P. scripta-elegans* was widely sold. The ease of farming and shipping the species has made it very popular commercially. It is estimated that the USA exports around three or four million turtles a year, most of which are *P. scripta-elegans* (Anon., 1985). The most important species recorded in CITES statistics were *Pelomedusa subrufa* and *Pelusios niger*, both having around 2000 individuals traded annually, representing 88% of all CITES-recorded trade in freshwater turtles. A number of South East Asian species of freshwater turtle are traded live within the region for food. The main species is *Amyda cartilaginea*, but this trade does not show in CITES statistics.

Sea turtles

Reported levels of trade over the period 1988-92 were very low, although five out of six sea turtle species were reported in trade. The most important species in trade is *Chelonia mydas* (green turtle).

Table 2.11 Net imports in live reptiles and amphibians in species listed in CITES, 1988-1992

TAXON		Species	1988	1989	1990	1991	1992	Total
Turtles/Tortoises		65+	46595	91437	45194	58153	42504	283883
	Freshwater	21+	2220	5133	6182	3913	6498	23946
	Land	37+	44320	86011	38793	54111	35472	258707
	Sea	7+	55	293	219	129	534	1230
Crocodylia		25+	19162	5386	9219	8302	15104	57173
Lizards		159+	225617	274711	478554	432454	641736	2053072
Snakes		87+	87845	88329	421668	342879	290805	1231526
REPTILES		335+	379219	459863	954635	841788	990149	3625654
AMPHIBIANS		29+	12091	8336	8127	11676	13769	53999

Source: CITES database, WCMC

Table 2.12 CITES reported trade in selected live reptiles originating in China by reporting country, 1988-92

Species/Reporting country	1988	1989	1990	1991	1992
Ptyas mucosus	*2,100*	*30*	*214,870*	*147,944*	*97,309*
China	150	0	211,718	147,922	97,309
Hong Kong	0	0	1,535	59,207	0
Naja naja	*5,832*	*578*	*75,849*	*73,827*	*51,337*
China	0	0	69,280	68,810	47,170
Hong Kong	0	0	1,028	26,451	0
Japan	0	0	350kg	2,150	0
Ophiophagus hannah	*248*	*108*	*13,270*	*3,364*	*1,232*
China	0	0	12,685	3,325	1,200
Hong Kong	0	0	0	367	0

Source: CITES database, WCMC.

Crocodilians

Over the period 1988-92, 57,173 live crocodilians were reported in international trade. Of these, 27,259 were *Caiman crocodilus crocodilus*, for which some range countries have established a low quota of live hatchlings for the pet trade. The second most important crocodile in trade was *Crocodylus niloticus*, with 17,692 live animals traded over the same period. *Caiman crocodilus fuscus* was the next most important taxon in trade with a peak of 7002 individuals traded in 1990, followed by a sharp decrease in 1991-92 to less than 40 specimens reported.

Lizards

In the live lizard trade, *Iguana iguana* was by far the most important species, with an average of 278,291 specimens being traded live between 1988 and 1992. The changes in trade in this species explain the main trends in the whole of the reported live lizard trade since *I. iguana* represented almost 68% of all trade. Live trade also represents most of the international trade in the species.

There were sharp increases in live exports from Colombia and El Salvador in 1990 and 1992. Colombia in particular has seen a rapid increase in the number of registered caiman farms, many of which also breed *I. iguana* (Luxmoore, 1992). Guyana, Honduras, Peru and Surinam were also significant regular suppliers. Table 2.13 shows the main trends in live trade in *I. iguana* from range countries by source. As can be seen, most of the trade came from Colombia, with El Salvador somehow substituting the previous levels of exports of Honduras.

Table 2.13 Trade in live *I. iguana* by main countries of origin and type of source reported in CITES, 1988-92

Country	1988	1989	1990	1991	1992
Colombia	1,000	3,000	175,906	148,932	252,501
Guyana	6,326	3,549	5,333	7,380	4,932
El Salvador	500	8,800	109,390	76,062	179,850
Honduras	64,680	105,843	4,843	0	0
Surinam	19,590	3,158	29,188	26,451	24,091
Peru	10,343	9,597	23,821	18,262	11,600

Source: CITES database, WCMC.

Most iguanas are exported from South America to the USA. In 1992, 462,490 live specimens were imported into the USA, out of which 33,793 were re-exported, mainly to Canada (14,112), Germany (6907), Japan (5569), Great Britain (2853) and Italy (1150). The USA therefore represented over 86% of the market for iguanas in 1990.

The second most important lizard reported in CITES statistics was *Chamaeleo senegalensis*, an African species. Trade was relatively low in all countries, with the single exception of Togo, which accounted for 99% of trade in 1988. Additional trade from other countries may be hidden in the large numbers of unidentified chameleons traded, averaging 3282 between 1988 and 1992.

Table 2.14 Net live imports of CITES-listed mammals, 1988-1992

Type of mammal	Species	1988	1989	1990	1991	1992	Total
Marsupials	7+	9	9	6	6	2	32
Bats	9+	0	0	225	91	18	334
Primates	139+	44374	44196	31140	37330	24423	181463
Edentates	8+	98	516	104	21	10	749
Rodents	10+	1082	116	53	262	60	1573
Cetaceans	8	42	40	40	71	33	226
Canids	5	94	141	108	201	51	595
Bears	8+	110	109	121	128	227	695
Otters	21+	553	320	131	131	647	1782
Mustelids and viverrids	8	22	17	35	89	102	265
Hyenas	2	0	0	0	4	1	5
Felids	32+	715	852	793	1027	631	4018
Seals	4	38	58	63	33	59	251
Aardvarks	1	0	0	0	2	0	2
Elephants	2	176	158	84	244	113	775
Manatees	1	1	0	0	0	1	2
Asses, horses and zebras	5+	74	37	45	33	55	244
Tapirs	3+	14	17	20	13	13	77
Rhinoceroses	4	37	44	54	25	54	214
Peccary and wild pigs	3	5	10	21	13	18	67
Hippopotamus	2	16	20	15	11	11	73
Guanaco and vicunas	2	139	13	21	25	21	219
Deer	18	29	27	33	22	33	144
Antelopes, gazelles, duikers and goats	25	378	310	260	382	364	1694
Total Mammals	327	48006	47010	33372	40164	26947	195499

Source: CITES database, WCMC.

Live Amphibians

Frogs and salamanders are very popular pets. The main CITES-listed species in trade was a salamander *Ambystoma mexicanum*, with 36,768 being traded internationally between 1988 and 1992, accounting for most CITES-recorded amphibian trade, as can be seen from Table 2.11. The second most important amphibian was the frog, *Rana tigerina*, with 3187 individuals traded. The purpose of this trade is uncertain, since this species is used in large quantities as meat. The live trade may represent breeding stock for attempts at captive breeding or they may simply result from an error in reporting. The third most important species in trade was *Dendrobates tinctorius* of which 2840 specimens were reported in trade.

Live Mammals

By far the most important trade in live mammals is in primates (see Table 2.14) for biomedical research; these will be treated separately in section 2.4.8. In the period 1988-92, more than 181,000 primates were traded internationally. Felids were the second most important group in trade with just over four thousand specimens traded over the five year period, of which more than half were big cats. Among the big cats, *Panthera tigris* (tiger) was the single most important species in trade with 866 traded, followed by *Panthera leo* (lion) with 639 and *Panthera pardus* (leopard) with 358 traded. With regard to small cats, the wildcat (*Felis silvestris*) and the leopard cat (*Felis bengalensis*) were the most important species in trade. As with many other mammals, the volumes of trade in individual species appear to be relatively low, particularly if compared with trade in live reptiles. This trade is mostly for zoos, education, breeding or introduction programmes and, to a lesser extent, for the pet market.

Live Ornamental Fish

Trade in ornamental fish, although minimal in comparison with trade in fish for food, nevertheless produces significant revenues in the international market. European trade statistics indicate a total value of imports of almost ECU55 million (Table 2.15). It is difficult to obtain estimates of the proportion of wild-caught trade. Prescott-Allen and Prescott-Allen (1986) estimated, for imports to USA, that about 80% of Thai exports came from the wild, while the figure for Latin America was around 85%. Together, they accounted for 75% of the almost US$8 million worth of imports between 1976 and 1980.

Table 2.15 Live ornamental fish imports into the European Community

	Year	Quantity	Value	Price
		(tonnes)	('000 ECU's)	(ECU/kg)
Freshwater	1989	1,957	46,393	23.71
Saltwater		454	8,322	18.33
TOTAL		2,411	54,715	22.69
Freshwater	1988	2,242	39,403	17.57
Saltwater		540	6,707	12.42
TOTAL		2,782	46,110	16.57

Source: Eurostat/nimexe series 4B. European Community, external trade statistics.

Live Birds

Birds have been among the most sought-after animals in live trade, with 2600 of the 9600 described bird species recorded in international trade statistics in the last 20 years. Trade in birds has been estimated to be in the range of two to five million specimens per year. There is a further unreported trade in Chinese songbirds, possibly adding some two or three million to the total, although data on trade in non-CITES species are incomplete (Inskipp, 1990). The current level is believed to be lower than in the early 1970s, due to increased trade restrictions and improved control. This estimate does not take into account the high mortality rate during capture and transport, nor domestic trade. Pre-export mortality rates have been estimated as low as 5% (India) and as high as 60% (Mexico) for illegal export. Some estimates suggests that the domestic markets use several hundred thousand birds per year (Thomsen *et al.*, 1992). Africa is the major source of wild-caught songbirds in trade, supplying over 68% of all CITES-listed species recorded in trade in 1988. Within Africa, Tanzania and Senegal are the most important exporters, together they exported 127,262 and 684,679 birds respectively, accounting for 53% of CITES trade in 1988. Central and South America are the second major suppliers of live birds (mostly psittacines) with 14% of CITES-reported exports (Inskipp, 1990).

From the consumer side, the major importers are the European Community, the USA and Singapore (Inskipp, 1990). The USA imported some 700,000 birds annually between 1984 and 1988 (Thomsen *et al.*, 1992). France, the largest EC importer, imported 234,000 birds in 1988, and the UK received between 150,000 and 250,000 per year between 1978 and 1989 (MAFF, 1979-1990). Singapore, the third largest consumer, imported 31,000 CITES-listed birds (Inskipp, 1990). In response to tighter restrictions on trade and the rising prices of rare species, captive-breeding operations are increasing. At present, they supply a significant fraction of the market. In the USA alone, it is estimated that around 15% of imported birds are captive bred.

Despite the high value of the bird trade, very little of it is captured by the local communities. The international bird trade has been valued at US$1.6 billion of gross retail value. The share of the revenues in the different stages of 'production' are characteristic of wild-captured animals, with the trappers having the smallest share (estimated at US$33 million) and middlemen significantly more (US$114 million) with the final retailer extracting the greatest share of the revenue (Thomsen *et al.*, 1992).

Second only to the reduction in habitats, hunting and trapping have been the main causes of declining bird populations. Birds are hunted for food, sport, or occasionally for plumage. Eggs are also taken for food or collections. However, none of these products features significantly in international trade, where it is the live bird trade which gives the greatest cause for concern. As with furs, fluctuations in the live trade are largely due to fashion and trade restrictions.

2.4.4 Corals, Pearls, Shells and Other Marine Trade

Corals

Coral reefs are one of the most productive and diverse of all natural ecosystems; they have been described as the marine equivalent of the rain forests. The richness of the coral reefs derives from the diverse environments and habitats created by the different assemblages of corals and the resulting heterogeneous food resources. Reefs help protect coastlines, prevent erosion, provide nutrients and breeding grounds for many commercial and subsistence fish species and habitat for many crustaceans and mollusca that are also caught for food. In addition, the tourist industry benefits from coral reefs (Groombridge, 1992).

Table 2.16 Summary of reported trade in CITES-listed stony corals by country of export (1986-1989)

Country Year	Imports	Exports	Imports	Exports
	Pieces		Kg	
1986				
Indonesia	280195	853451	1058	2220
Philippines	750541	1470825	2818	9149
Malaysia	133602	0		
Taiwan	78442	0	34407	
Other	22516	584	2	23
Total	1265296	2324860	38285	11392
1987				
Indonesia	185651	437592		
Philippines	1172692	55111	59833	
Fiji	25539	0		
Taiwan	263706	0	74099	
Other	15388	328	1175	
Total	1662976	493031	135107	
1988				
Indonesia	467057	758528		
Philippines	561583	0		
Fiji	27632	0		
Taiwan	106051	0	33276	
Other	33095	12214	0	34
Total	1195418	770742	33276	34
1989				
Indonesia	75894	135125		
Philippines	71665	0		
Fiji	46000	0		
Taiwan	168641	0	43929	
Other	35910	2237	10511	
Total	398110	137362	54440	

Source: CITES annual report data. Reproduced from Mulliken and Nash, 1993.

Some of the main threats to coral reefs are natural, such as storms, hurricanes and disease. However, human intervention can also have an adverse effect, either indirectly (through sedimentation or pollution) or by direct over-exploitation of reef resources (over-fishing, excessive number of tourists, coral mining, etc).

The rapid growth in coral trade during the 1970s and 1980s has created great concern over the sustainability of this international trade. In 1973, a ban was imposed on Philippine coral harvests as they were being depleted due to over-exploitation and poaching from Japanese and Taiwanese fishermen (Mulliken and Nash, 1993). Little information is available about the quantities of coral involved in trade.

Foreign statistics for many countries often classify coral under the same heading as shells and no country separates precious from stony corals in their trade statistics (Wells, 1981a). The listing of 17 genera of the most popular corals in trade in CITES Appendix II in 1985 has allowed better monitoring in recent years. CITES data, however, provide an incomplete picture of the coral trade, not only because of the limited number of genera in CITES, but also because a significant portion of trade is recorded as "pieces" with no indication of size or weight. The Philippines appears to be the largest exporter of coral in 1989, followed by Indonesia. The main importer has been the USA, with more than 70% of the market over the period 1986-88 (Mulliken and Nash, 1993).

Most of the stony corals are traded internationally for ornamental purposes. A very small amount is also used for surgical operations. A total of 95 species from 10 genera were reported in international trade from 1985 to 1990. Table 2.16 presents a summary of reported trade in CITES listed corals between 1986 and 1989. Despite the drop in trade shown for 1989, more recent data suggest that by 1991, world trade had increased to previous levels.

Table 2.17 European annual imports in coral, shells and cuttle bone

Year	Quantity (tonnes)	Value ('000 ECUs)	Average Price (ECU/kg)
1989	60,623	40,931	0.68
1988	46,071	30,270	0.66
1987	48,296	27,412	0.57
1986	45,155	21,531	0.48
1985	42,332	19,916	0.47
1984	34,388	16,866	0.49
1983	31,346	15,804	0.50
1982	30,925	20,176	0.65
1981	31,180	18,944	0.61

Source: Eurostat/nimexe series 4B. European Community, external trade statistics.

Table 2.18 Pearl imports into the European Community

Year		Quantity	Value	Average Price
		(tonnes)	('000 ECU's)	(ECU/kg)
1989	Natural, not mounted	1	2,891	2,891.00
	TOTAL	126	108,936	864.57
1988	Natural, not mounted	0	2,961	
	TOTAL	126	93,582	742.71
1987	Natural, not mounted	0	146	
	Natural pearl articles	42	35,632	848.38
	TOTAL	79	100,969	1,278.09
1986	Natural, not mounted	0	166	
	Natural pearl articles	40	41,627	1,040.68
	TOTAL	84	120,115	1,429.94
1985	Natural, not mounted	0	54	
	Natural pearl articles	15	32,545	2,169.67
	TOTAL	39	104,456	2,678.36
1984	Natural, not mounted	0	116	
	Natural pearl articles	11	33,012	3,001.09
	TOTAL	30	96,135	3,204.50
1983	Natural, not mounted	0	1,384	
	Natural pearl articles	168	22,922	136.44
	TOTAL	200	86,602	433.01
1982	Natural, not mounted	0	580	
	Natural pearl articles	134	19,708	147.07
	TOTAL	159	65,696	413.18
1981	Natural, not mounted	0	95	
	Natural pearl articles	112	21,272	189.93
	TOTAL	122	77,506	635.30
1980	Natural, not mounted	0	169	
	Natural pearl articles	46	18,057	392.54
	TOTAL	62	75,933	1,224.73

Note: Quantities less than 500Kg are denoted by 0.
Source: Eurostat/nimexe series 4B. European Community, external trade statistics.

International trade in corals is of minor importance in some countries in relation to domestic use in cement manufacture and the construction industry.

Shell and pearl trade
Although some of the most important uses of mollusca have been food production, their shells, composed mainly of calcium carbonate, are used for decoration and have a number of industrial applications, including lime for pottery, toothpaste, food additives and even road construction (Wells, 1981b). Pearls (produced by oysters and mussels) and nacre are used for decorative purposes. European statistics on coral, shell and cuttle bone trade are presented in Table 2.17; they show a rapid increase in volume during the 1980s, from 31,180 tonnes in 1981 to 60,623 tonnes in 1989.

Pearls are both cultivated and extracted from the wild. Half the imports of unmounted pearls and pearl articles into Europe in 1987 (see Table 2.18), involved natural pearls, as opposed to cultivated ones.

2.4.5 Rhino Horn and Elephant Ivory Trade

Rhino horn trade
Rhinoceroses have attracted much attention in recent years and are some of the world's most endangered large mammals. The decline in rhino populations has been due principally to over-exploitation resulting from the demand for rhino products, mainly horn (used to make dagger handles and medicines). More than 95% of Africa's black rhinoceroses have disappeared since 1970 (Milliken *et al.,* 1993). In South East Asia, Sumatran rhinoceroses number fewer than 1000 and Javan rhinoceroses number fewer than 100. Overall, the world's five rhinoceros species are on the edge of extinction. Recent studies estimate the worldwide population of rhinos to contain less than 12,000 individuals (Nowell *et al.*, 1992).

The horn, skin, blood and urine of rhinos are all important ingredients in traditional oriental medicine. Rhino horn derivatives are used to treat maladies including strokes, nosebleeds, dermatitis, fevers and headaches (Mills, 1993). Asian rhino horn is believed to be more effective than African. In a recent study on the perceptions of doctors in South Korea with regard to rhino horn and its effectiveness, 79% regarded rhinoceros horn as an essential medicine. Moreover, 43% of all oriental medicine shops surveyed claimed to sell medicines containing rhinoceros horn (Mills, 1993). These findings show that there is still a significant market, despite a prohibition on international trade. Research into potential rhino horn substitutes suggests that saiga antelope horn, buffalo horn or cattle horn could substitute for the anti-pyretic properties of rhino horn, but the oriental medicine community is reluctant to change (Nowell *et al.*, 1992).

In Yemen, African rhino horn is used to manufacture dagger handles, which are an important status symbol. Since the 1970s, North Yemen has been importing about half of the rhino horn on the world market, despite a ban in 1982, it has continued to be smuggled into the country (Cumming *et al.,* 1990).

As a result of the reduced number of rhinos, the price of their horns has increased dramatically over the last two decades (Table 2.19). Over the 1970s, prices in India and Japan increased more than sixfold, while over the same time, prices quadrupled in South Korea and Taiwan and in the following year (1980) prices in Taiwan had risen to be nine times higher than in 1971.

Elephant ivory trade
Under similar pressures to those of the rhinos, African elephant populations have been reduced and fragmented. In less than a decade, during the 1980s, the population has almost halved. For years, it was thought that the forest elephant was less vulnerable to poaching and that the main threat to it was reduction of its habitat. However, recent evidence indicates that for both savannah and forest elephant, illegal hunting in a poorly managed ivory market is the most important threat (Barbier *et al.*, 1990).

Table 2.19 Volume and price (in kg and US$/kg) of rhino horn by country

	India (1)		Japan		Taiwan		South Korea		North Yemen	
Year	Volume	Price	Volume	Price	Volume	Price	Volume	Price	Volume	Price
1971	21.9	1269	1270	56	130	50	52	91	"	
1972	7.1	1800	648	50	941	24	248	34	"	
1973	17.03	1650	1792	60	344	51	253	37	"	
1974	31.6	1750	684	70	1600	37	214	38	"	
1975	16.13	1760	181	84	1098	32	212	58	"	
1976	18.06	1454	823	75	681	40	277	49	"	
1977	30.04	1950	561	116	224	17	307	172	"	
1978	45.33	1957	853	308	905	82	51	284	"	
1979	39.49	7800	357	341	219	184	318	355	c.1,675	
1980			763	383	57	477	217	326	"	764
1981					47	476	142	530	"	764
1982					75	136	263	516	"	786
1983					117	654	300	537	"	891
1984					120	142			"	796
1985					43	168			c.1,000	1159
1986									c. 500	1032
1987										
1988										
1989										
1990									c. 120	1360

(1) Exports of Asian Rhinoceros. Sound horn price only. Other series are for African Rhinoceros.

Source: Compiled from Leader-Williams, 1992.

The ivory market experienced a sustained growth from 1945 through the mid-1980s, after which the price increased dramatically as a result of the lower volumes reaching the market. The decline in volume has been accompanied by lower average weights of tusks per individual, resulting in more elephants being killed per kilogramme of ivory.

As with other wildlife resources, ivory is exported to the manufacturing (carving) countries, and a proportion is re-exported to the final markets. Japan and Hong Kong have traditionally been the main carving centres, jointly covering 70% of the trade. Japan is one of the major consumers of ivory (Table 2.20), the USA and Europe are also principal importers.

Table 2.20 Japanese imports of ivory: 1980-1990

Year	Elephant Ivory	Value	Elephant Ivory	Value	Other Ivory	Value
	(tonnes)	('000 yens)	(tonnes)	('000 yens)	(tonnes)	('000 yens)
1990	0.0	0	0.1	5,922	0.8	82,548
1989	99.0	3,690,658	25.0	1,671,077	2.7	14,164
1988	106.0	2,959,916	26.0	1,259,568	2.1	7,971
1987	142.9	3,117,665	31.0	2,197,468	0.4	32,309
1986	79.0	1,536,848	29.0	2,147,484	3.4	30,927
1985	286.5	5,766,127	28.0	3,112,150	0.3	39,628
1984	473.7	7,590,958	33.0	3,015,038	1.4	56,425
1983	475.6	7,106,999	27.0	2,262,846	1.0	85,454
1982	284.8	5,398,422	24.0	1,491,859	0.5	42,828
1981	308.2	5,364,362	24.0	1,106,616	0.7	38,763
1980	274.0	4,722,516	21.0	921,428	0.3	34,274

Source: Japanese Customs Statistics, 1980-1990.

The more stringent regulations and better enforcement in some countries caused a shift to new ivory markets, such as Singapore and Macau. This phenomenon is illustrated in Table 2.21. The African elephant was listed in Appendix II of CITES in 1976, and in 1985 a Management Quota System was adopted to control the ivory trade and to allow the producer states to capture the returns from the trade. However, the system failed to control the growing illegal ivory trade and populations continued to decline. In 1989, the African elephant was transferred to Appendix I, effectively imposing a ban on trade.

Table 2.21 Net imports (tonnes) of raw and worked ivory by major consumers, 1979-1988

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
USA	6	23	11	7	20	55	24	17	21	9
Germany	74	181	32	35	43	-7	16	7	2	1
UK	-5	-26	0	-3	2	3	28	-1	7	3
Hong Kong	366	376	427	318	428	267	109	129	150	133
India	17	19	19	24	23	30	21	8	6	4
France	89	22	7	4	11	21	5	5	4	-2
China	7	10	10	54	20	7	7	19	39	50
Japan	270	240	256	205	174	179	206	29	103	75
Belgium	16	-90	-248	-123	-105	-116	0	0	-10	12
Singapore	-7	-4	3	7	0	120	60	324	-148	-129
Taiwan	11	18	17	18	28	34	21	18	80	5
Macau		0	0	5	16	38	82	57	8	11

Source: Barbier *et al.*, 1990, Table 1.3

Table 2.22 Estimated minimum net imports (tonnes) of game meat: 1980-1985

Net importers	1980	1981	1982	1983	1984	1985
Belgium-Luxembourg	2135	1615	1550	1625	1688	1965
Denmark	290	209	252	132	144	225
France	8313	8353	7210	9241	8088	8696
West Germany	19253	19656	17147	15692	16887	17431
Italy	2029	1551	1198	2085	1213	2900
Sweden	(*)	519	739	120	903	1153
Other	3272	2140	2005	1764	1814	1952
Total	35292	34043	30101	30659	30737	34322
US$ million	146	122	97	85	87	122

(*) Net exporter this year.

Source: Table 2.1, Luxmoore, 1989.

2.4.6 Animals as Food: Game Meat

Trade in game meat is recorded in published Customs statistics, but, unfortunately, appears in different levels of aggregation for different countries, while some countries do not provide any figures. Therefore, only a broad view of the game meat trade can be obtained. Total volume of international trade in game meat varied from 30-35 thousand tonnes between 1980 and 1985 and was worth some US$85-146 million. West Germany was the main importer, with just over half of net imports in 1985. Table 2.22 shows the estimated minimum net imports of game meat between 1980 and 1985.

In terms of species composition of trade, Customs statistics provide little insight. Therefore, it is necessary to turn to the exporting countries to ascertain the species in trade. For instance, Argentina, the main supplier of game meat during 1980-85 providing between a quarter and a third of all game meat, exports meat of the brown hare (*Lepus capensis*) almost exclusively. For the second major supplier, the UK, 2 of its 4.4 thousand tonnes per year of game meat were of red and roe deer, with the rest composed of small game (hares, rabbits and birds). Other fairly specialized producers are: Australia (mostly kangaroo meat), New Zealand (venison, particularly red deer), and South Africa (springbok, blesbok and ostrich). Imports of these species can be quite substantial. Table 2.23 shows a steady decline in the volume of imports to the EC between 1980 and 1989.

Canada and the United States are not included in the list of major importers of game meat because public health restrictions on imports require an *ante-mortem* veterinary inspection, precluding the import of game meat shot in the wild. European health regulations also effectively limit the range and amount of game meat being imported. Given these restrictions, it is surprising that so much game meat is exported.

Table 2.23 European imports of game meat (excluding rabbits and hares)

Year	Quantity	Value	Average Price
	(tonnes)	('000 ECUs)	(ECU/kg)
1989	27,307	135,826	4.97
1988	26,804	116,517	4.35
1987	36,050	120,117	3.33
1986	33,473	117,906	3.52
1985	37,089	144,621	3.90
1984	33,835	130,863	3.87
1983	33,598	111,007	3.30
1982	33,014	108,333	3.28
1981	36,115	123,304	3.41
1980	36,973	118,871	3.22

Source: Eurostat/nimexe series 4B. European Community, external trade statistics

Some frog species are traded internationally for food, especially *Rana tigerina* and *Rana hexadactyla*; both are now listed in Appendix II of CITES. The main suppliers of reported trade are Bangladesh, India and Thailand. A significant proportion of trade consists of re-exports from Belgium, Canada, the Netherlands, and the USA in the form of "French frogs' legs". During the period 1985-89, the main consumer was the USA, with over 80% of the imports, almost entirely for human consumption (Inskipp *et al.*, 1991), followed by Canada, the Netherlands, France, and Belgium. Table 2.24 shows the imports of frogs' legs into Europe during 1980-87.

Table 2.24 Frogs' legs imports into the European Community[a]

Year	Quantity	Value	Price
	(tonnes)	('000 ECUs)	(ECU/kg)
1987	5,763	18,822	3.27
1986	7,026	30,709	4.37
1985	5,229	21,884	4.19
1984	5,982	23,900	4.00
1983	7,490	31,269	4.17
1982	5,665	25,370	4.48
1981	7,966	29,226	3.67
1980	6,424	18,141	2.82

[a]/ On original statistics, frogs' legs are aggregated with whale and seal meat over this period. By inspection of the dissagreggated data in Table 2.26, we assumed that most previous trade data reflected primarily frogs' legs trade.
Source: Eurostat/nimexe series 4B. European Community, external trade statistics

2.4.7 Animals for Medicinal Use

Many animals or animal products are traded for their value as medicinal compounds. Most of the uses for western medicine are found in hormone extracts and antibodies, although these are usually extracted from domestic animals (Luxmoore, 1989). In contrast, traditional oriental medicine has greater reliance on products from a variety of wild animals. Many of the most popular products are derived from deer; the most valuable being the velvet from their antlers (Table 2.26). Other products include hard antlers, tail, bones, penes, heart, liver, sinews, placenta, blood and skin (Lee and Ch'ang, 1985) and musk. Rhino horn, discussed above, is also quite important.

Velvet is used mostly in the Far East, although a substantial demand arises from Chinese communities around the world. Data on international trade in medicinal products are incomplete. However, Thailand, Taiwan, the Republic of Korea and Hong Kong are probably the main importers of deer products. Table 2.26 shows the imports of medicinal products of deer to the Republic of Korea.

Among the other animal products used in traditional medicine, Fel Ursi is reported separately in Japanese Customs Statistics. Imports of Fel Ursi (bear's gall bladder) and Toad cake to Japan between 1989 and 1990 were worth 377 million yen on average (some £1.4 million). Fel Ursi is the source of medicinal compounds used to dissolve stones in the urinary tract. Table 2.27 shows the imports to Japan between 1970 and 1990. Musk imports are also reported separately by Japanese Customs statistics (Table 2.27). Musk derives from several species of musk deer (*Moschus* spp.), all of which are included in CITES Appendix I and should, therefore, be banned from trade. The legality of the imports shown by the Customs statistics is in question. Bear gall bladder mostly derives from the Asiatic black bear (*Selenarctos thibetanus*), which is in CITES Appendix II and yet no imports appear in the CITES statistics.

Table 2.25 Fats and oils of marine mammals, fractions of oils, excluding chemically modified products

	Whale oil and oils of other cetaceans			Fats and oils of marine mammals other that whale oil			Total		
Year	Quantity	Value	Price	Quantity	Value	Price	Quantity	Value	Price
	tonnes	'000 ECUs	ECU/kg	tonnes	'000 ECUs	ECU/kg	tonnes	'000 ECUs	ECU/kg
1989	0	2		1,427	613	0.43	1,427	615	0.43
1988	0	0		1102	528	0.48	1,102	528	0.48
1987	57	66	1.16	122	82	0.67	179	148	0.83
1986	26	30	1.15	36	35	0.97	62	65	1.05
1985	25	12	0.48	29	148	5.10	54	160	2.96
1984	32	23	0.72	161	162	1.01	193	185	0.96
1983	13	15	1.15	91	59	0.65	104	74	0.71
1982	118	130	1.10	194	113	0.58	312	243	0.78
1981	1,531	1,406	0.92	149	148	0.99	1,680	1,554	0.93
1980	4,920	2,969	0.60	1,469	1,030	0.70	6,389	3,999	0.63

Source: Eurostat/nimexe series 4B. European Community, external trade statistics.

Given the wide range of products involved and the lack of data on most medicinal applications, it is difficult to estimate the true value of the international trade in medicinal products, but from wild ungulates alone it is probably worth well in excess of US$30 million a year (Luxmoore, 1989). As with other wildlife products, illegal trade is likely to account for a considerable share of total trade.

2.4.8 Animals for Biomedical Research

Biomedical research represents another major use of wild animals and, in some species, such as primates, it is the biggest stimulator of trade. Parallel to more sophisticated demands by the scientists and advances in technology, growing concern over the levels of use has led to a reduction in the number of primates in research. Circuses, travelling shows and the exotic pet trade provide only a small market for live primates (Kavanagh, 1984).

Table 2.26 Imports of medicinal products of deer to the Republic of Korea

Item	Units	1980	1981	1982	1983	1984	1985
Velvet	kg	18411	17373	32122	22525	17553	20420
	US$1,000	6885	8052	8853	7432	6571	7295
Hard antler	kg	253268	364091	413356	422434	310848	415584
	US$1,000	2219	2624	3152	3092	2308	2906
Reindeer antler	kg	0	663	11562	3257	12553	0
	US$1,000	0	35	99	24	100	0
Musk	kg	56	37	33	11	111	132
	US$1,000	1277	850	638	779	1305	1253

Source: Luxmoore, 1989, Table 2.5.

Table 2.27 Medicinal products of animal origin imported by Japan

	Musk		Fel Ursi and Toad Cake		Other (1)	
Year	Quantity	Value	Quantity	Value	Quantity	Value
	(kg)	('000 yens)	(kg)	('000 yens)	(kg)	('000 yens)
1990	11	31,324	134	152,943		
1989	22	57,159	703	600,937		
1988	103	273,454	334	304,235		
1987	834	908,259	1,411	247,520	42,722	71,599
1986	378	466,040	1,441	259,981	15,715	36,678
1985	437	683,194	825	271,510	21,943	56,136
1984	304	472,497	899	386,515	15,365	42,117
1983	387	596,987	1,126	325,441		
1982	361	725,319	1,140	349,003	13,273	34,915
1981	343	814,808	808	309,959	10,711	27,677
1980	398	1,791,424	1,401	603,154	14,475	45,075
1979	334	1,732,747	1,250	491,127	15,657	26,018
1978	253	1,279,457	1,451	554,797	26,402	28,433

(1) Bile, cantharides, civet, castoreum and ambergris.
Source: Japanese Customs Statistics, 1978-1990.

Data on the historic levels of trade are scarce. However, it is known that the research market was relatively small in the 1940s, but by the 1950s, primates were routinely used in tests. For instance, it is estimated that some 1.5 million monkeys were used during the development of the polio vaccine (Kavanagh, 1984).

Primates are mostly demanded as subjects for biomedical research because of their genetic proximity to humans. As can be seen from Table 2.14, more than 36,000 CITES-listed primates were traded annually between 1988 and 1992. Their main markets were Europe, North America and Japan. Historically, Indonesia and Philippines have been the biggest suppliers of *Macaca fascicularis*, the long-tailed macaque, and this is still the main species traded, with an average of 21,441 individuals traded over 1988 to 1992, most of which were wild-caught. The USA imports large quantities of the species and re-exports them to research centres in Europe and Japan. Table 2.28 shows the Japanese imports of live monkeys during the 1980s.

The second most important species in trade was the vervet monkey, *Cercopithecus aethiops,* with an annual average of 4319 individuals. The two main countries of origin, Kenya and Tanzania, jointly accounting for 72% of all trade. *Saimiri sciureus*, the squirrel monkey, is the next most important primate in trade. Guyana was the main exporter, providing 9171 out of the 12,911 specimens reported traded over the period.

Other primate species with significant international trade are *Papio anubis*, the olive baboon, exported mostly from Ethiopia and Kenya and re-exported from the USA, *Macaca mulatta*, the rhesus monkey, mostly from China and *Callithrix jacchus*, the common marmoset, with nearly 29% of trade originating in the UK where the species is bred in captivity.
All the great apes are in CITES Appendix I and trade has, therefore, been limited to essential purposes. The main species used has been the chimpanzee (*Pan troglodytes*), with a total trade between 1988 and 1992 of 365 individuals.

Table 2.28 Japanese imports of monkeys, 1980-1990

Year	Quantity	Value
	(tonnes)	('000 yen)
1990	5.0	319,357
1989	12.0	278,425
1988	11.0	203,209
1987	9.0	210,345
1986	10.5	195,719
1985	9.0	206,801
1984	8.0	144,981
1983	8.0	176,069
1982	7.7	141,704
1981	9.0	128,769
1980	13.0	200,378

Source: Japanese Customs Statistics, 1980-1990.

2.5 PLANT TRADE

2.5.1 Ornamental Wild Plants

Ornamental plants are an important commodity in international trade. World imports of cut flowers, cut foliage and plants amounted to US$2488 million in 1985 (WCMC, 1992). Despite their economic importance, the conservation of plants is usually given a low priority.

Although some trade is in exotic and sometimes endangered plants, most trade involves mass cultivation of domesticated plants. The Netherlands are by far the most important exporter of both cut flowers and live plants, supplying a significant share of the European market (see Table 2.29).

A study on nurseries carried out in 1991 (Jenkins and Oldfield, 1992) concluded that trade in wild-collected species still persisted within Europe. The nature of the trade fell into three categories:

i) mass importation of some species for general or 'supermarket' trade,
ii) importation of prestige 'specimen' plants for non-specialist trade, and
iii) importation of plants for the specialist collector.

Some of this trade is concentrated on a limited range of species, such as the Dutch plant and cut-flower trade. However, horticultural trade has shown an ever wider diversification of plant species demanded. Despite the fact that some plants have been selectively bred from their wild ancestors and are now produced through a variety of methods, a surprising quantity of plants are still collected directly from the wild. The wild-collected plants include a variety of bulbs, corms and tubers, air plants and Venus fly-traps. Cycads, cacti and other succulents also appear in garden centres. In the specialist trade, a much wider range of wild plants, especially orchids, cacti and succulents, is available.

Regulation within the EC protects native wild plants. However, a wide range of horticultural plants is imported from other countries around the world. The size of the trade is difficult to assess accurately since it is largely not monitored or managed and some of it is illegal. The listing of a number of species in the CITES Appendices has allowed some data to be gathered on the legal trade. Over 5000 orchid species were recorded in CITES statistics during the period 1983-1989. An average annual trade of 14 million cacti and 135,000 CITES-listed succulents came annually from Madagascar alone. Estimates of the trade in cacti and orchids are shown in Table 2.30. Another category of plant trade, the bulbs, is less well monitored, because few of the genera were covered by CITES regulations prior to 1989, but it is very significant. For instance, the UK, exported nearly 87 million narcissus worth £4 million in 1987.

Collection for international trade has had significant effects on wild plant populations and, together with habitat loss and the introduction of predators, has resulted in 25,000 species (10% of world's flora) being under some degree of threat (Groombridge, 1992).

If sustainably managed, wild plant populations could provide a source of income and an incentive to maintain natural habitats. Unfortunately, proven examples are difficult to find. Species as diverse as the Mexican living rock cactus and the South Indian lady's slipper orchid and the giant pitcher plant, all endemic species, have been driven near to extinction by collectors. As with many other species, the people who collect wild plants are usually paid very low rates compared with the prices paid by final consumers.

Table 2.29 Value (US$ millions) of world trade in flowers and plants, 1981-1985

Cut flowers					
Imports	**Annual mean**	**%**	**Exports**	**Annual mean**	**%**
EEC-9	815.2	65.8	Netherlands	701.5	63.7
USA	206.9	16.7	Colombia	121.7	11.0
Switzerland	63.1	5.1	Israel	73.3	6.7
Austria	37.8	3.1	Italy	73.4	6.7
Sweden	30.2	2.4	Spain	18.0	1.6
Others	365.2	29.5	Others	114.0	10.3
Total	1,238.8	100.0	**Total**	1,101.8	100.0
Live Plants					
EEC-9	597.0	65.2	Netherlands	389.7	44.2
USA	37.7	4.1	Denmark	123.8	14.0
Switzerland	41.9	4.6	Belgium-Luxembourg	92.6	10.5
Canada	43.7	4.8	West Germany	51.9	5.9
Sweden	60.0	6.6	France	37.3	4.2
Others	503.8	55.0	Others	186.9	21.2
Total	915.8	100.0	**Total**	882.2	100.0
Source: Table 25.7. Groombridge, 1992.					

2.5.2 Plants as Food

Of the estimated 250,000 species of flowering plants, only 3000 have been regarded as a food source. Around 200 plants species have been domesticated for food, with only 15-20 of major economic importance. In fact, the four big carbohydrate crops (wheat, rice, maize and potatoes) feed more people than the next 26 crops combined (Swanson *et al.*, 1993).

Despite this, at a local level, plant resources provide a varied source of nutritional needs. For instance, in a region of Peru, fruits of 193 species are regularly consumed; of these, 120 species are exclusively wild-collected and a further 19 originate in both wild and cultivated sources (Groombridge, 1992). Some of these wild-collected plant products, such as Brazil nuts, are traded internationally.

Table 2.30 Cactus and orchid trade data for 1989

	Cacti		Orchids	
	Imports	Exports	Imports	Exports
Asia	209716	3749060	6017522	7133797
USSR	0	0	0	1499
Europe	3038304	100906	1671781	984041
North & Central America	3204234	1462004	408654	40126
South America	17	1127863	5203	124525
Oceania	60327	0	138112	11023
Africa	359	73807	56273	18040
Other	690	7	15543	37
World	6513647	6513647	8313088	8313088

Source: Table 25.8. Groombridge, 1992.

The biggest brokers of Brazil nut kernels from Brazil, Bolivia and Peru have an approximate volume of about seven tonnes of nuts per year entirely harvested from the Amazonian forests, with a market value of around US$14 million. Nuts are normally exported to confectioners in the USA, Brazil and Australia, where they are processed and packed for final consumers. The growing demand for 'organic' and 'sustainable harvest' products has also increased the demand for products, such as honey and nuts, which are harvested in the wild and marketed by local communities.

2.5.3 Plant Genetic Resources

Biomedical research, medicinal plants, pharmaceuticals

Around 119 pure chemical substances are still extracted from higher plants. At a local level, however, a much wider range of species is used medicinally (Groombridge, 1992). The WHO lists over 21,000 plant names with reported medical uses, and around 80% of people in developing countries rely on traditional medicines. These medicinal plants are largely harvested from the wild.

In recent decades, greater attention has been paid to traditional medicines and there are various examples of pharmaceutical companies importing wild plant specimens for screening programmes. The biggest programme carried out on wild plants was the National Cancer Institute's programme, which, over 20 years, screened thousands of plants in search of drugs to fight cancer. In total, 1400 plants with some pharmacological activity were identified, one of which yielded compounds currently in clinical trials. Another programme that has attracted much attention is the screening programme at INBio, where Merck has invested over US$1 million in a contract involving the payment of royalties for each successful compound that eventually reaches the market.

It is estimated that the USA alone annually imports over US$20 million worth of rain forest plants for medicinal purposes. In 1979, the former Federal Republic of Germany imported over 28,000 tonnes of medicinal plants worth US$56.8 million. The European Community in 1980 imported 80,738 tonnes of 'vegetable plant material used in pharmacy' (ITC, 1982) and in 1984, Germany, France and Italy were the largest individual consumers of prescription drugs using plant extracts (Principe, 1990).

In addition, a large quantity of medicinal plant material was used for the preparation of herbal and medicinal teas and, while India was the major individual supplier, Eastern Europe (as a region) remained the major source (ITC, 1982)

It appears that allopathic and herbal medicine will increase in the future, mainly as a result of changing consumer preferences, EEC legislation favouring herbal medicine and aggressive marketing techniques (Lewington, 1993).

Plant breeding

The fact that only a handful of plant species are regarded as food sources does not imply that the remaining species serve no purpose in food production. The genetic material stored in wild specimens can help to improve existing varieties and increase production or avoid diseases. In this respect, the economic value of such a genetic pool can be quite substantial. The preservation of wild genetic material is *currently* keeping these options open. However, the owners of such genetic pools are seldom compensated for their preservation activities.

Of the various characteristics that can be selected through plant breeding programmes, the most common use has been in the introduction of resistance to pests and diseases. The tomato, maize and potato are prime examples of this process. The fourth chapter in this publication reviews the current state of wild genetic resource use by plant breeders and no further comment will be made in this section.

Prescott-Allen and Prescott-Allen (1986) carried out a detailed study of the economic contribution of wild genetic materials to the improvement of crops in the US economy. By estimating the proportion of crop supplied by cultivars with wild germplasm and attaching a fraction of the value of those cultivars to the factors controlled by the wild germplasm, they were able to produce a monetary value for wild germplasm in current production. They estimate that, in the 23 crops considered, the value of the crops with wild germplasm was US$6040 million out of which US$342 million was attributable to the contributions of wild germplasm, with US$229 million coming from imported crops.

2.6 TOURISM

Wildlife-related tourism can broadly be divided into two types: Eco-tourism (aimed at minimizing disturbance of habitat with no consumptive use) and game hunting tourism. Apart from the value of the game in the second type of tourism, it is difficult to ascertain the value of tourism attributable to wildlife. Game hunting is a major industry in Africa, attracting mostly foreign hunters, therefore providing a source of foreign currency for the countries that allow it. The usual practice is to charge a fixed daily fee for accommodation and the services of a professional hunter and camp staff, with additional trophy fees depending on the species of game shot. Average daily rates in 1983 varied from US$333 in Namibia to US$1200 in Zaire, whereas trophy fees ranged from US$19 for a duiker to US$6,783 for a white rhinoceros (Luxmoore, 1989).

Estimates of the expenditures for wildlife tourism are difficult to obtain. The World Tourism Organization estimates annual expenditure by all international tourism to be around US$195 billion. International tourism represents a significant proportion of domestic exports (Table 2.31).

Table 2.31 Distribution of international tourism revenues (1987)

Region	Arrivals	Receipts	Total Tourism Revenues and Share of domestic exports
Sub. Africa	2.8%	2.6%	$ 3.5b (11%)
L. America	7.7%	11.2%	$13.4b. (13%)
E. Asia	7.5%	11.4%	$18.5b. (9%)
S. Asia	0.8%	1.4%	$ 2.0b. (9%)
Source: Swanson, 1991b, Figure 11.3.			

Domestic tourism may account for around US$1.5 trillion. It is not known what proportion of these revenues is wildlife-related, but it is estimated that special-interest tourism (which includes wildlife and adventure) is growing at some 10-15 per cent per annum, compared to 8 per cent mass tourism (Barnes *et al.* 1992).

In countries where wildlife tourism is a major attraction, particularly in African countries, it is possible to get a more refined idea of the amount of tourism attributable to wildlife. For instance, Kenya attracts some 500,000 tourists every year, and wildlife tourism accounts for US$400 million per year (Barnes *et al.* 1992). This kind of tourism is sometimes associated with a particular species, such as the migrating monarch butterflies in Mexico or the gorilla in the Parc National des Volcans in Rwanda. However, in other cases, it is impossible to assign the value to a single species.

Apart from the specialised tourism noted above, most tourism is motivated by a mixture of reasons. Evidence of this has been provided by a survey carried out by E. Boo in 1990 on the reasons for selecting travel destinations in Latin America (Groombridge, 1992). The results of the survey are illustrated in Table 2.32.

Table 2.32 Reasons for selecting travel destinations in Latin America

Reason	Respondents	%
Natural history	167	38.3
Sightseeing	161	36.9
Visiting friends/relatives	132	30.3
Sun, beaches, entertainment	130	29.8
Cultural/native history	102	23.4
Business/convention	87	20
Archaeology	63	14.4
Source: Boo, 1990.		

2.7 OVERVIEW OF TRADE AND CONCLUSIONS

Obtaining an accurate figure for the value of worldwide trade in wildlife products is not possible, given the major gaps in existing data. Illegal trade, under-reporting, mis-reporting and the discrepancies between declared and market values are major limitations. In Table 2.33, an attempt to obtain such a figure is made by compiling the data presented in the previous sections. Whenever possible, the original data for each region were used, or an estimate derived from their market share. The table combines estimates for different years, and thus it does not portray the nature of trade in a given year, but rather attempts to show the likely size of wildlife trade in the major economies, which are also the major consumers.

The inclusion of processed materials in the calculation of the overall wildlife trade is a controversial matter, given that the reported value will also include the cost of manufacturing. In their study, Prescott-Allen and Prescott-Allen (1986) considered that the inclusion of processed products distorted the overall contribution of wildlife to the US economy less than if they were excluded. For the present estimate, both values are quoted whenever they were reported, and manufactured products were excluded from the global estimate.

Another issue is the separation between wild-caught and captive-bred specimens. In the case of furs, we relied on the data used by Prescott-Allen and Prescott-Allen (1986) but, in other cases, we have tried to indicate whether wild or domesticated specimens were involved. In the final calculation, the items combining both domesticated and wild-caught animals or plants were excluded from the calculation. This excluded major markets with a high proportion of domesticated produce, such as the cut and live plant trade. The inclusion of such markets would have distorted the overall picture of wildlife trade and it was thought best not to include them without more data on the wild-caught share.

Therefore, the figures in Table 2.33 have to be taken as absolute *minimum* estimates of the value of wildlife imports into the USA, the EC and Japan. Due to the lack of comparable data for all three regions, it would be incorrect to draw any conclusion about the relative shares in the total wildlife trade apart from partial comparisons on particular wildlife products. The total value obtained for the USA was over US$566 million. Other estimates based on total declared wildlife imports into the USA (including manufactured products) valued US wildlife trade at US$1.1 billion in 1989. Some other reports (Prescott-Allen and Prescott-Allen, 1986) placed the value at US$9.8 billion annually between 1976 and 1980 including forestry and fishery products. Our values were much smaller, mainly due to the cautious approach taken when dealing with manufactured products or domesticated wildlife, otherwise our estimate would conform with the previous estimate. With regard to the European and Japanese wildlife markets, it was not possible to find a reliable figure for wild plant imports for industrial or food purposes, a significant share of value in the US calculation. The European total was US$430 million, whereas the Japanese wildlife trade reached US$72 million.

Sustainable wildlife use is not only a strategy for the conservation of species, it is also a necessity for human development. This report has shown how wildlife is used at different levels by human beings. From food to ornamental uses, wildlife contributes significantly to global welfare. International trade is only one dimension in the full spectrum of uses of wildlife at a local, national and global level, but its importance, reflected in the data shown here, underscores the value of efforts to promote sustainable management of those wildlife resources which are traded. Although the wildlife trade accounts for a relatively small share of international trade, it is vital for some purposes such as its uses in medicinal and biomedical applications, for which there are no good substitutes.

Table 2.33 Estimated minimum value of wildlife imports into the USA, the EC and Japan by type of resource (excluding fisheries and timber) in US$

			Importing Region		
		Source[1]	**USA**	**EC**	**Japan**
			Furs, reptilian skins, shark skin and products		
Reptile skins and leather			Raw 49,000,000 Manuf. 257,000,000	74,195,703	31,022,371
	Turtle	JA			1,111,988
	Lizard	ES,JB	21,358,000	16,686,000	12,681,374
	Alligator & crocodile	ES,JB	2,937,000	19,581,000	14,685,715
	Snake	JA,JB	17,810,000	27,987,000	2,544,282
Lynx fur skins		PA	4,524,000		
Sharkskin leather		PA	652,000		
Marten fur skins, whole raw		PA	1,940,000		
Beaver fur skins		PA	1,442,000		
Mink		ES,PA	3,268,920	6,060,250 /a	
Rabbit, hare		ES,PA	10,397,000	9,666,060 /u	
Seal		ES,PA	48,000	558,638	
Sea otter, nutria		ES,PA	98,000	11,986,378	
Muskrat, marmot		ES		26,405,497	
Wild feline		ES		8,819,990	
Other		ES		304,305,881 /b	
Game meat		ES		157,422,330	
Frogs legs		ES		21,814,700	
Crude shells		ES,PA	10,980,000	32,465,908	
Aquarium fish		ES,PA	7,989,000	63,415,000 /b	
Raw/worked ivory		ES,PA,BA	6,369,000	1,830,220	27,032,264
Crude/worked coral and cameos		ES,PA,WE	4,895,000	2,409,000	958,000
Birds for pet trade		TEM	17,804,000	35,608,000 /c	712,000 /c
Birds eggs		ES		1,341,658 /b	

Natural pearls, parts & buttons		PA	1,880,000	Raw 3,350,669 Manuf. 41,297,488	2,558,000
Live monkeys		JA			2,383,261
Live animals nspf		PA	807,000		3,034,211
Ornamental hydroids		PA	727,000		
Live turtles		PA	31,000		
Medicine					
	Medicinal plants	AL		56,800,000 /d	
	Musk	JA			330,160
	Fel Ursi, toad cake	JA			2,813,433
	Bile, cantharides, civet, castoreum and ambergris	JA			520,693
	Rhino horn	LW			292,229
Plants					
	Food use	PA	87,000,000		
	Industrial use	PA	142,000,000		
Wild genetic resources					
	Crops	PA	172,800,000		
Cut flowers /e		GB	196,980,000 /b	(1,120,000) /b	18,000,000 /b
Live plants /e		GB	4,030,000 /b	(134,960,000) /b	950,000 /b
Estimated minimum wildlife resource trade /f			566,756,920	429,785,580	71,657,610

(1) Source: AL Lewington (1993), PA Prescott-Allen and Prescott-Allen (1986), ES European Statistics 1980-1990, JB Jenkins and Board (1994), JA Japanese Customs Statistics, LW Leader-Williams (1992), BA Barbier et al.(1990), TEM Thomsen, Edwards, Mulliken (1992), GB Groombridge (1992), WE Wells (1981a).
(2) Estimates of total wildlife imports to the USA are around US$1.1 billion, suggesting that the above estimate may be considerably lower than the real value, possibly for all three regions.
nspf not specified.
a/ estimated 1% wild-caught proportion.
b/ includes wild and domesticated.
u/ unknown proportion of wild and domesticated.
c/ estimates from TEM data assuming average bird value equal worldwide.
d/ German imports only.
e/ figures in brackets denote net exports
f/ excludes manufactured reptile and pearl products, and combined wild and domesticated items.

Humanity cannot afford to loose the goods and services provided by DWR for future generations. National and international agencies are now moving towards closing the gap between use and conservation, making sustainable wildlife management a key tool in both development and conservation programmes. The design of effective and sound management programmes will depend on the successful interfacing between the different systems involved: biological, economic, political and cultural.

2.8 REFERENCES

Anon. 1985. The hazards of pet turtles, *TRAFFIC Bulletin*, 8(1): 12.

Anon. 1991. *Review of Significant Trade in Species of Animals Listed on Appendix II of CITES, 1983-88. Background Data*. Wildlife Trade Monitoring Unit, WCMC, May 1991, Cambridge.

Anon. 1993. *Significant Trade in Wildlife: A Review of Select Animal Species in CITES Appendix II, Draft Report to the CITES Animals Committee.* WCMC/IUCN/TRAFFIC International, June 1993, Cambridge U.K.

Barbier, E.B., Burgess, J.C., Swanson, T.M. and Pearce, D.W. 1990. *Elephants, Economics and Ivory*, Earthscan, London.

Barnes, J., Burgess J. and Pearce, D. 1992. Wildlife tourism. In: Swanson, T.M. and Barbier, E.B. (Eds.) *Economics for the Wilds*. Earthscan Publications Ltd., London

Boo, E. 1990. *Ecotourism: the Potentials and Pitfalls*. World Wildlife Fund, Washington.

Callister, D. 1992. *Illegal Tropical Timber Trade: Asia-Pacific*, A Traffic Network Report, TRAFFIC International, Cambridge.

Cumming, D.H.M., Du Toit, R.F. and Stuart, S.N. (Compilers) 1990. *African Elephants and Rhinos: Status Survey and Conservation Action Plan*, IUCN/SSC African Elephant and Rhino Specialist Group.

FAO 1990. *Review of the State of World Fishery Resources*. Marine Resources Service. FAO, Rome.

FAO 1991. *FAO yearbook: Fishery statistics, commodities 1989*. FAO, Italy.

FAO 1993. *FAO yearbook: Forest Products 1980-1991*. FAO, Italy.

Groombridge, B. (Ed.) 1992. *Global Biodiversity: status of the Earth's living resources*. World Conservation Monitoring Centre, Chapman & Hall, UK.

Inskipp, T.P. 1990. *Overview of the Numbers and Value of Birds in Trade*. Paper presented at the Symposium on Trade in Wild Birds, Twentieth World Conference of International Council for Bird Preservation, Hamilton, New Zealand.

Inskipp, T.P., Corrigan, H., Allan, C., Heywood, M., Luxmoore, R., Brautigam, A. and Howes, J. 1991. *Review of Significant Trade in Animal Species Included in CITES Appendix II.* Based on data for the years 1983-1988, Draft Report to the CITES Committee prepared by WCMC and IUCN/SSC with assistance from the TRAFFIC Network, August 1991.

ITC 1982. *Markets for Selected Medicinal Plants and their Derivatives*. International Trade Centre/UNCTAD/GATT, Geneva.

Jenkins, M. and Oldfield, S. 1992. *Wild Plants in Trade*. A Traffic Network Report, TRAFFIC International, Cambridge.

Jenkins, M. and Broad, S. 1994. *International Trade in Reptile Skins: A Review and Analysis of the Main Markets*, 1983-91, A Traffic Report, forthcoming.

Kavanagh, M. 1984. A review of the international primate trade. In: Mack, D. and Mittermeier, R.A. (Eds.) *The International Primate Trade: Legislation, Trade and Captive Breeding*. TRAFFIC USA, Washington.

Leader-Williams, N. 1992. *The World Trade in Rhino Horn*. A Traffic Network Report, TRAFFIC International, Cambridge.

Lee, C.H. and Ch'ang, T.S. 1985. Marketing and utilization of deer products in Asia. *Royal Society of New Zealand Bulletin* 22: 307-310.

Lewington, A. 1993. *Medicinal Plants and Plant Extracts: A review of their importation into Europe*. A Traffic Network Report, TRAFFIC International, Cambridge.

Luxmoore, R.A. 1989. International trade. In: Drew, K.R. and Baskin, L.M. (Eds.) *Wildlife Production Systems: economic utilisation of wild ungulates*. Cambridge University Press, Cambridge, UK.

Luxmoore, R.A. (Ed.) 1992. *Directory of Crocodilian Farming Operations*. Second edition, WCMC/IUCN, Cambridge, UK.

Luxmoore, R.A. and Joseph, J. 1986. UK trade in tortoises. *TRAFFIC Bulletin*, 8(3): 46-48.

Luxmoore, R.A. and Collins, L. 1994. *World Trade in Crocodilian Skins, 1990-1991.* Prepared for the International Alligator and Crocodile Trade Study, Wildlife Trade Monitoring Unit, WCMC.

MAFF 1979-1990. Importataion of Birds. Mortality statistics from quarantine returns. MAFF, Surbiton.

Mills, J.A. 1993. *Market under Cover: The Rhinoceros Horn Trade in South Korea.* A Traffic Network Report, TRAFFIC International, Cambridge.

Milliken, T., Nowell, K., and Thomsen, J.B. 1993. *The Decline of the Black Rhino in Zimbabwe: implications for future rhino conservation.* A Traffic Network Report, TRAFFIC International, Cambridge.

Mulliken, T.A. and Nash, S.V. 1993. The recent trade in Philippine corals. *TRAFFIC Bulletin 13(3): 97-105.*

Myers, N. 1984. *The Primary Source.* W W Norton & Co, New York.

Norse, E.A. 1992. *Marine Biological Diversity Strategy and Action Plan.* First draft, January 6, 1992. To be published by the Center for Marine Conservation, Washington DC, USA.

Nowell, K., Chyi Wei-Lien and Pei Chia-Jai 1992. *The Horns of a Dilemma: The Market for Rhino Horn in Taiwan.* Final Report for WWF Project II3637.03, TRAFFIC International, Cambridge.

Oldfield, M.L. 1989. *The Value of Conserving Genetic Resources.* Sinauer Associates Inc., USA

Oldfield, S. (Ed.) 1991. *Pre-project Study on the Conservation Status of Tropical Timbers in Trade.* Final report prepared for ITTO by WCMC.

Prescott-Allen, C. 1988. *Genes from the Wild: Using Wild Genetic Resources for Food and Raw Materials.* Earthscan, London UK.

Prescott-Allen, C. and Prescott-Allen, R. 1986. *The First Resource: Wild Species in the North American Economy.* published in cooperation with the World Wildlife Fund for Nature, Yale University Press, USA.

Principe, P.P. 1990. Valuing diversity of medicinal plants. In: Akerele, O., Heywood, V. and Synge, H. (Eds) *Conservation of Medicinal Plants.* Cambridge University Press, Cambridge, U.K.

Redford, K.H. and Robinson, J.G. 1987. The game of choice: patterns of Indian and colonist hunting in the Neotropics. *American Anthropology* 89: 650-667

Robinson, J.G. and Redford, K.H. (Eds) 1991. *Neotropical Wildlife Use and Conservation*, University of Chicago Press, Chicago, USA

Sleeper, B. 1988. The High Price of Fur. *Animals,* November-December 1988: 14-19.

Swanson, T.M. 1991a. *An Economic Framework for the International Regulation of Wildlife Utilization: A Case Study of* Varanus salvator *Demand in Japan.* TRAFFIC review of the reptile skin trade. CITES.

Swanson, T.M. 1991b. *Wildlife Utilisation as an Instrument for Natural Habitat Conservation: A Survey of the Literature and the Issues.* London Environmental Economics Paper DP 91-03, May 1991.

Swanson, T.M., Pearce, D.W. and Cervigni, R. 1993. *Appropriation of the Global Benefits of Plant Genetic Resources for Agriculture: An Economic Analysis of Alternative Mechanisms for Biodiversity Conservation*, A report to the Commission on Plant Genetic Resources, CSERGE, London.

Swingland, I. R. and Klemens, M.W. (Eds) 1989. *The Conservation Biology of Tortoises*, Occasional Papers of the IUCN Survival Commision (SCC) No. 5, IUCN.

Thomsen, J.B., Edwards, S.R. and Mulliken, T.A. (Eds) 1992. *Perceptions, Conservation & Management of Wild Birds in Trade.* TRAFFIC International, Cambridge.

WCMC 1992. *Global Biodiversity : status of the earth's living resources.* Chapman & Hall, London.

Wells, S.M. 1981a. *International Trade in Corals.* IUCN Conservation Monitoring Centre (now WCMC), Cambridge.

Wells, S.M. 1981b. *International Trade in Ornamental Shells.* IUCN Conservation Monitoring Centre (now WCMC), Cambridge.

3. BIODIVERSITY AND THE PHARMACEUTICAL INDUSTRY

Nathalie Olsen, Timothy Swanson and Richard Luxmoore

3.1 INTRODUCTION

In order to assess the use of biological diversity in the pharmaceutical industry and the industry's perception of the importance of such biological diversity, a survey was made of appropriate institutions. A questionnaire was circulated to pharmaceutical companies, 25 of which responded. This was followed up with interviews either in person or by phone and additional literature was collected. These three sources were combined to prepare the results summarised in this chapter. Except where public sources were used, the names of the companies have been removed to respect commercial confidentiality.

3.2 SURVEY RESULTS

3.2.1 Drug Discovery and Natural Products Research: Evolution to the 1990s

The role of nature in medicine and health care

Natural products have of necessity always been used in the treatment of human ailments. Today, one out of four prescription drugs in the USA contains active ingredients extracted or derived from plants. Nevertheless, only 40 different plant species are used, and less than one percent of the world's 250,000 tropical flora has been screened for biochemical activity.

Despite the considerable contribution of natural products to health care, less than ten percent of the estimated 250-500,000 flowering plant species have been screened for pharmacological activity. The expansion of synthetic chemistry in the twentieth century has meant that there are limited resources available for natural product research (NPR). However, public unease prompted by the unexpected side effects of synthetic drugs - for example, the thalidomide tragedy of the 1960s - has renewed interest in drugs from natural sources.

Plants produce a vast range of diverse chemicals. Where other organisms may react physically to stress, danger and environmental changes (by moving away), plants tend to react or adapt to changes by producing chemicals called secondary metabolites. Similarly, marine and terrestrial invertebrates produce a variety of chemicals and toxins.

Secondary metabolites produced by plants and microorganisms are not part of universal primary metabolism, i.e. they are not crucial for the basic operation of the organism; but they are produced for chemical defence. Examples include a wide chemical diversity of alkaloids, terpenes, rubbers, sterols and steroids, and tannins. Many of these complex molecules have therapeutic potential for a number of human ailments and are useful as medicines, pesticides, dyes, flavourings, and building materials.

A handful of wonder drugs from nature have helped to spur investment in NPR research and development (R&D). For instance, the synthesis of contraceptive steroids is based on the use of the steroid diosgenin from the Mexican yam *Dioscorea* discovered in the 1960s. The serendipitous discovery of the anti-cancer properties of the rosy periwinkle *(Catharanthus roseus)*, a pan-tropical weed native to Madagascar, resulted in sales of US$100 million in 1985. Taxol, a treatment for ovarian cancer, was originally extracted from the bark of the Pacific yew tree *(Taxus brevifolia)*.

Natural product research in the 1990s

Since World War II, investment in R&D of natural products in the pharmaceutical industry has been characterised by significant cyclical fluctuations and has focused on micro-biological programmes. The 1990s has witnessed a resurgence and diversification in NPR. The larger pharmaceutical companies are re-establishing NPR programmes and small companies are being created to develop highly targeted and specialised approaches to drug discovery.

The cyclical fluctuations in investment in NPR are the result of the changing balance between the cost-effectiveness of NPR and that of alternative methods of drug discovery, notably rational drug design. Since the 1920s, many pharmaceutical companies have repeatedly launched NPR in response to clear evidence that nature contains innumerable chemicals with therapeutic effect.

The idea of tapping the vast reservoir of diverse chemicals contained in nature is widely accepted as sound. However, to do so may not be cost-effective; the development of the ability to synthesise drugs chemically has made natural products research relatively expensive. Research programmes are evaluated on the basis of productivity, i.e. research must produce a marketable drug with potential for significant commercial success within a time horizon of only a few years. One scientist at a large pharmaceutical company emphasised that NPR requires a longer time horizon than rational drug design, and felt that management and non-NPR scientists do not sufficiently appreciate this.

Another scientist commented, only half-jokingly, that a new NPR programme could not be launched in his company until those who had been involved in earlier NPR retired. Perceptions of the difficulties associated with NPR appeared to lag behind technological advances which would significantly reduce those difficulties. Some scientists would argue that NPR has in the past appeared less cost-effective than other research approaches as a result of using standards and criteria that may be appropriate to other research programmes but not to NPR. Others would argue that a research programme must yield results within a given period of time, in order to be viable.

Technological synergies with other research programmes

NPR programmes cannot be considered in isolation from other ongoing research programmes. It is largely technological advances in the screening of synthesised chemical libraries that have increased the cost-effectiveness of screening natural products. Chemical libraries are collections of chemical structures that have either been synthesised in the laboratory or isolated from natural sources. These compounds are "screened" in simple biological tests which measure activity with respect, often, to only a single enzyme. The test may be scaled to allow a large number of diverse compounds to be tested against the enzyme (termed high through-put screening). The objective is to determine whether a chemical compound or natural product extract can alter the activity of the enzyme in a particular way, i.e. cause a "hit".

Advances in natural products chemistry and molecular biology have increased the ability to identify and synthesise compounds, encouraging pharmaceutical companies to use natural product novel compounds as blueprints for the synthesis of drugs. If a natural product extract produces a positive result during a screen, a range of tests will subsequently be undertaken to identify, isolate and characterise the exact structure of the active compound. A series of analogues are then synthesised for further testing, structurally modified to alter their behaviour or potency, etc. Natural products chemistry encompasses structural elucidation (determination of the structure of a molecule), purification technologies (to remove chemicals which may produce false "hits" in screens), and analytical and spectroscopic capability.

The top priority of all large companies and most of the small companies is to synthesise lead molecules. In effect, the final drug may be a biochemically modified, fully synthesised chemical in which the natural source of the initial compound may be virtually forgotten and difficult to trace. In this sense, the initial molecule is used as an idea, a blue-print for the synthesis of new drugs.

Some of the small, specialised pharmaceutical companies exploit plant cell culture (PCC) technologies to scale up the production of chemical compounds. PCC is based on cell cultures which produce secondary metabolites in mass quantities. Furthermore, the secondary metabolites produced in a plant cell culture may be manipulated by varying the conditions under which the culture is grown and maintained. Scaling up production may be desirable if compounds cannot be synthesised on a commercial scale or if plant material is scarce. For example, Phytopharmaceuticals was started up to mass produce the anti-cancer drug taxol for commercialisation because of the scarcity of yew trees and the extreme difficulty of synthesising the taxol molecule.

PCC technology is also used to increase the diversity of chemicals produced by organisms. At Phytopharmaceuticals, cultures from *Taxus* plants have been manipulated using chemical genetics to induce the production of new taxoid molecules which, although related to taxol, may differ in therapeutic or pharmacodynamic potential, and may develop into "second generation" drugs. The production and screening of analogues of lead compounds is an approach widely adopted in the industry.

Microorganisms are highly sensitive to the conditions under which they are grown. Using plant cell culture, microorganisms are grown under varying conditions of light, temperature, motion, etc. to encourage the production of novel chemicals.

Finally, almost all companies surveyed emphasised the importance of pursuing different types of drug discovery programmes simultaneously. Different types of research complement each other not only through technological advances but also in support networks. For example, the NPR new leads discovery division at one of the largest pharmaceutical companies screens both natural products and synthetics for leads, and is heavily supported by other groups in the company, e.g. biochemists and pharmacologists.

Research objectives

The changes in the technology on which drug discovery is based have caused a shift in the objectives of NPR. Twenty years ago, NPR was geared toward the discovery of new drugs. Today, the main objective is to isolate novel structures from natural products to serve as blueprints, or starting material, for the biochemical synthesis of new drugs. The critical difference is that discovering a new drug entails identifying an active molecule from a natural source which can be developed into a marketable drug without the aid of biochemistry and synthesis (such a drug is termed a "silver bullet" in the industry). A novel structure, on the other hand, simply refers to discovery and identification of a novel molecule which may be modified to change behaviour or facilitate synthesis. In effect, discovering structures is a less stringent process than discovering drugs: molecules which need modification or molecules from organisms that are not widely available or cultivable are still useful.

In the pharmaceutical industry today, the value of an organism lies in its potential to contain an unique biologically active compound that can be fully synthesised in the laboratory. Companies are concerned with problems of the continuity of supply of raw material. If the lead molecule is highly complex and biochemical modification cannot be used to simplify its structure (while maintaining its activity and potency), the source organism may be cultivated. If it is not easily and cheaply cultivable, the lead will most likely be dropped from the research programme.

3.2.2 Expenditure on Research and Development of Natural Products

Total R&D expenditure on natural products

It is difficult to provide estimates of corporate expenditure on NPR. Firstly, this information is commercially sensitive and therefore confidential. Secondly, it is often not possible to delineate NPR clearly from other research programmes. For example, the drug discovery programmes of the larger pharmaceutical companies are based on the screening of diverse compounds for a broad range of therapeutics. Both synthesised compounds and extracts from natural products are screened; tracing the origin of compounds becomes important only after a hit occurs. It would require too much time and too many resources to establish the nature of compounds prior to signs of bio-activity because of the large numbers of compounds currently being screened.

In spite of renewed interest in NPR, R&D expenditure on natural products remains low relative to expenditure on rational drug design programmes. In the larger pharmaceutical companies, NPR absorbs a small percentage of total R&D spending, roughly 5-20%. While some smaller pharmaceutical companies specialise predominantly, if not exclusively, in NPR, the total amount available for R&D in these firms is quite small, i.e. ranging from US$1-5 million per annum.

Roughly one-third of the companies involved in this study are small specialised companies, most of which undertake collection, screening, and drug development activities. Most of these small companies were set up in the late 1980s, and therefore very few of them have drugs in production and on the market. Only Shaman Pharmaceuticals, Genelabs and Phytera have drugs derived from natural products on the market.

Reasons given for low levels of expenditure on NPR in the industry as a whole are:

1. NPR is a relatively high risk activity due to complications of supply and resupply, extract treatment, the reliable identification and classification of biotic samples, and the lengthy process of molecular characterisation.

2. Because of the long lead time for drug development, it is too early to determine whether NPR which took place in the 1980s will consistently produce new drugs. Dimasi *et al.* (1991) have estimated that in the 1980s the cost of producing a marketable drug was US$231 million (out of pocket costs and the costs of drugs abandoned during development) and 12 years (time costs). As discussed above, the cost-effectiveness of NPR in the 1980s have been increased dramatically by advances in technology, especially advances in screening technology; new methods to purify extracts to increase efficiency in screening (by avoiding false positives); and advances in molecular chemistry which increase the ability to manipulate the chemical behaviour of compounds and synthesise molecules.

3. Despite advances in the treatment and purification of extracts, the screening of natural products is more problematic and more costly than screening synthetics. Plant extracts, for example, contain chemicals such as tannins and chlorophyll which cause false positives and register binding proteins.

4. Structural elucidation of natural products takes time and money. When synthetic compounds are screened, their structure is known because they have been produced by chemists in the laboratory. When a hit occurs, subsequent development is fairly straightforward, the structure is known and because it is simple (chemists will not willingly produce complex molecules) it will be easy to synthesise and easy to modify to allow testing of analogues and the development of "second

generation" drugs. On the other hand, signs of biochemical activity in a natural products extract must be followed by a long period of testing to isolate and characterise the active compound. The active compound may be highly complicated and chemists may alter its potency or behaviour in attempts to simplify the structure. Because most natural products molecules are not simple, they will be more difficult to synthesise.

Expenditure on collection, extract treatment and screening
There are a number of activities common to all research programmes in the companies surveyed: prospecting, treatment of and work with extracts, screening and molecular characterisation/biochemistry. Each requires different levels of expenditure.

The past decade has witnessed attempts to harness commercial forces to fund conservation of natural habitats. Very few companies have the financial resources to offer a significant amount of money up-front to institutions or communities undertaking collection. This suggests that the scope for money being provided up-front to fund conservation in biodiversity-rich (but resource constrained) countries is limited. Nevertheless, there is potential for source countries to benefit from collection and maintenance of medicinal plants. Profits from the successful development of drugs derived from natural products may be channelled to source countries and conservation projects through some type of royalty arrangement and, in some instances, through the contribution to local research facilities by pharmaceutical companies.

All the pharmaceutical companies involved in collection have stated a willingness to negotiate royalty payments with collecting institutions if and when a drug enters the market and some of the more specialised companies already have royalty agreements in place. A royalty agreement simply helps to ensure that a fixed proportion of profits from a commercially successful drug is returned to the country which supplied the organism from which a drug is derived. Companies are hesitant to reveal the level of royalties, but emphasised that royalty payments were going to be lower than expected by source countries. First, source countries tend to overestimate the profitability of successful drugs. Second, the percentage of profits offered for royalty payments is contingent upon the role played by the natural product; if a drug is the result of extensive biochemical modification and is fully synthesised, pharmaceutical companies view the contribution of natural products as minimal. On the other hand, a unmodified natural product drug may produce far higher royalty payments.

Under the Merck-INBio agreement, Merck provided US$1 million up-front to fund collection of plants and insects by the National Institute of Biodiversity (INBio) in Costa Rica. This was the first collaborative agreement to provide funds up-front. Expenditure on collection is generally low as compared with other stages of drug development.

Expenditure on the treatment of extracts varies; this stage of research has, however, remained relatively labour intensive, and most large companies and some of the smaller companies prefer to receive crude extracts of plants and invertebrates.

Different organisms also require different degrees of treatment. Microbes and fungi are usually received in soil samples and processed in-house because of the effects that variation in conditions of storage or growth have on the secondary metabolites they produce. Expenditure on treatment may be significant due to the labour and facilities required. A small number of companies are screening collections of microorganisms developed by academic researchers or developed for other purposes.

By far the highest expenditure is allocated to screening. It is, however, difficult to get an estimate of the proportion of the NPR budget allocated to screening because most screening programmes encompass both natural product compounds and "pure" synthesised compounds. Moreover, in the larger companies, only a small proportion of compounds screened are natural product compounds.

It has been suggested that expenditure on a particular NPR activity does not reflect its importance relative to other activities in the NPR programme. For instance, prospecting activities require relatively little expenditure while biochemical modification and testing absorbs a large proportion of the NPR budget. Yet many companies have emphasised that the collection and acquisition of diverse compounds is the most important stage in the process of drug discovery. The likelihood of discovering novel active compounds rests on maximising the diversity of compounds screened.

3.2.3 Company Strategies

There is a broad range of approaches to NPR developed by pharmaceutical companies. Large companies, whose NPR is only a small component of total R&D and who have extensive screening facilities, usually try to maximize the number of diverse compounds acquired and screened. The greater the number of diverse organisms (and hence chemicals) screened, the greater the probability of discovering a lead compound.

Large pharmaceutical companies

While emphasis tends to remains on microbial research, NPR programmes now include microbes, fungi, plants and marine and terrestrial invertebrates. Only a handful of companies are analysing terrestrial invertebrates, notably insects, spider and snake venom.

Large pharmaceutical companies tend to contract out collection activities and prefer to receive samples in the form of crude extracts. A crude extract is a biotic sample that has been ground up, but not yet purified. It is cheaper and politically expedient for companies to link up with infrastructure and expertise already existing in academic and research institutions rather than establishing prospecting facilities in-house.

Sample collection from collaborations with research institutions may be supplemented by informal in-house collection i.e. employees on holiday in exotic places may return with soil samples and fungi. For example, two of the more unusual hits have come from extracts developed from fungi growing on an old rusty mailbox and a log picked up by an employee of a pharmaceutical company waiting for a plane in Phoenix, Arizona. This type of informal collection, however, is not encouraged for plants and marine organisms because of the possibility of overexploitation of endangered species and intellectual property rights issues.

Small companies

Small to medium sized pharmaceutical companies (often funded with venture capital or developing as commercial offshoots of academic and research institutes) who do not have the budget and facilities to screen vast numbers of diverse compounds develop different strategies for sample collection and for the treatment of extracts.

Specialised collection strategies are designed to increase the chances of drug discovery through careful selection of organisms and/or regions to compensate for the lack of facilities to screen large numbers of compounds. For instance, Shaman Pharmaceuticals restricts collection to tropical rainforests because this habitat has the greatest number of biologically diverse organisms per hectare. Small companies, e.g. Sharman and Phytopharmaceuticals, may narrow the range of compounds considered by focusing exclusively on plants.

Specialised drug discovery approaches may rely on the use of particular types of information in collecting biotic samples; for instance, Shaman Pharmaceuticals uses ethnobotanical information. Alternatively, particular technologies may be exploited to increase the diversity of compounds available and to avoid complications of resupply, e.g. the use of plant cell culture by Phytera and Phytopharmaceuticals.

Company cases:

1. Shaman (the name means medicine man) Pharmaceuticals Inc. of San Francisco base their collection entirely on ethnobotanical information using tropical plants with a history of medicinal use. Their source material comes entirely from tropical forests from all around the world. Shaman has formed collaborative arrangements with Merck and Eli Lilly for screening and development of certain compounds identified by Shaman. To date, the company has produced two products in clinical trials and ten compounds which are being evaluated in animal studies.

2. Phytopharmaceuticals (PPI) utilises plant cell culture following primary screening to increase access to potentially useful active compounds. PPI has developed proprietary chemical genetics technology which is designed to optimize the therapeutic properties of lead molecules. Chemical genetics uses plant cell culture to manipulate gene expression in numerous successions to create thousands of distinct but related molecules. Plant cell culture is also used to mass produce compounds for commercialisation when they cannot be synthesised. For example, PPI came into existence to scale up the cheap mass production of taxol.

3. Phytera, on the other hand, uses plant cell culture before primary screening to produce a wide range of secondary metabolites to be screened. The US parent company undertakes screening and medicinal chemistry, while Phytera UK (a spin-off from Sheffield University) focuses on plant tissue culture and genetic manipulation. Phytera is trying to construct a library of tissue cultures from a wide range of plants and to apply genetic engineering, hormones and other elicitors to "turn on" production of secondary metabolites.

4. Genelabs provides an example of a small pharmaceutical company which has maintained its emphasis on the biochemical synthesis of new drugs and has only a very informal and unsystematic method of natural products collection. Genelabs focuses on developing novel assays and approaches to drug discovery rather than on novel sources of drugs. Scientists may receive purified compounds through collaborating academic researchers or chemical libraries/banks of collaborators. One of its major drugs (anti-HIV) is a modified plant compound. A semi-synthetic anti-cancer drug is now in Phase I of clinical studies.

5. Merck, one of the largest companies surveyed, conducts 5% of the research by pharmaceutical companies worldwide (35 plants in 17 countries and eight research laboratories in seven countries) and in 1992 invested more than US$1 billion in research and development. Public service drugs produced from natural source compounds by Merck include Ivermectin, highly effective in preventing human and veterinary parasitic disease, including onchocersiasis (river blindness); Lovastatin is the active ingredient in Merck's cholesterol-lowering drug Mevacor which is produced by a common soil microorganism. Merck has an agreement with the National Institute of Biodiversity in Costa Rica to provide plant, insect and soil samples for potential natural products which is designed to return conservation benefits to Costa Rica.

6. At Glaxo, another of the larger pharmaceutical companies, some 7,000 staff are engaged in the process of discovering and developing new medicines, and in 1992-1993 revenue expenditure increased to £739m. In the search for new medicines from natural products, The Glaxo Institute of

Applied Pharmacology, officially opened at the end of 1992, works within the Pharmacology Department of the University of Cambridge. Another new centre for natural product research is the Institute of Molecular and Cellular Biology at the University of Singapore. At the Natural Products Discovery department at Glaxo Group Research in Greenford, UK, the search for new leads is intensifying with supplies from China (some 9,000 plants and up to 750 soil samples and microbial cultures expected between 1993-1996), the University of Illinois in Chicago, French Guyana, Colombia, Mauritius and the Chelsea Physic Garden in London, among others. Extracts of marine organisms are also screened in the UK.

7. Biotics Ltd., UK, was launched in 1983 as a biotechnology consultancy service company specialising in areas of natural product chemistry. In 1986, it was approached by the European Commission Biotechnology Unit to explore opportunities for promoting the sustainable utilisation of the indigenous genetic resources of developing countries, and Biotics has undertaken to share any royalties on any subsequently developed phytochemical leads with the original plant source country. Together with its plant extraction facility BioEx (UK), it has today marketed over 3,000 plant samples and extracts for screening by pharmaceutical and agrochemical companies. Natural product factionation, structure determination and analog synthesis are additional services jointly provided by Biotics and the School of Chemistry and Molecular Sciences at the University of Sussex, UK.

3.2.4 Sample Collections

Prospecting refers to preliminary research (for non-random collection) and the physical collection of organisms, including transport to laboratories. Preliminary ethnobiological research may be undertaken using literature searches, databases (e.g. NAPRALERT), casual reports of collectors, ethnobiological information, etc.

While prospecting may be the least expensive component of NPR, it is the most politically sensitive and publicly visible activity linked with issues of intellectual property rights. Prospecting is the activity least amenable to control by pharmaceutical companies. The complexity of dealing with foreign governments, indigenous peoples and academic institutions and the public goods nature of genetic resources have encouraged most pharmaceutical companies to contract out the collection stage of NPR.

The players

Preferred collaborators are institutions and individuals who, through existing research and collaborations (or simply more specialised activities), have the resources and knowledge to obtain high-quality biotic samples while avoiding conflict over property rights and compensation. With a few exceptions, prospecting is at least in part contracted out to botanical gardens, research institutes, universities, or prospecting organisations. Prospecting is contracted out for a number of reasons:

1. Pharmaceutical companies often have neither the personnel with the necessary skills (botanists and taxonomists) nor the infrastructure available. The infrastructure and knowledge required for high quality and reliable collection already exists in botanical gardens and universities; tapping in to established institutions is both less costly and less risky.

2. Concern has also been voiced that poor collection procedures could result in the inadvertent decimation of plant populations. Such comments suggest that pharmaceutical companies are wary of endangering future access to genetic resources by being seen to exploit these resources in unsustainable ways.

3. Collaborations with non-commercial research institutions brings credibility to commercial companies and provides assurance about their respect for genetic resources. For instance, the pharmaceutical companies contacted for this survey worked variously with the Missouri Botanical Garden, the New York Botanical Garden, Kew Gardens, the University of Illinois and a number of individual botanists.

4. Source countries are concerned that their genetic resources might be exploited unsustainably and without due compensation. Scientists associated with academic and research institutions who have worked in high biodiversity countries for many years on identification and classification of genetic resources may help to ensure mutually beneficial exploration and extraction. Their interests are seen to lie more in expanding knowledge of national genetic resources and conservation than in profiting from commercial use of these resources.

5. Ciba-Geigy emphasised that it does not deal directly with source countries and institutions because there is such large scope for misunderstanding: pharmaceutical companies are often accused of plundering genetic resources, and there is a feeling that source country universities do not fully realise the high degree of risk and the low level of returns to NPR. Biodiversity rich countries see the handful of successful natural product drugs grossing hundreds of millions of dollars annually, but they do not see the thousands of failed drugs that cost pharmaceutical companies millions of dollars.

Types of information used

There are a variety of types of information used in the collection of samples. Most of the companies interviewed undertake some random collection, in addition to using taxonomic and ecological information in sample selection. The dominant philosophy seems to be to maximize the diversity of compounds screened. This entails maximising environmental diversity, genotypic and phenotypic variation, the number of families considered, etc.

Some companies have interest in plants close to the limits of their ecological niche because "stressed" plants produce a greater number of potentially interesting secondary metabolites. If a compound shows activity in a screen, research may focus on closely-related chemicals.

Companies receiving samples or crude extracts from other institutions often leave methods of collection to the discretion of the collecting institution. Collectors are required to have the necessary authorization from source country governments and abide by acceptable codes of conduct. Pharmaceutical companies may or may not provide guidelines depending on the nature of the particular research programme/therapeutic area in question. At the stage of collection, the dominant priority is to acquire chemical diversity which in turn requires diversity of organisms from diverse ecological systems.

Some companies seem surprisingly flexible (given their size and commitments) with regard to the types of organisms they accept from collaborating institutions, provided that collection procedures fall within accepted policies and guidelines, and that the funds and interest exist.

Ethnobiology

Use of ethnobiological information frequently supplements other information used to guide collection. Most pharmaceutical companies use ethnobiological information sometimes; this has changed very little in the past five to ten years. Companies expect future use of ethnobiological information to remain roughly at today's levels. It may be that companies with established NPR programmes have fairly rigid research approaches/strategies which tend to evolve slowly in line with other in-house research programmes, rather than change dramatically over time.

Companies take note of traditional uses of organisms and may on occasion use this information systematically in tightly-targeted research programmes. Often pharmaceutical companies who contract out collection do not know whether ethnobiological information is used. However, one scientist suggested that current pharmaceutical use of approximately 75% of the 121 plant-derived medicinal compounds on the market is correlated with original, traditional use by indigenous peoples.

Shaman Pharmaceuticals is the only company interviewed that concentrates on collecting plants solely based on ethnobotanical knowledge contained in indigenous communities. If a plant is used for the same purpose in three different communities, investigation is undertaken. Shaman has a hit rate of 50%. After only two years, Shaman has two products in human clinical trials (Provir and Virend, anti-virals), statistics which the company feels support the use of ethnobiological information. Both anti-viral drugs currently in clinical trials contain active ingredients from a plant grown in several South American countries. Using random screening, perhaps only one molecule in 10,000 may reach the market as a drug.

What is important in considering the debate about hit rates is that the level of activity screened for may differ between research programmes. Large companies screening tens and hundreds of thousands of extracts annually cannot handle too many hits from samples screened. To limit the number of hits registered, the level of activity at which a hit is revealed is raised. Some companies register only high potency compound hits in their screens. This directly affects the hit rate. Because Shaman restricts the number of compounds screened, through the use of ethnobotanical information and the exclusive screening of botanical compounds, the company is able to screen for various levels of activity. This may be an advantage because high potency compounds are not necessarily the most promising for drug development.

Reservations about the use of ethnobiological information were voiced by a range of companies. The dominant concern is that use of ethnobiological information limits the diversity of compounds screened for activity, although it may result in the discovery of a drug. Advances in molecular biology have opened up opportunities to study undreamed-of targets. There is no point in limiting the range of compounds screened to compounds with past medicinal use. Pharmaceutical companies want unique compounds, so they want as much diversity as possible. The use of ethnobiological information imposes restrictions (unnecessarily) on the diversity of compounds screened.

In addition, the utility of ethnobiological information is limited to therapeutic areas where symptoms are clearly visible. For example, a company may research on anti-fungals. Medicine men and women use local plants extensively as anti-fungals since fungal infections can easily be diagnosed and rainforest peoples are particularly at risk from fungal infections due to the climate and the slow healing of open wounds.

Moreover, the target compounds that developed country pharmaceutical companies and research institutions are interested in today differ from those used by indigenous peoples. The ailments which afflict ageing populations in the West are different from those, such as malaria, that afflict rainforest peoples. On the other hand, use of an organism to treat an ailment may indicate biochemical activity which, although not employed for its traditional remedy, may work in other therapeutic areas. For example, oil of evening primrose from *Oenothera* species was used by native peoples in Madagascar for skin problems. This traditional treatment relates to its current use for eczema, but not to is use against pre-menstrual syndrome. Similarly, anti-cancer activity of etoposide was discovered in the mayapple, *Podophyllum peltatum*, traditionally used for diabetes.

Sources of ethnobiological information
A variety of sources of ethnobiological information are used in conjunction with each other. Literature searches are common. Databases such as NAPRALERT at the University of Illinois are consulted frequently. This contains information about traditional uses, location, general properties, current use, medical research already undertaken (insofar as this information is published), etc. Companies may use NAPRALERT at different stages of research. The database may be used to guide collection activities or it may be consulted following an interesting hit under screening. For some of the larger companies, it is ethnobotanical information contained in NAPRALERT that is consulted prior to extraction and screening, particularly when undertaking targeted research programmes.

Information acquired casually with random collections tends to be limited. Access to this type of information depends to a great extent on the identity of collectors and their relationship with local communities. This type of informal information would not be consistently reported and the individuals contacted via this survey might not have been aware of it. Evidence of use by native groups may also be important. Shaman sends collecting expeditions composed of ethnobotanists and medical doctors into the field with indigenous medicine men and women.

3.2.5 Work with Extracts

The procedure
Expenditure and labour requirements for obtaining extracts from different organisms vary because treatment methods used, and the quality and form of samples received, differ. In general, the treatment involves grinding, extract preparation and isolation of compounds, including the isolation of undesirable compounds. Quality varies not only with the organism, but also with the collecting institution. Collectors have different degrees of expertise and extract preparation facilities.

Most fungi and microbes are received as soil samples and are grown in a variety of culture conditions to generate secondary metabolites. By providing conditions which inhibit the growth of common microbes, the chances of discovering a novel compound are increased. Given a fixed number of samples, chemical diversity can be manipulated through the treatment of extracts and many companies prefer to maintain control over this process in-house.

Upon receipt of plants, samples are ground up, extracts are prepared and pre-treatment measures are undertaken to remove tannins and other compounds which may cause false positives to register in screens. The treatment of marine and terrestrial invertebrates includes similar stages. For insects, some companies prefer to separate body parts prior to grinding; others grind the entire animal.

While companies often prefer to contract out collection activities, preference for biotic samples or crude extracts differs between companies and it is difficult to generalise. The proportion of biotic samples received as extracts depends on the type of organism, the source country, and the collaborating organisation.

Organisation of extract treatment
Some companies prefer to produce their own extracts from samples to maintain control over this process, because the extracting treatment determines which chemicals are retained.

The equipment and expertise necessary for extraction procedures frequently do not exist in source countries. It is, however, more costly to process extracts in-house. A general impression gained from the pharmaceutical industry as a whole is that there is, indeed, a willingness to contract out the processing of samples to source country institutions, provided the expertise and technology are sufficient to ensure the maintenance of quality. Often companies prefer to restrict themselves to high-tech activities, avoiding routine work whenever possible.

Some source countries have shown increasing interest in producing and exporting crude extracts. Brazil and Australia, for example, have banned the export of entire plants. Pharmaceutical companies may soon have to accept receipt of extracts (and the consequent loss of control over this stage) as source countries try to capture additional value added and control over genetic resources.

Some companies have high quality collaborations with institutions in source countries. These include significant funding of local research, training and the provision of equipment, and having extracts produced at source (see Phytopharmaceuticals); more technologically advanced procedures, such as plant cell culture, are also being planned for the future.

3.2.6 Screening

Recent changes in screening technology

Since World War II, research has focused on the discovery of new antibiotics via research on bacteria and fungi. Drug discovery research is based on the screening of chemical compounds. The 1970s and 1980s saw the screening of fermentation broths for antibiotics extended to screening in other therapeutic areas, notably use of anti-cancer assays. The 1990s has seen a dramatic increase in the types of screens used, the range and number of therapeutics covered and the diversity of organism included in research programmes.

Screening in the 1990s no longer focuses on anti-cancer and anti-virals. Pharmaceutical companies may screen for activity in 30 different bio-assays; competition between therapeutic areas is often fierce and turnover of screens is rapid. *In vitro* screens have in the past been fairly general, but in the last decade screens have become highly specific, testing for a particular type of activity in a clearly defined type of bio-assay. The choice of screen type varies between companies according to scientific criteria and is shaped by the needs and character of the overall research programme.

The resurgence in NPR in the 1990s can, in large part, be attributed to changes in technology and the subsequent emphasis on access to biological and chemical diversity. The development of efficient automated screening techniques has changed the search for novel compounds into a "numbers game". The speed at which samples can be screened has increased one hundred-fold. This has allowed expansion of the range of organisms screened and has reduced screening costs.

To complement advances in screening technologies, advances in molecular biology have increased the ability to modify natural products compounds (to enhance potency, decrease toxicity); increased use of these biochemical modification techniques have increased the utility of natural products as blueprints for the development of new drugs. These advances greatly enhance the potential of biodiversity as a source of molecules which may be modified directly or used as leads for the synthesis of analogues.

Given the growth in the number of therapeutic areas covered, the increased efficiency of screening and the advances in molecular biology, access to biologically diverse compounds has become a crucial determinant of success in drug discovery programmes. The dominant strategy in the pharmaceutical industry is to maximise the number of diverse compounds screened to maximise the probability of discovering novel compounds for drug development. Pharmaceutical companies constantly search for diversity of structures, and the industry has known for many years that natural products contain this diversity. However, not until the 1990s has the background technology been adequate to exploit these products.

Screening activities include both natural products and "pure" compounds synthesized in laboratories by chemists. The larger pharmaceutical companies screen these chemical libraries, often with little concern for the origin of compounds (until, of course, a compound shows activity in a screen). The proportion of compounds in these chemical libraries originating in natural products is often as low as 5%. Numbers range from around 300 plant species per year screened in a small company to hundreds of thousands of natural products and synthetic compounds screened annually at large ones. Most screening is undertaken in-house. A handful of companies have collaborators in source countries who undertake preliminary screening, but this appears limited because of the need for special equipment and reactants.

The amounts of material required by research programmes have also decreased dramatically. This has allowed a broader range of organisms to be considered. For example, screening of spider venom today requires only a few microlitres of venom (extracted using a catheter and mild doses of electrical shock to stimulate venom secretion so spiders do not need to be killed). This simply was not possible 25 years ago. Research on scarce or difficult-to-obtain organisms was out of the question because the number of organisms required merely for testing (let alone development) was prohibitive. As novel compounds emerge from the research process, significant quantities of the compound need to be prepared for clinical trials. If the compound passes successfully through clinical trials, large-scale production processes and manufacturing capacity are developed.

Limitations on screening

A drawback arising from the increased speed of screening is that companies limit the number of active compounds on which they undertake future research by demanding a higher threshold potency to register in today's bio-assays. However, low potency compounds are not necessarily inferior to high potency compounds in their usefulness as blueprints for drug development. With current emphasis on biochemical modification and synthesis, disregarding low potency compounds may cause many potential drugs to be overlooked.

Another potential problem with screening is the increasing specificity of *in vitro* screens used by many companies. This results in compounds being screened for highly specific activity in a limited number of therapeutic areas. A compound may be discarded as inactive simply because it is not screened in an assay in which it is active. Some scientists would like to see more general screens more widely used.

Choice of organisms

There are a range of factors which influence the selection of natural products to be screened. All companies, regardless of size and research priorities, are concerned primarily with ease of supply and, more importantly, with the reliability of future supply. Only one company reported the rate of success with samples to be the most important determinant. Ease of use in laboratory (referring to treatment of extracts and screening complications) and the cost of samples seem to be least important. Two companies emphasised that all of the above factors were considered when choosing organisms to screen, yet ultimately the aim is to screen as broad a range of diverse organisms as possible to maximise chemical diversity.

NPR has been and remains dominated by microbial research. This is in large part because of the greater control over research and development through fermentation technology. Using fermentation techniques in which genetically identical microorganisms are reproduced rapidly and under controlled conditions, it is relatively easy to scale up and modify natural product compounds. This is not the case for higher organisms and research into non-microbial natural products may be inhibited as a result.

However, useful drugs resulting from screening of bacteria and fungi may be mostly limited to antibiotics. In effect, microbial research is restricted to a small number of therapeutic areas. A scientist interviewed described the screening of microbes as "a bit of a dead horse" because companies have been screening microbes for years with no new results. Hundreds of thousands of microbes are being fed into assays and companies may well be screening the same organisms repeatedly as it is difficult to identify and keep track of those screened.

Historically, plants have been avoided in the pharmaceutical industry. Firstly, there has been a lack of plant science experience in the pharmaceutical industry. Scientists with skills in plant cell propagation, cell biology and natural products chemistry have been in short supply. Secondly, supplies have been unreliable and inconsistent. If a company discovers a natural product lead compound which can not be synthesised, production will have to be based on a reliable supply of raw material of consistent quality. While initial testing of natural products requires increasingly smaller amounts of material, testing following a hit in a screen may require significant amounts of material and unless this has been accurately identified and can be produced reliably, further research will not be undertaken. Thirdly, there have been problems producing a supply of material. A major concern of the pharmaceutical industry is having to be dependent on a small number of countries (which may lack infrastructure, may suffer from environmental calamities or political instability) and collectors for raw material for the production of a major drug which may gross over $100 million per annum.

A major problem with marine organisms is that chemical activity is closely related to what they have eaten immediately prior to collection. This sensitivity makes research on marine organisms particularly risky. Signs of biochemical activity may be difficult to trace to their origin. Other problems with marine invertebrates are that they cannot be cultured easily, cannot be collected on a large scale, and recollection is a problem. In addition, a scientist commented that compounds from marine organisms often cannot be synthesised. Given the great number of alternative organisms to be included in research programmes, many companies are hesitant to tackle the numerous complications linked to marine organisms.

3.2.7 Details of Natural Product Research Programmes

Organisms screened and geographical focus of NPR by each company
All of the companies questioned in this survey use plant material for their NPR, but 40% specialise in microbes and fungi. Marine and terrestrial invertebrates are used by a minority of companies (Table 3.1). Most companies use material from more than one region, although some specialise in the New World (Table 3.2). There is a clear preference for tropical regions.

3.2.8 Collaborations

Collaboration with non-commercial institutions is becoming widespread as companies make use of existing infrastructure, expertise and institutions to gain access to biodiversity. Meanwhile, non-commercial institutions obtain much-needed financial support for targeted programmes and their own collection activities.

Good quality collaborations are characterised by high quality samples, correct identification, accurate locational records, reliable resupply and general expertise. Collaborations with universities and research institutions tend to be of this type and are increasingly sought after.

Collaborations with developed country institutions
Several large pharmaceutical companies have collaborative arrangements with botanic gardens for all or some of their collection. This ensures that the quality and identification of material is of a high standard. Resupply of materials is also the responsibility of the collaborating institution.

For instance, Pfizer has just entered into collaboration with Dr Michael Balick at the New York Botanical Garden (NYBG). NYBG performs all collection and identification in addition to the processing of extracts. Pfizer has helped to set up the facilities and procedures for extract treatment, and does not want to receive raw materials. All screening and chemical elucidation are done by Pfizer. Through this collaboration Pfizer has side-stepped problems of supply. Resupply of material is the responsibility of the NYBG and the quality and identification of material is of high quality. Through this interaction, Pfizer is contributing to a floristic survey of the US which, although unlikely to uncover new species, is providing new geographical information on the incidence of species which will prove useful for conservation efforts.

Biotics Ltd. is a commercial prospecting organisation which has developed a novel approach for interfacing new sources of tropical plant material with the high through-put screening technology of pharmaceutical companies. A major condition of the supply of plants or extracts is the payment of royalties on any natural product derived drug, which Biotics will share equally with the source country.

Collaborations with developing country institutions

Source country research institutions and universities are becoming increasingly involved in the commercial use of their genetic resources. As expertise and facilities are expanded, source country institutions are able to play a greater role and thereby appropriate a larger portion of value-added. In Costa Rica, INBio's agreement with Merck provides funds not only for collection, but also for technical training.

A number of pharmaceutical companies emphasised that the financial aspect of collaborations does not accurately reflect the benefits accruing to both parties. Small companies who are unable to provide funds for collection directly, stress that training of local personnel in taxonomy, cataloguing (developing herbarium sheets), extract preparation, preliminary screening, and even plant cell culture helps to ensure that source country institutions receive foreign funds enabling them to expand their own facilities and research. For instance, Phytopharmaceutical's collaborators in Thailand, Brazil and China not only receive funding for training purposes, but also receive funds to develop their plant cell culture technologies. If an extract of interest is identified, plant cell culture procedures can be undertaken in source countries.

There may be stringent conditions placed on collaborating institutions. Companies pay for the selection of biotic samples according to their guidelines and protocols (protocols in this context deal with the technical details of the drying and treatment of samples). Usually all costs are covered and further funds are provided for training. It is felt by some companies that while the principle of royalties is fine, it is more important to provide immediate benefits through training and transfer of technology.

Shaman Pharmaceuticals does extensive research not only on indigenous peoples and their traditional medicine systems, but also on the needs of the communities prior to collection expeditions. Approximately ten percent of the funds of expeditions are ploughed into the local community, based on the requests of individuals from that community. For instance, on a research expedition to Amazonian Ecuador, Shaman provided resources to expand a local community's airstrip so planes could take more than one passenger at a time. Shaman also provides direct support for laboratories in developing countries, e.g. research materials and scholarships are provided annually to a Nigerian laboratory working on plant treatments for malaria.

Table 3.1 Major groups of organisms screened by 15 pharmaceutical companies questioned

Company	Plants	Microbes and fungi	Marine organisms	Terrestrial invertebrates
1	100%			
2	yes	focus		
3	yes	focus	yes	
4	40%	60%		
5	yes	yes		Insects
6	yes	yes	little	
7	45%	21%	34%	
8	yes	yes		yes
9	100%			
10	9.5%	90%	0.5%	
11	yes	yes	yes	
12	100%			
13	yes	50%	yes	Insects, spiders
14	20%	80%		
15	100%			

The National Cancer Institute natural product extract collection

The National Cancer Institute (NCI) is currently offering to "lease out" its collection of extracts (from all types of natural products) to a number of pharmaceutical companies. Under a specific arrangement, pharmaceutical companies pay a minimal fee per extract and undertake to screen extracts for anti-AIDS and anti-cancer activity. Pharmaceutical companies may also undertake screening for other therapeutic areas, but hits must be shown to have relevance to cancer or AIDS. Identification of extracts is given down to the level of family of the source organism. When positive activity is found, more information is provided, and the identity of the collector is given to the pharmaceutical company, who may approach the collector for further material. Furthermore, the company must provide the government with highly confidential information about the compound. In addition, this information must be shared with scientists from the source country; investment in the source country research facilities is also encouraged.

If a drug is developed, the pharmaceutical company must negotiate intellectual property rights and royalty payments directly with the source country. Pfizer has declined to enter into this leasing arrangement because it is not clear what institution is to be negotiated with. Pfizer would prefer to have a fixed royalty arrangement with the NCI, and leave negotiations with source country institutions to the NCI. Pharmaceutical companies prefer to avoid arrangements with uncertain/ambiguous elements.

Similarly, Pfizer avoids shared funding of research programmes to avoid ambiguity over who owns what. Pfizer also emphasised that the rules of the game change significantly when there is government participation.

3.2.9 Chemical Libraries

Pharmaceutical companies are primarily interested in plants because many of their active compounds are unlikely to be synthesised *de novo* for screening programmes. Advances in screening technology have dramatically increased the relative importance of screening in drug discovery and development. Some scientists are of the opinion that the dominance of screening may undermine NPR. A major disadvantage of NPR is that once activity is discovered in a screen, it takes time and resources to discover the structure of the active molecule. A scientist interviewed estimated that it costs approximately $60,000 to determine the chemical structure of a natural product compound. Despite improvements in structural elucidation technologies, four to five years pass between a hit and Phase I clinical trials. When screening chemical libraries of synthetic compounds, on the other hand, the structure of molecules is known; when a hit takes place, it is relatively straightforward to move on to drug development stages.

NPR tends to be more expensive and to incorporate more factors less amenable to control/manipulation than synthetic chemistry, but the natural products add diversity to research programmes. However, some scientists feel that it will eventually be possible to get sufficient diversity in synthetically derived chemical libraries. The potential of chemical libraries is limited only by existing technology, which is advancing quickly. For instance, for one pharmaceutical company surveyed, two-thirds of screening activities used to be focused on natural products, but the past few years have witnessed a shift to increased screening of synthetic compounds. Advances in technology have allowed the synthetic production of the chemical diversity previously available only in nature.

Unique complicated molecules are unlikely to be found in synthetic chemical libraries, but for the most part it is not the complicated molecules that are the most useful leads. Much effort is spent modifying molecules of natural products to make simpler molecules while maintaining/accentuating the required activity. However, no company has a sufficiently diverse chemical compound file and there will always be a need for "Nature, which is the supreme chemist for synthesis of novel structures" (Dr Gordon Cragg, NCI).

A major drawback of the screening of chemical libraries of pure compounds and their relatives is that one simply gets a group of compounds with the same activity profiles. All the compounds are somewhat related, and relatives of leads show similar negative side effects, rendering screening of relatives slightly pointless.

3.2.10 The Convention on Biological Diversity

The general feeling among the pharmaceutical companies interviewed is that the Convention on Biological Diversity (CBD) provides basic guidelines for use of genetic resources and contains a number of useful concepts. US-based pharmaceutical companies find the CBD to have limited implications for their activities as the US interpretive statement (linked to President Clinton's signature of the CBD) allows the US, in effect, to ignore difficult clauses.

Shaman emphasized that the improved equity and management of genetic resources arising from the CBD is better for all parties. In light of concern about challenges to intellectual property rights in the pharmaceutical industry, the CBD provides positive guidelines. While there may now be control gates with regard to use of genetic resources, access will be greater. If companies work up front with sound collaborative arrangements, the CBD should not be a problem.

Table 3.2 Major regions and ecosystems used for source material for NPR by different pharmaceutical companies questioned. (NZ- New Zealand;] - included with S. America; ? - ecoregion uncertain)

Company	1	2	3	4	5	6	7	8	9	10	11	12	13
Continent:													
Asia	y	y	y			33%		50%	y	y	80%	y	30%
Africa		y				33%				y			
North America		y			y		y			y	20%		
Central America	y	y		y	y	]				y			]
South America	y	y			y	33%		50%		y			36%
Europe		y								y			
Australia	NZ									y			
Arctic										y			
Zone:													
Tropics:forest		y	70%	y	y	y		40%	y				100
Tropics:other		y	25%	y		y		40%	y				
Temperate:forest		y	5%		y		y	10%	?				
Temperate:other		y			y		y	10%	?				
Polar													
Marine		y			y	y			y				

3.3 SUMMARY

It would appear that virtually all research and development (R&D) in the pharmaceutical industry has its source in some naturally generated information. However, the time and money spent on this R&D remains difficult to quantify as the industry is not very precise as to what it considers to be "Natural Products Research" (NPR). Previously, NPR used to focus on the identification of material from within an organism which could be used directly in medicinal products (called a `silver bullet'). It is very seldom that nature provides such a ready-packaged molecule, already purified and isolated for direct use by humans (although many of the pharmaceuticals now in use derive from about 40 such substances). Pharmaceutical companies usually declaim NPR for the high cost of either: a) developing biological material into synthetic material; or b) procuring secure supplies of biological material through time.

More often, the value of biological material lies in its more generalised, but fundamental, information that has to be refined and developed. It seems that the vast majority of screened molecules are of this once-removed nature, derived from human modification of natural templates. Literally hundreds of thousands of permutations may be built upon the foundation of a single template, and so synthesised substances are seen as being the focus of the screening industry. However, it cannot be overemphasised that the raw material for this enterprise comes initially from natural templates. The industry seems to be able to run long cycles of discovery based upon periodic injections of these templates from nature.

There are some pharmaceutical companies that claim that it is now possible to produce wholly `rationally designed' pharmaceuticals. For the most part, these substances are identified through screening, but by means of specially identified screens and by developing the screened molecules in logical directions from natural templates. Although this is sometimes said to represent a new independence from nature, it might simply imply much shorter cycles of discovery (between injections of new biological materials) if the new technologies mean that the screening process becomes much more efficiently directed.

This survey of the pharmaceutical industry indicates that, as would be anticipated, biological diversity is a crucial factor in the production of modern medicine, even though the industry itself recognises its contribution only when it works most directly and completely. It appears that naturally generated information has had at least some role in the creation of virtually every pharmaceutical to date, and continues to provide the templates for current research. Although modern medicine has moved away from the use of plant and herb extracts, and toward reliance upon the isolation and modification of chemicals produced in nature, it still appears that the degree of fundamental (albeit indirect) reliance is nearly absolute.

3.4 CONCLUSIONS

1. Although 25% of prescription drugs contain active ingredients derived from plants, these come from only about 40 different species.

2. Whereas research used to be focused on identifying naturally occurring active compounds which could be used directly without further synthesis ("silver bullets"), the trend is now towards isolating lead compounds which can be synthesised into active drugs.

3. Technologies for screening for pharmacological activity have advanced so that large numbers of compounds or natural products can be screened at low cost. This has increased the through-put and scale of screening.

4. The use of ethnobotanical information to narrow down the number of organisms screened is widespread.

5. Once activity has been detected, the active compound must be isolated and its structure identified. This tends to be more time-consuming and expensive than the initial screening.

6. Bulk production of active compounds is usually achieved through chemical synthesis or through cell culture techniques for more complex molecules. Extraction from natural organisms is not favoured because of the cost and problems of securing a reliable supply.

7. All the pharmaceutical companies questioned use plant source material for NPR, but many prefer to use microbes or fungi which are easier to grow in cell culture.

8. With the exception of a few specialist companies, expenditure on natural product research and development tends to be low because it is slow and high risk. Screening of synthetic compounds is preferred.

9. Little money is available in advance for obtaining natural products for screening, but some collaborative arrangements have been developed to build research capacity in source countries. Royalty payments for production drugs are already in place with some collecting institutes, and most companies expressed a willingness to consider them in future.

4. THE USE OF PLANT GENETIC RESOURCES IN AGRICULTURE

Nathalie Olsen, Timothy Swanson and Harriet Gillett

4.1 INTRODUCTION

Genetic material is the source of new information for the development of new products and the improvement of existing ones. Genetic information stored in different species is regularly being used by industries such as the pharmaceutical and those involved in plant and animal breeding. In these industries, the availability of new information is of paramount importance in the search for new products and the long term development of the industries. Indeed, the development of gene banks and their use by industry is evidence of the importance of genetic resources.

Developments in technology, i.e. biotechnology, have increased the range of searches and improved the ability to retrieve information stored in genetic resources. In other words, they have effectively increased the amount of information available and made it easier to retrieve. When searches of existing genetic material become unproductive, new accessions are made to the "library" of unexplored wild genetic material. This has been the main source of new information, although the development of new techniques, such as induced mutation, also now provides a source of genetic material.

Hence, in order to asses the importance of biodiversity conservation to the section of the agricultural industry concerned with plant crops, we have to examine the role of plant genetic resources. Questions such as: what is the current and future value of the genetic resources for the industry? or what is the quantity and quality of biodiversity that the industry is keen to preserve for commercial reasons? can be answered only by understanding the decision-making process within the industry. We therefore decided to carry out a survey of the industry, this involved sending a questionnaire to plant breeding and seed companies and interviewing various representatives, to gauge their views on a number of these issues. This report presents the findings of the survey and is based on the information obtained from the 20 companies which responded to the questionnaires. In order to preserve confidentiality of commercially sensitive information, the names of the firms have been concealed.

4.2 THE BASICS OF PLANT BREEDING

The primary objective of plant breeders is to develop new domesticated varieties, containing desirable traits, superior to existing commercial cultivars. New varieties may have greater disease/pest resistance, may produce higher yields, may thrive under stressful conditions of drought, high salinity, temperature, etc. Research and development (R&D) efforts therefore focus on identifying seed (from cultivars[1], landraces[2] or wild material) with desirable traits from as closely related species as possible and incorporating these into existing cultivars. Desirable traits may be found in a wide range of germplasm.

---

1 Cultivated variety. An assemblage of cultivated plants with clearly distinguished characters which are maintained when produced sexually or asexually.

2 Highly variable, local crop cultivars that have evolved in diverse environments under traditional agricultural practice, over a long time period.

The generally high costs (in time and money required) of breeding programmes mean that they tend to be highly targeted, i.e. they respond to current problems encountered in agriculture. The type of germplasm used to improve domesticates is shaped by three factors: the rarity of the desired characteristic, the ease of transferring the desired characteristic and the importance of the crop/domesticate.

4.2.1 Determinants of Germplasm Use

The rarity of the desired characteristic

Preferred sources of germplasm are locally available commercial cultivars or closely related minor crops. Breeders may, however, look abroad for closely related commercial cultivars; while these varieties may not be adapted to the local climate, they display the required yield and quality characteristics. Desired cultivars, in general, display characteristics of yield, quality and environmental adaptation required for commercial success.

If, however, the trait sought is quite rare, then breeders may turn to wild species and primitive landraces despite the more complicated breeding procedures that are usually required for unadapted material. This material broadens the range of characteristics available for use in commercial agriculture. Even though wild species generally contain traits that are undesirable in agriculture, such as weediness and low yield (hence they have not been domesticated), they may be far more hardy or more resistant to pests and diseases than domesticates.

Wild species are species which reproduce independently of human control. The habitat required by wild species for reproduction and nutrition can regenerate without human intervention. Wild species grow in closed, primary habitats, in open, naturally disturbed habitats and in both open and closed areas disturbed by human activity. Primitive landraces are races or populations of crops that have become adapted under natural and artificial selection processes to the local conditions under which they are cultivated.

Ease of transfer of the desired characteristic

The ease with which a characteristic can be transferred to a domesticate is a critical factor in the selection of germplasm to introduce into a breeding programme. It is often a complex procedure to isolate and incorporate the desirable trait into the domesticate while minimising the number of undesirable traits carried over in conjunction with the desirable trait. Wild species are used only as a last resort due, firstly, to possible difficulties of crossing and, secondly, to the so-called package-deal effect.

1. Difficulties of crossing

The ease of crossing depends on how closely related the domesticate to be improved and the plant embodying the desired characteristic are. The closeness of relation and the subsequent ease of breeding are indicated by the category of gene pool into which the new germplasm falls. The primary gene pool (corresponding to the concept of a biological species) is made up of domesticates and wild species which are inter-fertile and hybridise easily. The transfer of genes is relatively easy and the offspring are fertile. The secondary gene pool is made up of species that can be crossed with the domesticate using conventional breeding methods. Gene transfer is less easy and only some of the offspring are fertile and may not reach maturity. Species in the tertiary gene pool can be crossed with the domesticate only by using techniques of grafting or tissue culture, and hybrids are sterile and non-viable.

Breeding programmes select offspring displaying different degrees and combinations of the characteristics of the parents. Offspring are crossed over a number of generations to recover the required characteristics of the domesticates while incorporating the desired trait of the wild relative. Because commercial cultivars grown in the same region tend to be closely related and easy to cross, they are considered first when a new trait (e.g. disease resistance) is required. It is less likely that a wild species will be in the primary gene pool of the domesticate.

It must be noted that advances in genetic engineering are blurring the distinction between gene pools as ways to identify, isolate and move genes, using biotechnological methods, are developed. In fact, biotechnology is dramatically changing the accessibility of individual genes to breeders. Breeders may cut short many years of conventional breeding by technically manipulating and transferring genes between plants. Current use of biotechnology and implications for germplasm utilisation are discussed later.

2. The `package-deal' effect
Difficulties are encountered when using wild species over and above the difficulties associated with crossing techniques. The so-called `package-deal' effect refers to the fact that genes for a particular characteristic may be linked to genes for many undesirable characteristics. For instance, a gene for high yield may be linked to genes for poor quality and foul smell. It can be extremely difficult to separate these genes. This linkage of genes means that even if a wild plant is one of the few species known to carry a required resistance and even if this species is in the primary gene pool of the domesticate, there may still be reasons to avoid its use. As a result, wild species tend to be employed in breeding programmes to improve particular crops and traits, but are not used a generalised or frequent basis.

The importance of genetically improving the domesticate
Whether a breeder is willing to attempt the complicated process of using wild species depends mainly on the importance of the crop to be improved (and the importance of the trait required). The relative importance of the crop in question is reflected by its position in world agriculture. Commercial breeders must be able to recoup R&D expenditure through seed sales and royalties from seed sales. It is more likely that wild species will be utilised for crops which feed a large proportion of the global population, e.g. cereals and oil crops, and which therefore are the subject of extensive breeding programmes, than for crops consumed on a small scale and limited to particular regions of the world.

4.2.2 The Dynamic Use of Wild Genes in Research: The Cascade Effect

Comments concerning the source of germplasm used should be treated cautiously, as the tendency is to vastly misinterpret the reality of the situation. Wherever possible, breeders will use a genetic resource only once. If a breeder identifies a useful character in a wild species or landrace, and incorporates it into a variety, other breeders will then use that variety (i.e. adapted cultivar), rather than the original source material. This continual re-use is known as the cascade effect.

The cascade effect is well-demonstrated in the instance of breeding grassy stunt virus resistant rice. Something like 17,000 rice accessions and over 100 wild taxa were tested, during a four year programme, to identify the one accession of *Oryza nivara* with grassy stunt virus resistance. Once this work was done, at the request of plant breeders, only one accession needed to be given to breeders. Merely to report on numbers given to breeders without taking account of work done to identify characters is to undervalue the use of the genebank (i.e. the entire genebank was "used" previously to identify one relevant accession) and entirely misrepresents the true source of the selected material. Thus, the use of genetic resources *per se* is reduced, but their value (as source material of the character) is dramatic. In the rice example cited above, the character is now present in nearly all newly released varieties of rice, with a multi-million dollar value. Nevertheless, the genetic resource is reported to have been "used" just once in one breeding programme.

4.3. SURVEY RESULTS

4.3.1 Seed Companies and Plant Breeders

The companies included in the survey undertake breeding, production and marketing of crop seed, with a handful also acting as agents. A European company is involved in agrochemicals in addition to plant breeding, and one US company leans more towards being an agricultural biotechnology company than a seed company, but, in general, questionnaires were directed to companies involved directly in research and breeding activities.

Geographical range
Eighteen European-based companies and two US-based companies provided information about their research and breeding activities. These companies are not necessarily the largest seed companies, but rather represent different types of companies with diverse turnover and research expenditure, and significant variation in the major crops they breed. In general, the firms that provided data in this survey were involved in breeding European or North American crops.

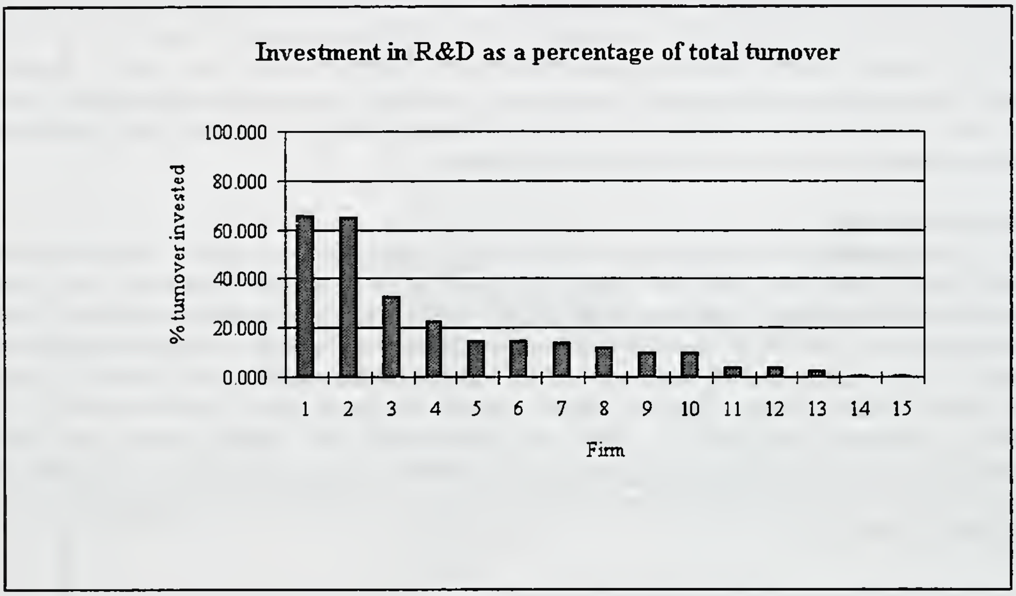
Size range
An indication of the size of breeding companies is provided by approximate annual revenues from seed sales. For 1993, annual revenues ranged from £1.5-£65 million. Because companies did not provide time-series data on annual sales revenue over the last decade, it is difficult to determine a time trend in seed sales revenue. Also, in light of the spate of mergers and acquisitions in the seed and agrochemical industry in the 1980s, some respondents provided information on the breeding activities of a particular subsidiary, while others provided data on the overall multinational operations of a large diversified corporation.

Expenditure on research and development
The proportion of annual turnover spent on breeding and research programmes ranges from 0.5-66%.

The breeders allocate, on average, 18% of annual turnover to breeding and research activities. Most breeders (73%), however, spend between 0.5 and 15% of annual turnover on research and breeding. The large variance in the proportion of turnover invested in research and breeding may reflect the diverse activities of the companies questioned. For instance, while most companies undertake breeding, production and marketing of seeds internationally, some have diversified into agro-chemicals or other activities. As a result, spending on breeding and research may be dwarfed by these other enterprises. Furthermore, the sums of money involved may vary dramatically from year to year as expenditure tends to be higher when breeders are setting up operations or expanding existing breeding programmes. For example, of the three breeders with the highest research expenditure (as a proportion of turnover), two set up plant breeding facilities in 1987 and spent 66% and 65% of annual turnover on the companies breeding and research programme in 1993. The third highest spender was privatised in 1987, and in 1993 spent 33% of turnover on research and breeding.

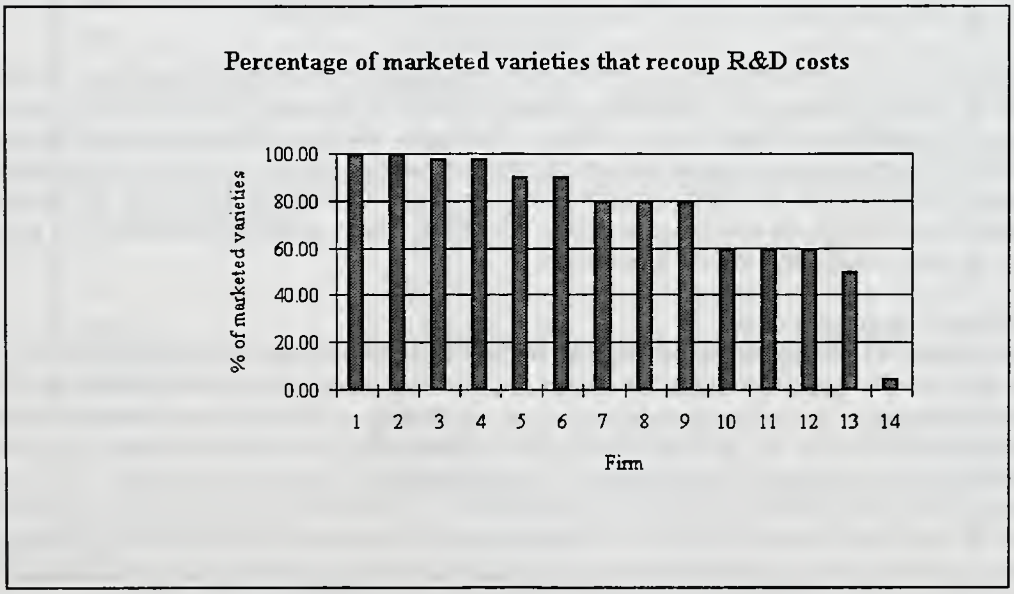
Recouping R&D expenditure
Fourteen breeders provided information on the proportion of marketed new varieties which recouped R&D expenditure. Although responses ranged from 5-100% (Figure 4.2), an average of 75% of the new

Figure 4.1 Investment in R&D as a percentage of total turnover



varieties were reported to recoup R&D cost. However, it was clear from the survey that most varieties fail before reaching the market. In effect, it is highly likely that a variety will be profitable if it successfully completes the pre-marketing stages of registration and testing.

Figure 4.2 Percentage of marketed varieties that recoup R&D costs



While it takes 10-11 years, on average, to develop a new variety, it then has only 6-7 years to recoup costs once on the market, because of competition from other varieties. As a result, even if the duration of patent protection was extended this would do little to spur investment in breeding, as the chances of recouping breeding costs would not be increased. In essence, difficulty getting returns on investment in breeding is not associated with inadequate implementation of property rights for new varieties. However, a number of breeders have emphasised that, with the advances in biotechnology, the ability to patent genes and particular combinations of genes is crucial if breeders are to be provided with incentives to allocate the necessary resources to breeding programmes.

Range of crops bred

Most of the companies have highly diversified breeding activities and grow at least two types of crop. Cereals and oil crops were bred most commonly, by 14 and 11 companies respectively. The cereals include maize, winter wheat, winter and spring barley, sorghum, and some other minor cereals. The oil crops include winter and spring oilseed rape, linseed, sunflower, soybean and safflower. Nine companies breed root crops such as potatoes, sugar beet, fodder beet and swedes and four breed vegetables (vining peas, beans, tomatoes, onions, peppers, lettuce, carrots, all species). Other crops covered are fruit (melons), commodity crops (tobacco), fibre crops (cotton, flax), new industrial crops (lesquerelles, cophea, meadow joan), flowers (bedding and pot), and amenity and forage grasses (clover, alfalfa and forage maize). Some information on grape vines and root stock is also included. This information is presented in Table 4.1.

4.3.2 Use of Germplasm in the Breeding Industry

Breeders were asked to report on the relative importance of different sources of germplasm used in their breeding programmes. The germplasm could be conserved either *in situ* or *ex situ*. In this context, *in situ* conservation refers to the maintenance of a wild gene pool in its native habitat, e.g. in a national park or a nature reserve, or of a landrace in the region in which it evolved. *Ex situ* conservation refers to the maintenance of the wild gene pool outside its natural habitat; germplasm may be maintained in a seed bank, or the living plant may be conserved in a botanical garden or plantation. In this survey, *ex situ* conservation implies the storage of seed in seed banks. The operational definition of "use" in this context is the incorporation of source material into a breeding programme.

In general, the breeders providing data for this survey focus on European and/or North American crops. This is probably because the availability of domesticates with desirable traits is more common in temperate crops than in tropical crops. In addition, the range of species available per crop, and the range of traits available per species contained in *ex situ* genebanks, is also greater for temperate crops than for tropical crops. However, breeding programmes differ according to the crops bred and the characteristics sought. On the whole, if a wide range of traits is available in closely related domesticates, wild species will be rarely be used as a source of germplasm.

Sources of germplasm used

The source of the germplasm used in breeding programmes differs between crops and depends, in part, on the number of genes controlling the desired characteristic. Table 4.2 shows the importance of the different sources of germplasm averaged across all crops (mostly temperate species) and for a number of individual crop types. As can be seen from this table, the germplasm source differs quite dramatically depending on the particular crop. For instance, wild species from a genebank are frequently (19%) used when potatoes are involved, but rarely (1%) for oil crops. However, the most important source by far (83.4% - averaged across all crops), is the adapted material of commercial cultivars. The advantages of using these cultivars include the fact that they present the fewest obstacles to successful crossing and that many of the traits desired by breeders are present in these closely related domesticates.

Table 4.1 Crops Covered by Survey

CROP		Number of Companies breeding crop
cereals	maize winter wheat winter and spring barley triticale sorghum other minor cereals	14
oil crops	winter/spring oilseed rape linseed sunflower soybean safflower	11
root crops	potatoes fodder beet swedes sugar beet	9
vegetables	vining peas winter and spring beans tomatoes onions peppers lettuce carrots	7
fruit	cantaloupe melon	1
commodity crops	tobacco	1
fibre crops	cotton flax	2
new industrial crops	lesquerelles cophea meadow joan	4
flowers	bedding and pot	3
amenity and forage grasses	grass clover alfalfa forage maize	
grape vines and root stock		1

Roughly 7% of germplasm used is unadapted material of various types. The dominant type of unadapted material used is germplasm from wild species obtained from genebanks, which totals 2.6% of germplasm utilised. The second most commonly used unadapted material is germplasm from primitive landraces obtained from genebanks, amounting to 1.6% of breeding programme germplasm. Germplasm conserved *in situ* makes up the remainder of unadapted material used with 1.4% of germplasm from primitive landraces conserved *in situ* and 1.1% from wild species conserved *in situ*.

While germplasm from wild species constitutes only a small proportion of the germplasm used in breeding programmes, almost all (c. 94%) of the breeders reported using wild species from either genebanks or *in situ* conservation areas. Similarly primitive landraces are rarely used, but just under 70% of breeders use landraces from genebanks and *in situ* conservation areas as breeding material. As previously discussed, despite the fact that this material is only injected into the research process in a small proportion, once their genes enter into commercial cultivars they are repeatedly re-used in the future.

The results also suggest that breeders prefer to obtain unadapted material from *ex situ* genebanks rather than *in situ* conservation areas. Genebank material is more accessible to breeders, who simply request a number of accessions; it also tends to be free of charge, there may be fees to cover transactions costs, but these are minimal. Moreover, genebank material tends to be more highly characterised, i.e. traits relevant to breeding efforts are available. Furthermore, material in genebanks may have undergone a small degree of germplasm enhancement, i.e. early stages of breeding may have transferred a desired characteristic of unadapted material into adapted material displaying traits required by commercial breeders.

On average, 4.5% of germplasm utilised is obtained through biotechnological methods. In this context, biotechnology refers to technologies such as tissue culture, molecular genetics and genetic engineering. However, biotechnological methods can be applied to only some crops. The importance of biotechnology relative to other sources of germplasm should be evaluated on the basis of data from individual crops. For example, almost no biotechnology is used in vegetable breeding programmes, while just under 18% of germplasm in potato breeding programmes is produced by biotechnological methods.

Around 2.2% of germplasm is obtained through induced mutation by either ionising radiation or chemical treatment. As with biotechnological methods, the use of induced mutation is far more prevalent for particular crops. For instance, less than one percent of breeding material for cereals and vegetables, but over seven percent of breeding material for oil crops, is obtained via mutation.

In general, genebanks offer a greater range of germplasm for temperate than for tropical species. This is partly due to the tendency for tropical species (including important crop species such as cocoa, coconut, mango, cinnamon, nutmeg, avocado, tea, breadfruit and jackfruit) to produce recalcitrant seed - that is seed that cannot withstand drying. Seedbanks cannot be used for their conservation and they have usually been conserved in field genebanks. Although such genebanks take up considerable space and have other limitations, valuable collections of crops such as banana, plantain, oil palm and coffee exist.

Cereals

Almost all (87.6%) germplasm used in breeding cereals comes from adapted material, the vast majority (87%) from commercial cultivars, with only 0.6% from minor crops.

In contrast, only 4.3% of germplasm was from unadapted material, with 1.7% of this from primitive landraces obtained from genebanks. About 75% of the cereals breeders used this type of germplasm, with quantities ranging up to 10% of total breeding material. Approximately 1.2% of germplasm was

Table 4.2 Source of germplasm used in all crops and in four crop types

Source of Germplasm	All crops averageg	Potato average	Cereals average	Oil crops average	Vegetable average
Adapted material: commercial cultivar	83.4%	50%	87%	78.8%	95.7%
Adapted material: minor crop *	1.4%	8.3%	0.6%	1.2%	0.3%
Wild species from genebank	2.6%	19%	1.2%	1%	1.4%
Wild species conserved *in situ*	1.1%	0	0.7%	0.1%	0.1%
Primitive landrace from genebank	1.6%	1.7%	1.7%	2.3%	1.7%
Primitive landrace conserved *in situ*	1.4%	0	0.7%	2.8%	0.4%
Induced mutation	2.2%	3.3%	0.7%	7.2%	0.3%
Biotechnology	4.5%	17.7%	3.5%	6.8%	0.1%

* minor crop cultivated on a small scale with some improvement over wild ancestors.

from wild species maintained *ex situ* in genebanks; 50% of the cereals breeders used at least some (1-10%) germplasm from wild species obtained from genebanks. Cereal breeders use very little *in situ* unadapted material. The same, small, amount of breeding material (0.7%) was used from wild species conserved *in situ* as was used from primitive landraces conserved *in situ*. It is worth noting that *in situ* conserved germplasm was used mostly in maize (3.3%). These figure suggest that although the proportion of breeding material that was unadapted material is quite small, the majority of breeders use at least some unadapted material despite the associated breeding difficulties. This suggests that breeders are often unable to find the characteristics they require in adapted material. Hence, the actual value of the unadapted material in the breeding Industry may actually be underestimated by the proportion used in R&D.

The use of mutation was very limited in the breeding of cereals. Just under one percent of germplasm was obtained using these methods. On average, between 3-4% of germplasm was obtained using biotechnological methods, but one cereal breeder relied on biotechnology for 40% of its germplasm, while half of the cereal breeders relied on biotechnology for only 1%, or thereabouts, of germplasm.

Oil crops

As with cereals, most (805) of the germplasm used to improve oil crops was from adapted material, with commercial cultivars providing 78.8% of this. The percentage of commercial cultivars in total oil crop germplasm used ranged from 50 to 95%. Slightly more than one percent of germplasm was obtained from minor crops.

Approximately 6.2% of oil crop germplasm used was obtained from unadapted material, predominantly from landraces conserved both *ex situ* and *in situ*. Some 2.8% of germplasm used in breeding programmes was from landraces conserved *in situ*; while 2.3% was from landraces obtained from genebanks; 1% was germplasm from wild species obtained from genebanks and only 0.1% from wild species *in situ*.

Most (c. 75%) oil crop breeders use some induced mutation of germplasm. Approximately 7.2% of total oil crop germplasm was obtained in this way. Similarly, just under 7% of germplasm was obtained through biotechnological methods. A very high proportion of oil crop breeders (87%) use some biotechnology in crop improvement.

Vegetables
Breeders of vegetables rely more heavily on adapted material than any other breeders, obtaining 95.7% of their germpalsm from commercial cultivars and a further 0.3% from minor crops. Most of the small amount of unadapted material used is from landraces and wild species in genebanks (1.7% and 1.4% respectively). Use of induced mutation and biotechnology by these breeders is almost non-existent (0.4%)

Potatoes
Potato breeders rely less heavily on adapted material than do breeders of other crops. Only 50% of germplasm was obtained from commercial cultivars, while just over 8% was obtained from minor crops. Instead, potato breeders rely most heavily on the use of germplasm from unadapted material. Over 20% of germplasm was obtained from unadapted material; 19% was germplasm was from wild species conserved in gene banks, 1.7% was from primitive landraces conserved in genebanks and a further 0.7% was from landraces conserved *in situ.*

Only one potato breeder uses induced mutation, amounting to 10% of germplasm in the breeding programme. All three potato breeders surveyed, however, use biotechnological methods which provide, on average, around 18% of germplasm.

4.3.3 Institutional Sources of Germplasm

In light of the dominant use of germplasm from commercial cultivars in crop- improvement programmes, it is no surprise that all breeders have extensive in-house collections of germplasm.

In-house collections
Germplasm contained in a breeder's in-house collections comes from a variety of sources (Fig 4.3). Around 75% is material from the company's current breeding programme, while 15% is material from other companies' breeding programmes. This suggests that, despite the extremely high degree of competition, breeders are able to use the released material of other breeders to improve their own varieties. In-house collections contain predominantly adapted material, on average only 4% is unadapted material, most of which is *ex situ* maintained genebank material (3%), while the remaining 1% originates in *in situ* conservation areas.

The dominant factor determining the extent of in-house germplasm collections is security (Fig 4.4). Around 55% of breeders believed that ensuring a stable supply of high quality breeding material was the top priority of in-house collections. Having in-house collections also makes it easier to establish property rights over some of the germplasm. Some 44% of the breeders felt cost to be an important determinant of in-house germplasm.

Just over a quarter of breeders maintain some germplasm in-house because of non-availability or scarcity of particular species in genebanks and in *in situ* conservation areas. In light of the rising rate of extinction of plant species, through overexploitation and habitat encroachment, breeders are keen to ensure they have access to relatives of commercial crops which may in the future provide useful characteristics. One grass breeder noted that there are differences between collecting for breeding and collecting for gene conservation. The implication is that the raw and adapted material contained in genebanks and some public research institutes may not be the material which breeders find most useful.

Figure 4.3 Sources of in-house germplasm

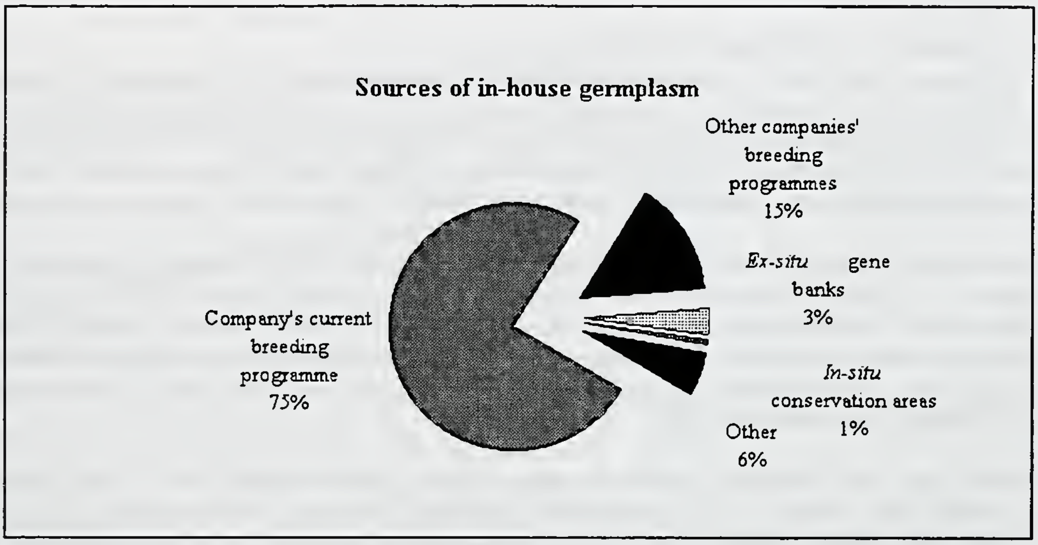
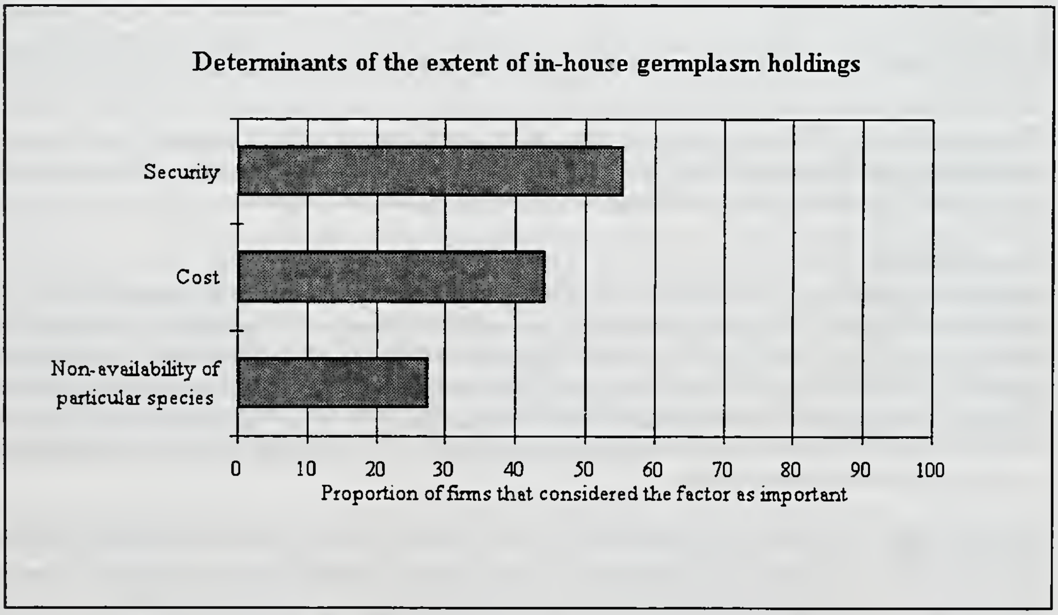


Figure 4.4 Determinants of the extent of in-house germplasm holdings



This is also another reason for breeders to perform their own collections and maintain that germplasm for future breeding material.

Genebanks and public research institutes utilised
All but one of the breeders access public genebanks and obtain germplasm from public research institutes and universities. Two breeders used genebank material passed on by other private plant breeders. On average, breeders obtained genebank germplasm between two and three times in the period from 1987 to 1993 for each major crop bred. The frequency with which genebanks are approached for material is determined by the crop. Unfortunately, there are not sufficient data to provide information by crop.

Data on the frequency of use of genebank germplasm in the years 1987-93 should be considered with caution. Acquisition of germplasm is infrequent and slow unless a breeder is starting a new programme. Hence use of genebank germplasm may be underestimated if many breeders expanded breeding programmes or launched new programmes prior to 1987 and subsequently required no further material. Alternatively, use of genebank material would be overestimated if there had been a general expansion in breeding programmes after 1987.

Furthermore, the frequency with which breeders access genebank material tells us little about the quantities used. Whether a breeder receives 400 accessions once a year or 40 accessions ten times a year makes little difference in reality. Similarly, in their publication *The Review of UK Policy on the Ex-Situ Conservation of Plant Genetic Resources* the Ministry of Agriculture, Fisheries and Food (MAFF, 1992) emphasises that frequency of requests for material is not a valid indicator of the benefit ultimately derived, given the potential for improving a variety with high commercial and agronomic potential.

4.3.4 Allocation of Breeding Activities

The activities of plant breeders and seed companies range from plant exploration and collection, testing of unadapted material, introgression of traits, growing out/viability tests, breeding, and the development and application of genetic modification techniques. Not all of these activities are undertaken in-house; activities may be contracted out to other private plant breeders, gene banks and/or other public institutes. Due to preexisting infrastructure and expertise, other institutions may have a comparative advantage in performing some of these activities. Table 4.3 summarises the findings of the survey, indicating how the diverse breeding activities are distributed among the various bodies involved.

Plant collection
Systematic exploration and collection of crop plant genetic resources was essentially started in the 1920s by the Russian geneticist Nikolai Vavilov. Vavilov, under the auspices of the All-Union Institute of Plant Industry in Leningrad, was the first to identify the major centres of genetic diversity. When it became clear, in the 1950s, that genetic resources were being eroded and that a high percentage of accessions contained in genebanks were no longer available in living collections and presumably extinct in the wild, the US set up the National Seed Storage Laboratory (NSSL). National gene banks were established in most of the industrialised countries.

Since the 1960s, the Food and Agricultural Organisation of the United Nations (FAO) has been actively involved in the formulation and implementation of international policies on the exploration, collection, conservation, documentation and evaluation of plant genetic resources. The International Bureau for the Protection of Plant Genetic Resources (IBPGR) (currently known as IPGRI) was set up under FAO auspices in 1974 specifically to deal with plant genetic resources. Establishing a global network of plant genetic resource collections was one of the mandates of IPGRI. The participating genebanks included some regional and national ones, as well as those of the Consultative Group on International Agricultural Research (CGIAR).

Table 4.3 Organisation of research and breeding activities

Activity	In-house	Private plant breeder	Gene bank	Other public institute	% of breeders involved in activity
Plant exploration and collection	40%	2%	28%	30%	89%
Testing of unadapted material	61%	2%	8%	29%	89%
Introgression of traits	85%	0%	0%	14%	94%
Growing out/ viability tests	76%	2%	11%	11%	71%
Breeding	96%	2%	0%	2%	100%
Genetic modification: development	62%	16%	0%	22%	76%
Genetic modification: application	84%	2%	0%	13%	71%

Since the 1960s, in effect, activities associated with collection and conservation of plant genetic resources have moved away from individuals and governments to a small number of international bodies. Nowadays the FAO and IPGRI provide guidelines for the collection of plant genetic resources, and the expeditions are undertaken by national and international institutions, collecting for genebanks. These genebanks, and other public institutions, have an important role in the plant breeding industry as sources of germplasm. Data from the survey indicate that more than half (58%) of germplasm collection is contracted out to expeditions supplying public genebanks and other public institutes. In effect, no individual contracts are signed. Instead, in accessing genebanks for germplasm, breeders allocate responsibility for exploration and collection to an institution that has the infrastructure, expertise and experience to collect a wide range of species over a broad geographical are, and thereby avoid political complications of collecting plant genetic resources themselves.

On average, some 40% of all collecting activities are performed in-house (Table 4.3). The extent of in-house collection varies. Some breeders undertake 100% of collection, while others undertake as little as 5%. A very small proportion (2%) of exploration and collection is contracted out to other private plant breeders. This may seem surprising high in light of the emphasis that breeders have placed on the use of commercial cultivars in crop improvement programmes. However, 40% may be a fairly large proportion of a very small number, i.e. given the infrequent use of wild species and primitive landraces, the total volume of plant exploration and collection is likely to be small.

To illustrate the nature of in-house collection, a breeder of forage grasses undertakes 95% of collection in-house, collecting accessions mainly from intensively used natural pastures and from roadsides (yet the breeder asserts that "we do not believe in *in situ* conservation"). Germplasm from these pasture areas makes up 25% of all new breeding material used by this breeder.

Germplasm enhancement

Germplasm enhancement (also known as pre-breeding) includes two stages: firstly, testing of agronomic characteristics and secondly, the introgression of desirable traits into breeding material. Several cycles of selection and crossing may be required to produce a plant sufficiently adapted to be bred with domesticates. Short-term germ enhancement programmes aim to identify potentially useful accessions and increase the willingness of breeders to invest in longer-term breeding programmes by ensuring that breeders know the characteristics of the material they are working with.

On average, 61% of the testing of unadapted material and 85% of the introgression of traits into breeding material is performed in-house by commercial breeders (Table 4.3). Such in-house activities are carried out by most (90%) of the surveyed breeders (Fig 4.5). The second most important providers of enhancement activities are the public research centres and universities, with half of the breeders contracting out some of their activities to them (Fig 4.5). Public research institutes and universities perform 29% of testing of unadapted material and 14% of the introgression of traits. Some germplasm enhancement is also undertaken within genebanks, and about one quarter of breeders receive germplasm that has been pre-bred in genebanks (Fig 4.5). On average, 8% of the testing of unadapted material takes place in genebanks. While very few firms contracted out enhancement activities to other private breeders (5%), 20% of breeders contracted out to public plant breeders (Fig 4.5). Germplasm enhancement is a fundamental preliminary stage in breeding, and is so closely linked with breeding programmes that there is little to be gained by contracting out to other breeders (who would have little interest in performing germplasm enhancement alone when they could use the results for long-term breeding programmes themselves).

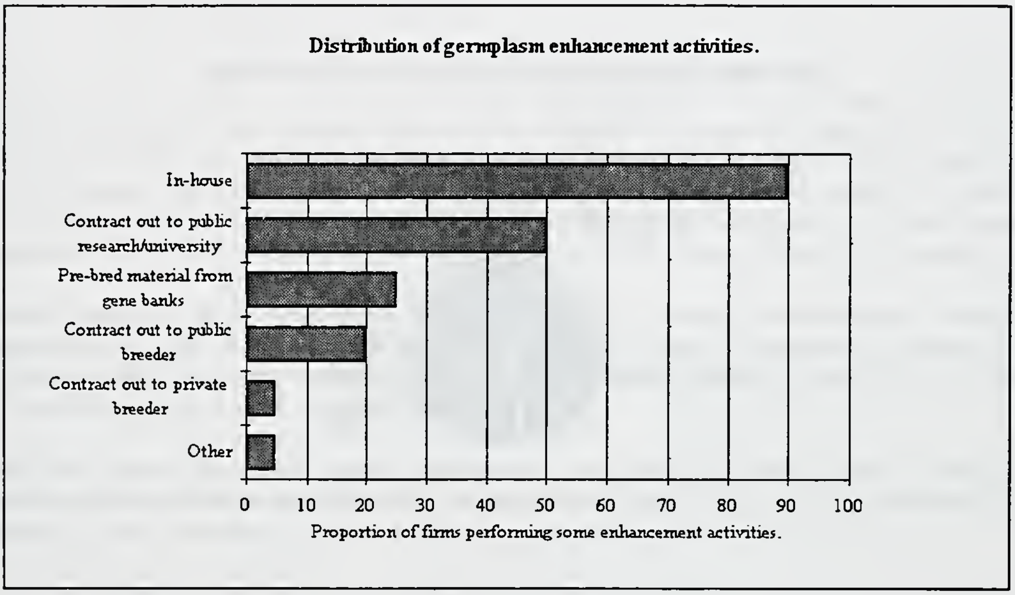
It is not clear whether breeders prefer to have public institutions provide preliminary information and testing of germplasm, while they retain greater control over the introgression of traits, or whether public institutions simply do not have the resources to develop comprehensive germplasm enhancement programmes, and therefore have a greater role in the earlier preliminary work.

Growing out/viability tests

If humidity and temperature conditions in genebanks are not controlled adequately, germplasm collections lose viability, experience mutations, and/or die. Seeds also lose viability when not grown out regularly. Even well-controlled storage at low temperatures affects the genetic material within seeds. Genetic material stored for long periods of time needs to be regularly grown out and tested for viability. Poor management and lack of resources in many of the world's genebanks result in the demise of a significant number of crop species. In fact, according to a survey undertaken by IPGRI, the majority of the world's genebanks do not meet generally accepted safety standards.

According to the survey results (Table 4.3), most (76%) growing out and viability testing was undertaken by the breeders themselves; to ensure the quality of their breeding material, breeders must undertake activities they might prefer to contract out. About 11% was performed by public research institutes. A number of plant breeders have commented that they might approach institutions with genebanks more frequently if these institutions accepted a greater share of germplasm enhancement activities, and if they maintained the quality of their collections through growing out and viability tests. However, it is not clear if breeders would be prepared to pay for the real cost of implementing this.

Figure 4.5 Distribution of germplasm enhancement activities



Breeding
Virtually all breeding is done in-house. While 96% of breeding activities are undertaken in-house, only 2% is contracted out to public research institutes and 2% to private plant breeders (Table 4.3). Genebanks undertake no breeding activities.

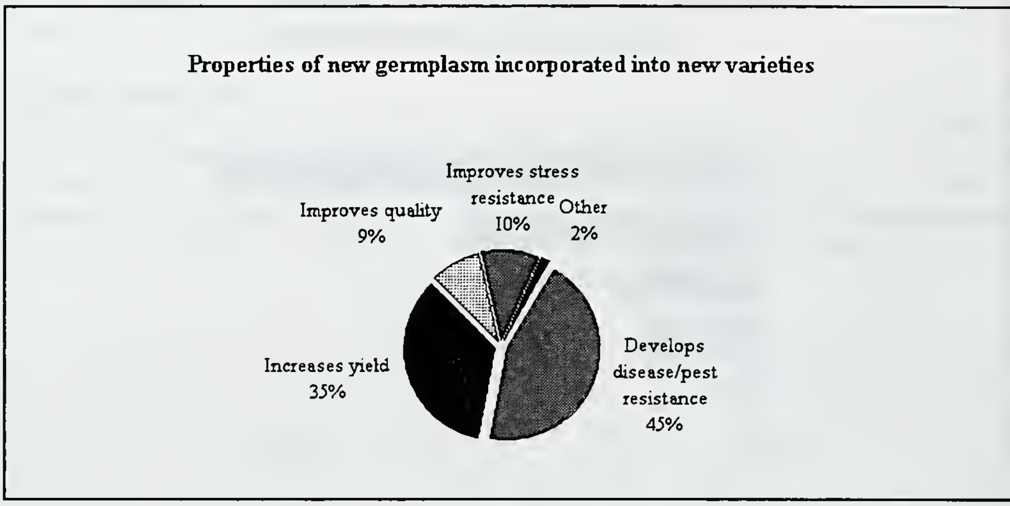
4.3.5 Research Priorities

The breeding programmes of commercial breeders tend to be highly targeted, and are a response to a particular problem commonly encountered in agriculture. As discussed above, the type of germplasm used to improve a commercial domesticate depends on the crop in question and the ease with which breeders are able to transfer the desired characteristic (the number of genes controlling a characteristic dictates the ease of transfer). Breeders were asked to provide an indication of the properties of new germplasm that were selected for and incorporated into new varieties (Fig 4.6).

Disease and pest resistance
The largest portion of germplasm, about 45%, incorporated into new varieties is aimed at developing disease and pest resistance. In general, resistance is controlled by a single dominant gene, so it is easily manipulated and transferred. In addition, disease resistance is very visible to breeders, much more so than, for example, marginally higher yield. As a result, disease resistance is the most important benefit to agriculture obtained from wild species.

One breeder estimated that it takes roughly 10-11 years to develop resistance. However, it takes only 4-5 years for resistance to 'break down' as pathogens and pests evolve far more quickly than does crop resistance. This implies that a constant supply of new genes with durable resistance is required.

Figure 4.6 Properties of new germplasm incorporated into new varieties



Yield

In the past 30 years, improvements in crop yield have, to a large extent, been due to the application of genetic resources from domesticated species. To date, the role of wild species has been quite limited. In general, yield is controlled by a number of linked genes, and it is difficult to increase yield in a domesticate without undermining other desired characteristics such as stress resistance and quality. Increases in yield in the UK since World War II are the result of years of painstaking conventional plant breeding.

The fact that yield is controlled by a number of linked genes might suggest that the scope for future use of wild species in yield increasing breeding programmes will be greatly expanded by the increased application of biotechnological methods. In our survey, 35% of germplasm incorporated in new varieties aimed to increase yield.

Stress resistance

Some 10% of the germplasm was aimed at improving the stress resistance of commercial varieties. Stress resistance includes the tolerance of soil problems, extreme temperatures and varied water conditions.

Quality

Overall quality improvement was sought by breeders only 9% of the time. The relative unimportance of this property was possibly due to the higher value put on improving particular characteristics, such as disease resistance and yield, in existing crops. Additionally, quality is a less tangible property, more likely to be associated with a wider range of genes and more subject to changes in consumer preferences.

4.3.6 Breeding Methods

Traditional crossing and backcrossing still form by far the most important (91%) method of plant breeding, while biothechnological methods, mostly combined with traditional methods, are being used in 6% of research (Fig 4.7). Advances in biotechnological capability are likely to increase the demand for genetic resources as techniques for genetic manipulation develop. Biotechnology has the ability to introduce greater biodiversity into agriculture as techniques develop to move germplasm between organisms that do not exchange genes naturally.

Using conventional breeding methods, it may take 15 years for the basic introduction of a characteristic from a commercial cultivar, and using wild material often doubles that time. Biotechnology allows the selection of individual genes mechanically instead of through tedious years of crossing and selection. In effect, the desirable characteristics of wild species can be used avoiding the package-deal effect arising from the linkage of genes. However, there are no genetically modified agricultural crops on the market in Europe yet and breeders have emphasised that application of biotechnology in their breeding programmes is still very limited (pure biotechnological methods account for only 1% of research).

Approximately 76% of the breeders are allocating resources to develop biotechnological methods to genetically modify crop cultivars. Approximately 62% of biotechnological development programmes are performed within the breeding company itself, 16% is contracted out to other private plant breeders and 22% is contracted out to public research institutes.

Over 70% of firms are already applying these genetic modification techniques in their crop breeding programmes. Some 84% of these biotechnological applications are performed in-house with most of the remaining (13%) performed by public research institutes (Table 4.3).

4.3.7 The Industry's Perceptions of the Maintenance of Germplasm

***In situ* conservation**

It is clear from the analysis of the types of germplasm used in current crop improvement programmes, that germplasm from *in situ* areas is little used. A total of 2.5% of germplasm used in breeding programmes is obtained directly from *in situ* conservation: 1.4% is germplasm from primitive landraces and 1.1% is from wild species.

Given the inherent complications of obtaining germplasm from *in situ* areas and given the complications in using breeding material which may contain a small number of desirable traits with many undesirable traits, it is unsurprising that the amount of germplasm obtained from this source is small. However, the fact that 32% of breeders access this type of germplasm, in spite of the breeding complications, testifies to its importance.

There is a range of means for obtaining germplasm maintained *in situ*. Over 70% of breeders who do use *in situ* germplasm obtain germplasm through in-house collecting activities, an equal proportion of breeders source from germplasm collected by intermediary public research institutions or universities. Roughly 30% of breeders have collection undertaken by an intermediary commercial organisation (Fig 4.8).

In an attempt to estimate a value for advantages accruing from use of *in situ* conserved germplasm, breeders were asked whether they would be willing to pay (more) for germplasm maintained in *in situ* conservation areas than for *ex situ* genebank material. About 80% responded that they would not be willing to pay (more) for *in situ* germplasm, 13% responded positively, and one breeder (7%) responded "possibly". Germplasm obtained from genebanks is not charged for and breeders see no direct commercial advantage in using germplasm that has evolved over time in a natural environment, especially if it is more costly. In effect, the range of germplasm that is available from *ex situ* genebanks is perceived by breeders to be greater than current requirements, and they do not expect the exhaustion of genebank material in the foreseeable future.

Figure 4.7 Methods of development in new marketed cultivars

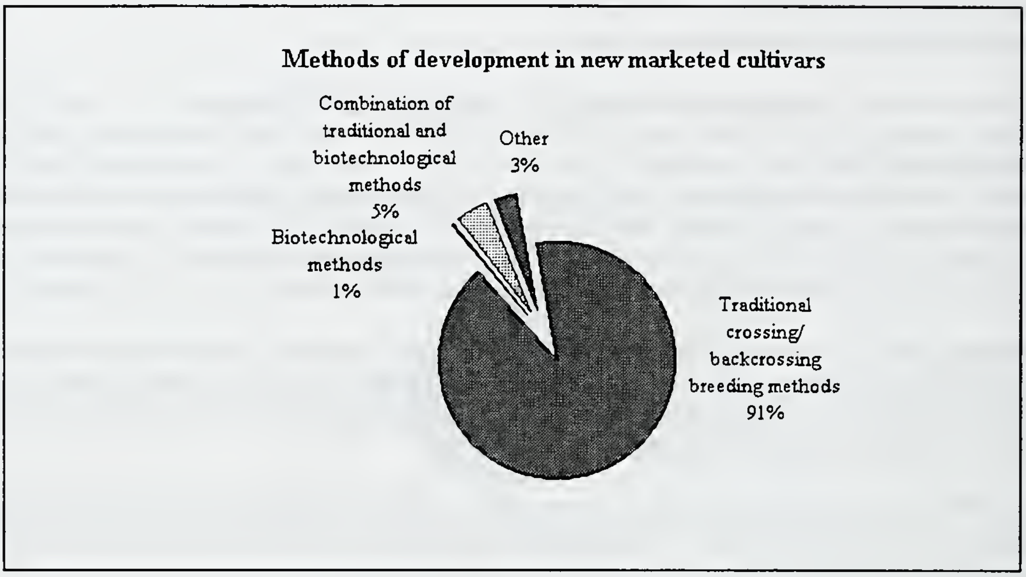
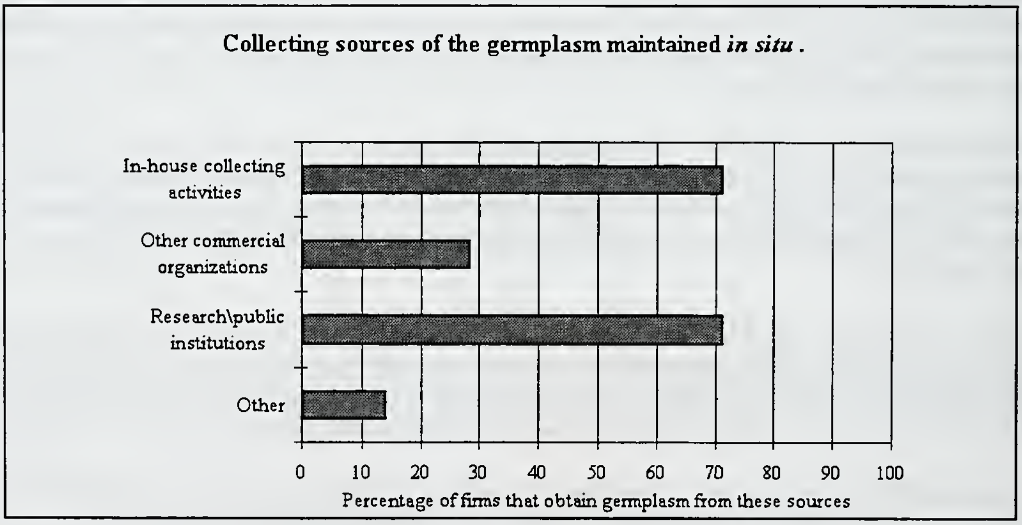


Figure 4.8 Proportion of firms accessing in situ sources directly



Ex situ conservation

Breeders were asked their perceptions of the quality of germplasm obtained from genebanks. In particular, they were asked to characterise the quality of storage facilities (reflected by the germination rate), the range of species available for given crops, the range of traits available for given species, and changes over time in genebanks. Details were to be provided for the breeders' major crops and genebanks accessed.

Germination rate

The germination rate of seed obtained from genebank collections is indicative of the quality of storage facilities and procedures (regular growing out, viability tests, etc.). Low germination rates are problematic because they reduce the material breeders have to work with. In addition, genetic drift, shift and contamination all present serious problems.

On average, the proportion of seed obtained from genebanks which germinates successfully is quite high as a result of widespread concern over the quality of storage facilities in genebanks. The average rate of germination experienced by the respondents was 80%. Roughly 50% of breeders considered that the germination rate had improved in the last twenty years; the other half considered that the germination rate had not changed over time.

Range of species available

The number of different species available is an indication of whether genebanks have collected as many species as possible to provide a variety of traits to breeders. However, most breeders felt unable to evaluate the performance of genebanks because they accessed them so infrequently. Only eight breeders responded; of these, three felt the range of species to be broad, three found it to be adequate, and two felt it to be narrow. On balance then, for 75% of breeders the range of species is at least sufficient. Three of the eight responding breeders felt that the range of species available for given crops has improved, while the remaining five considered the range of species to have remained the same. This may reflect the fact that genebanks have not performed extensive collection of new plant genetic resources in recent years.

It is important to bear in mind when considering the range of species available that the breeders involved in this survey are predominantly involved in breeding temperate crops. The plant genetic resources of temperate crops are more extensively characterised in genebanks; there are few known species not accessible through some international genebank. It may well be that the range of species contained in genebanks specialising in non-temperate crops is less adequate.

Range of traits available

A second indication of the quality/utility of a germplasm collection is the range of traits available for a given species. The number of traits that a genebank has identified (termed the characterisation of a plant) is crucial for the utility of that plant germplasm in breeding programmes. Having a broad range of species which have not been adequately characterised, so that breeders are not aware of the traits contained in the genebank collection, makes that collection somewhat useless.

Of the six responding breeders, one found the range of traits available for a given species to be broad, four found the range to be adequate and one identified it as narrow. Two of the responding breeder found that the range of traits available per species had become better, while three considered it had remained the same.

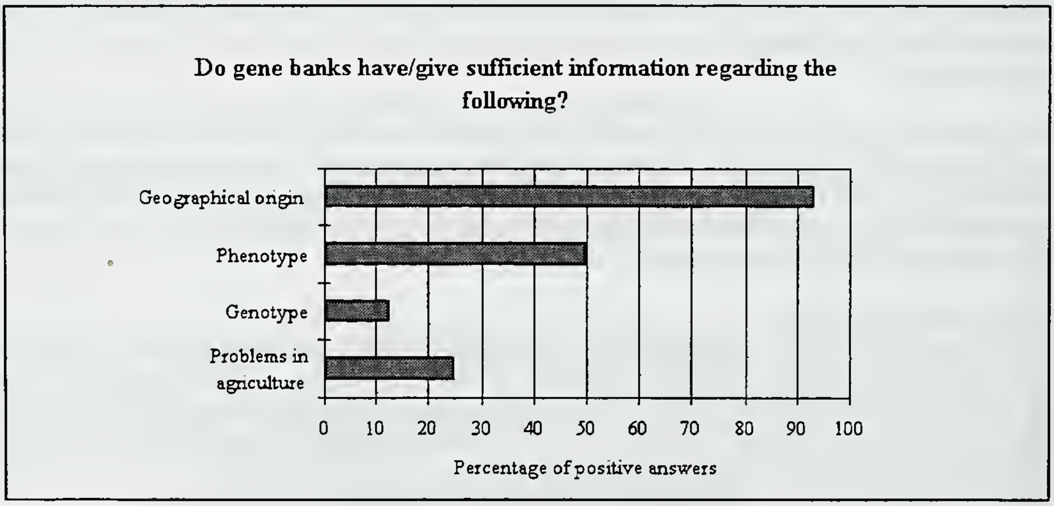
The need for evaluation/characterisation

The more detailed information an institution is able to provide about the germplasm holdings in its genebank and individual accessions, the more useful it is for breeders wanting to use that germplasm. The quality of germplasm characterisation was mentioned as one of the major problems with some genebanks and this prevents greater commercial use of genebank resources. Preliminary evaluation data may include information on basic agronomic characters such as maturation time, plant height, percent germination and disease resistance. Breeders can devote intensive breeding efforts to only a small number of accessions, so information which allows breeders to identify accessions with the greatest potential is critical. Increased availability of this information would augment use of genebank material.

It is not solely the responsibility of institutions with genebanks to acquire these data. The dominant users of germplasm are both private and public plant breeders. Dr Donald Duvick has emphasised that the plant breeding and gene resource communities must cooperate in the provision of financial, organisational and practical stimuli to gather these data.

Of the breeders that use genebank germplasm in breeding programmes and who feel in a position to evaluate the quality of characterisation, 92% find that genebanks provide sufficient information regarding the geographical origin of plants. This type of information is the most developed (Fig 4.9). On the other hand, only half of the breeders feel that genebanks have sufficient information regarding the phenotype (the physical characteristics) of plants. Less than 15% of breeders consider that sufficient information regarding the genotype (a particular combination of genes) of plants is provided (Fig. 4.9). It is far easier to grow out seed in order to describe phenotypes, which are clearly visible, than to identify the genetic make-up of plants. Because some genes are recessive and their existence cannot easily be ascertained, genotypic characterisation would require resources not currently available.

Figure 4.9 Replies to the question "Do gene banks have/give sufficient information regarding the following:"?



Only 25% of breeders found that the genebank institutions had sufficient information regarding problems currently being encountered in commercial agriculture (Fig 4.9). In effect, institutions with genebanks are not seen consciously developing their germplasm collections to meet the current needs of breeders. Given the severe resource constraints on genebanks, it is difficult to even maintain the viability of the collections, it is hardly surprising that resources are not allocated to programmes targeted at the particular problems of commercial breeders.

Fifty percent of the breeders support, financially or technically, the testing/and or enhancement of germplasm maintained within genebanks. Breeders contribute to the maintenance of germplasm by multiplying accessions and by taking part in evaluation programmes. Some breeders fund genebanks directly (although none of those included in this report do so). On the other hand, some breeders regard the support of genebanks to be strictly a governmental responsibility and see a clear division of labour between public institutions and commercial breeders.

4.3.8 Biodiversity and Agriculture

Breeders were asked for their opinion about the impact of the Convention on Biological Diversity on their work. Their answer to this question was either negative, or not given, implying either that the convention was seen to have little relevance to their work, or that they were unaware of the implications of the convention. There was a general agreement that breeding activities increased genetic diversity in agriculture, but that little impact was made on nature.

4.4 SUMMARY AND CONCLUSIONS

The survey results from the plant breeder/seed industry provides a portrait of biodiversity reliance that fits the description provided in the initial sections of this paper. The stock of germplasm relied upon by society for the maintenance of its agricultural system may be seen as a continuously eroding asset. Research and development is constantly required in order to maintain the current production system against the forces of biological invasion; this is what the industry terms research into `resistance' and `stress'. The industry reports that the viability of any given product is only about five years, with pests and disease being primary factors for the obsolescence of the product.

In order to combat these biological forces for the erosion of the system, the industry continues to perform research on the development of resistance. In order for this research to take place (and to provide the raw materials for the new resistant strains) a stock of germplasm must be maintained for reference. The industry cannot merely resort to the same stock of biological material for an indefinite period of time, as there would be insufficient variety to provide resistance to the wide range of invaders. Instead, the industry must provide infusions of new genetic material in order to maintain adequate diversity to preserve the existing equilibrium.

The primary result of this study is that the industry's current rate of utilisation of diverse germplasm indicates a rate of required injection in the order of 7-8% p.a. of the germplasm base. That is, at present rates of replacement, the plant breeder/seed industry is totally renewing the stock of germplasm in use over a period of about 10-15 years. If this is indicative of the rate of depreciation of the existing germplasm pool (i.e. if this rate of injection is necessary in order to forestall substantial losses of agricultural product), then the loss of a pool of diversity from which to draw new characteristics would be disastrous in the near term.

The figures supplied by the eighteen companies that responded to the questionnaire demonstrated, not unexpectedly, that the vast majority of germplasm utilised in breeding programmes comes from existing cultivars, from genebanks. However, the fact that the majority of those that responded used some wild material, even if this represented a very small percentage of the total germplasm incorporated, demonstrates the vital role that such material plays, given the relative difficulty of incorporating wild material.

Additionally, it is clear that some of the value of wild material is continuously used through the storage of `once wild' genetic material in commercial cultivars. However, it is difficult to assign a value to these repeated accessions to genetic material that is incorporated in commercial cultivars. By the perceptions of the plant breeders, it is clear that such repeated accessions are not considered re-use, nor a valuable source of wild germplasm.

Comments from the breeders demonstrated that, in general, they were not prepared to pay more for germplasm maintained in *in situ* conservation areas than for *ex situ* genebank material. However, it was noted in several instances that such conservation areas were of vital importance, and that they should be supported by government funds.

This situation is partly the result of the view of genebanks (the other major source of `exotic' genetic material) as a public resource, which the industry can use at a very low cost. This is also evidenced by the division in opinion regarding the adequate involvement of breeders in genebanks, while less than half of them support genebanks, the rest considers them a government responsibility.

The technological developments in the industry seem to indicate that new techniques are unlikely to become a substitute for the use of wild material. However, they may enhance the potential benefit of wild material by reducing the difficulties in breeding and transference of desired traits from wild to existing domesticates.

Overall, the survey results show that biodiversity plays an important part as a source of new information to the plant breeding industry. This information is refined and exploited in subsequent phases of research. However, the breeders themselves do not appear to recognise the importance of the world's biological diversity.

Industrial Reliance on Biodiversity

This study provides an assessment of the extent to which industry in the developed world relies on biodiversity as a primary input. The first section of the report reviews the direct consumptive use of wild species for food, fur, skin or other products and compares these with the two main industries in this field, fisheries and forestry. The remaining sections examine two specific industrial inputs: the use of wild genetic resources in plant breeding and the use of substances derived from the wild in the pharmaceutical industry. The project was funded under the UK Government Darwin Initiative.

The **WCMC Biodiversity Series** presents the results of projects carried out by the World Conservation Monitoring Centre, often in partnership with other organisations. This series is focused on providing support to the Parties to the **Convention on Biological Diversity**, helping them to identify and monitor their biodiversity, to manage and apply information on biodiversity effectively and to exchange information. The WCMC Biodiversity Series **General Editor** is Mark Collins, Chief Executive of the World Conservation Monitoring Centre.

Other titles in the series:

1. Biodiversity Data Sourcebook
2. The Biodiversity Clearing House - Concept and Challenges
3. Priorities for Conserving Global Species Richness and Endemism
4. The Diversity of the Seas: a regional approach
5. Assessing Biodiversity Status and Sustainability
6. Biodiversity Conservation in the Tropics

The **World Conservation Monitoring Centre**, based in Cambridge, UK, was established in 1988 as a company limited by guarantee with charitable status. WCMC is managed as a joint venture between the three partners in the World Conservation Strategy and its successor Caring For The Earth: IUCN - The World Conservation Union, UNEP - United Nations Environment Programme, and WWF - World Wide Fund for Nature. WCMC provides information services on the conservation and sustainable use of the world's living resources and helps others to develop information systems of their own.

IUCN The World Conservation Union UNEP WWF

WORLD CONSERVATION MONITORING CENTRE

Further information is available from
World Conservation Monitoring Centre
219 Huntingdon Road
Cambridge CB3 0DL, United Kingdom
Tel: +44 (0)1223 277314
Fax: +44 (0)1223 277136
Email: info@wcmc.org.uk

WORLD CONSERVATION PRESS

ISBN 1 899628 06 1