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A methodological model for ecogeographic surveys of crops

L. Guarino, N. Maxted and E.A. Chiwona

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for ecogeographic surveys of crops

L. Guarino, N. Maxted and E.A. Chiwona, editors

Introduction to the Series

The Technical Bulletin series is targeted at scientists and technicians managing genetic resources collections. Each title will aim to provide guidance on choices while implementing conservation techniques and procedures and in the experimentation required to adapt these to local operating conditions and target species. Techniques are discussed and, where relevant, options presented and suggestions made for experiments. The Technical Bulletins are authored by scientists working in the genetic resources area. IPGRI welcomes suggestions of topics for future volumes. In addition, IPGRI would encourage, and is prepared to support, the exchange of research findings obtained at the various genebanks and laboratories.

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Introduction

An ecogeographic study is the process of obtaining, collating and analysing different kinds of existing data pertaining to a taxon within a defined region (Maxted et al., 1995). Such a study—validated, refined and complemented by subsequent exploration and other fieldwork—is generally seen as an essential first step in the development of a comprehensive strategy for the conservation and use of plant genetic resources. Before sensible conservation decisions can be made, a basic understanding of the taxonomy, genetic diversity, geographic distribution, ecological adaptation and ethnobotany of a plant group as well asof the geography, ecology, climate and human communities of the target region is essential. This kind of analysis will help to explore such key issues as when, where and how to collect germplasm; where genetic reserves might best be placed and how they would need to be monitored and managed; and the relative contribution of *ex situ* and *in situ* approaches to an overall conservation strategy.

The concept of ecogeographic studies was originally developed almost entirely in the context of conservation of wild plant gene pools. For example, an early IBPGR publication on the subject was specifically concerned with crop relatives (IBPGR, 1985). Herbaria were recognized as being repositories of the kinds of information that plant genetic resources programmes needed to develop sound conservation strategies. The study of herbarium specimens and the data recorded on their labels thus became the centrepiece of ecogeographic surveys. Perhaps because of this, the concept of ecogeographic studies has not been explicitly applied to crops in detail. After all, herbaria do not as a rule store much cultivated plant material. However, Maxted et al. (1995) stressed that the ecogeographic process was equally applicable to crop conservation. They pointed out that locality data can be obtained from germplasm accessions in gene banks (passport data) as well as from herbarium specimens in herbaria (label data). They added that botanists have been collecting herbarium specimens for centuries whereas the systematic collecting of germplasm has only been done for the last few decades.

In this paper we discuss how to adapt the methodology of wild plant ecogeographic studies when dealing with cultivated species. We will show that the model presented by Maxted et al. (1995), with a few changes in emphasis and detail, proves robust enough to be applied to crops.

An ecogeographic model

Maxted et al. (1995) and Maxted and Kell (1998) state that an ecogeographic survey consists of three phases, each made up of a number of distinct, though interlinked, steps.

Phase 1: Design the project

- Commission the project
- Identify taxon expertise
- Select target taxon taxonomy
- Delimit and characterize the target region
- Identify taxon collections

Phase 2: Collect and analyze data

- Inventory conserved germplasm
- Collate data from taxon collections
- Survey other sources of information
- Analyze the data

Phase 3: Generate ecogeographic products

- Ecogeographic database, conspectus and report
- Identify conservation priorities

These steps, and how they differ when studying a crop as compared to a wild plant taxon, are discussed below. Because of the difficulty in generalizing about a methodology that could be applied to anything from a weedy species used as a leafy vegetable to a semi-domesticated fruit tree to a staple crop, and from a country's province to a sub-continent, the approach taken here is to present options with detailed examples whenever possible. Although examples are taken from various sources, a particular focus has been placed on various countries in southern and eastern Africa. An attempt was made to review both on-line information sources and conventional literature.

Phase 1: Design the project

Commission the project

The first step in any ecogeographic study is to commission the conservation activity. This should be laid out in the form of a statement such as the example below.

> The Malawi Plant Genetic Resources Centre is to carry out an ecogeographic survey for *Sorghum bicolor* (L.) Moench in Malawi. The survey has the dual objectives of identifying areas that contain novel genetic diversity not already conserved that could be utilized in selection or breeding programmes for the benefit of Malawian agriculture and helping ensure the conservation of Malawian sorghum diversity for future generations. The ecogeographic report should contain a detailed discussion of various potential conservation strategy options for the crop, including collecting routes, timing and suitable regional contacts and whether on-farm conservation is appropriate. It should also attempt to identify any accessions of immediate and medium-term potential value to Malawian agriculture that are not currently being utilized.

The commission statement should set out the objectives of the work and its scope with regard to the taxon and geographic area to be investigated, and whether a brief survey, or in-depth study, is to be undertaken. It should also outline some specific requirements as well as link conservation and the use of crop diversity.

Identify taxon expertise

The criteria used in selecting a researcher for the ecogeographic survey should be carefully considered. For a wild plant survey, the researcher must have at least a basic knowledge of the target taxon as there may be difficulties in the taxonomic identification when dealing with some wild plant groups. Ideally a specialist with the appropriate botanical skills should be selected. For a crop survey, familiarity with documenting, interpreting, and using genetic diversity at the infra-specific level is more important than classic taxonomic expertise. A plant breeder, or an agronomist with experience in the target gene pool, could carry out a crop plant ecogeographic survey.

Maxted et al. (1995) advise consulting taxonomic experts within the target region with a specialization in the target taxon (which could be a genus, section, or species) at an early stage of the ecogeographic survey. The researcher carrying out an ecogeographic study of a crop species should also contact botanists, in particular for information on wild/weedy relatives. They will be able to give advice on such important topics as the currently accepted taxonomy of the target group, any taxonomic problems or controversies, obscure sources of information, and the location of important collections. One can identify taxonomic experts by looking at the authorship of relevant scientific publications, by asking botanists at local herbaria, by consulting the *Plant Specialist Index* (Holmgren and Holmgren, 1992) and/or through various Internet resources, e.g. the Taxacom discussion group (contact: listserv@USOBI.ORG). For a full list of Internet resources in botany, see the *Internet Directory for Botany*[1].

However taxonomists may not necessarily be helpful in supplying information about the genetic level of variation within cultivated species. The insights of genetic resources collectors, agronomists, pathologists and breeders working on the target crop in national agricultural research systems, universities and the relevant international agricultural research centres can be more helpful in this respect. These germplasm users will be able to provide advice on the perceived gaps in existing collections, constraints in the use of collections, regions known or suspected to harbour interesting germplasm, and what traits to look for and pay particular attention to when in the field. These experts can be identified through scientific publications (see Phase 2, *Survey other sources of information on the taxon* for bibliographic sources) and specialized databases and directories. Specialized institutes and centres such as those of the Consultative Group on International Agricultural Research (CGIAR) are important sources of expertise and information on their various mandate crops. Global and regional crop-specific networks could also be approached for information on how to contact relevant experts, especially as they bring together conservationists and users of genetic resources. The International Plant Genetic Resources Institute (IPGRI) maintains information on plant genetic resources expertise worldwide and occasionally produces specialized directories, an example being the one of researchers and development workers with an interest in African traditional vegetables[2], while the International Network for the Improvement of Banana and Plantain (INIBAP) has published a *Banana and Plantain Directory of Researchers* (Arnaud, 1994).

Genebanks routinely plan and carry out their germplasm collecting in collaboration with breeders, pathologists, and other crop experts. These are after all their main ’customers’. District agricultural officers, extension agents and rural development workers could also take part in the planning process. Extension agents are regularly co-opted by collecting teams in the field to act as guides and go-betweens with the local communities. They could usefully be involved in the whole process much earlier, i.e. in the ecogeographic survey work as well. In particular, they could help identify communities where landraces are still grown, or where there is imminent threat of genetic erosion.

Individuals working in rural development projects in the target region, whether for non-governmental organisations (NGOs), governmental, or international agencies, can also be important information resources. Some countries have national registers and published directories of NGOs working in different fields. Various agencies are creating databases of NGOs; for example, IPGRI has supported the compilation of a directory of NGOs working in plant genetic resources conservation in Africa. The Electronic Development and Environment Information System (ELDIS), which is funded by Danida and hosted by the Institute of Development Studies, Sussex, UK, is a gateway to on-line information on development and the environment. It provides information on NGO directories[3]. The Development Gateway also has information on NGOs[4].

Finally, social scientists with experience in the target region can be useful sources of information on farming systems and crops. As a first step, the ecogeographer should consult sociologists and anthropologists working in the relevant departments of local universities. There is a growing network of international, national, and regional Indigenous Knowledge Resource Centres that can be contacted for advice on accessing relevant information and expertise. A list is provided on *the Netherlands Organisation for International Cooperation in Higher Education (Nuffic)* Internet[5] site and also in each issue of the network's newsletter, *Indigenous Knowledge and Development Monitor*. The *Monitor* itself is available on the Internet[6]. Social scientists with expertise in a specific region or crop(s) can also be identified through their publications and through international professional associations such as the Rural Sociological Society (RSS)[7] and the Association of Farming Systems Research-Extension. RSS has a directory listing members alphabetically, by geographical region and by area of competence. Specialized directories may also be available, for example, *A Register of Social Scientists in Eastern and Southern Africa* (OSSREA, 1994).

Women play key roles in the management of many crops. As such, female members of home economics or community development departments could be involved in the planning process and in the field. Expert sources with a specific understanding of gender-related issues include the Association of Women in Development, the International Federation of Women in Agriculture, the Associated Country Women of the World, and the Women in Rice Farming Systems Network. The Development Gateway, an interactive portal for information and knowledge sharing on sustainable development and poverty reduction, has a section on Gender and Development[8]. The School of Development Studies at the University of East Anglia, Norwich, UK, web site has list of other gender links[9].

In addition, comprehensive listing of Internet resources in anthropology is available on the Vanderbilt University web site[10].

Box 1 provides sample lists (not exhaustive) of the kinds of experts that could be consulted for advice by the national genebank during the planning stages of an ecogeographic study of finger millet in Kenya and common beans in Zimbabwe (George Mahuku, pers. comm.).

Box 1 – Examples of possible sources of expertise on crops

Sources of information on finger millet in Kenya

1. Gramineae botanist - East Africa Herbarium, National Museums of Kenya, Nairobi
2. Breeder, agronomist, pathologist, economist – National Agricultural Research Centre, Kenya Agricultural Research I
3. Staff of Regional Research Centres in finger millet growing regions, e.g. Kakamega
4. District and Divisional Agricultural Officers in finger millet growing areas
5. Field extension officers in finger millet growing areas
6. NGOs active in finger millet growing regions, e.g. Organic Matter Management Network in Western Kenya
7. ICRISAT Regional Office, Nairobi
8. IPGRI Regional Office for Sub-Saharan Africa, Nairobi

Sources of information on common bean in Zimbabwe

1. Bean breeder, legume agronomist, legume pathologist, legume entomologist - Department of Research and Specialist Services (DR&SS), Harare
2. Pathologist, virologist, agronomist, breeder, entomologist - Department of Crop Sciences, University of Zimbabwe, Harare
3. Commercial Farmers' Union (CFU) and the Oil Seeds Producers' Association
4. AGRITEX (extension branch of Ministry of Agriculture)
5. NGOs such as COMMUTECH and ENDA-Zimbabwe
6. CIAT bean programme staff in Kampala, Uganda (Pan-Africa Bean Research Alliance)

Select target taxon taxonomy

One of the first steps when carrying out an ecogeographic survey of a wild plant group is to set taxonomic limits to the study and provide a solid nomenclatural foundation. This can be done by consulting experts, recent revisions, monographs, floras and databases. Using the multi-purpose shrub *Sesbania sesban* and its relatives in Malawi as an example, Lock's *The Legumes of Africa. A Checklist.* (1989), the accounts of the genus in *Flora Zambesiaca*[11], and *Flora of Tropical East Africa* [12] would be logical starting places. Lock's checklist is also available on the International Legume Database and Information Service (ILDIS)[13] LegumeWeb database. Additional references can be identified from these publications and databases, from specialized bibliographies (e.g. Agishi and Heering, 1991) and from bibliographic databases such as *PlantGeneCD*. Prendergast (1995) reviews the methodology for identifying relevant taxonomic and ecological literature.

The problem is somewhat different for crops. Nomenclature, botanical identification and species boundaries usually are not significant issues for crops, though that does not mean that some aspects may not be controversial for some crops. More important is an understanding of morphological, agronomic and genetic variation within the crop. The pattern of variation within cultigens caused by the activities of farmers is often quite different from that found in wild species (Harlan, 1975).

The infra-specific taxonomies that have been developed for crops and their wild relatives range from complex hierarchical classifications to non-structured, special purpose schemes (Hanelt and Hammer, 1995). When a crop receives formal taxonomic treatment, the result is often over-classification (Harlan, 1975). For practical infra-specific classifications of crop taxa, classical herbarium taxonomists and their publications are not the sources to consult, although exceptions do exist, e.g. the *Flora of Cultivated Plants of the Soviet Union*. Zeven and de Wet (1982) and Schultze-Motel (1987) are useful resources on crop taxonomy and evolution. The staff at the Institute of Plant Genetics and Crop Plant Research (IPK) published a series of reviews on crop taxonomy and evolution from 1978 to 1993 (for a list, see Hanelt et al., 1993); *Plant Genetic Resources Abstracts* (CD-ROM version, *PlantGeneCD*) now contain this information.

Box 2 summarizes the history of infra-specific classifications of cultivated sorghum as an example.

Delimit and characterize the target region

Maxted et al. (1995) strongly recommend that an ecogeographic study of a wild taxon should be as geographically inclusive as possible to increase its predictive value. Ideally, it should encompass the entire area of distribution of the target taxon, or at least an area that is floristically well defined. Thus, our conservationist in Malawi developing a strategy for *Sesbania* would ideally document information on intra-specific variation, distribution etc., from

Box 2 – The taxonomy of cultivated sorghum: Results of a literature search

Snowden's (1936) treatment, the first major attempt to classify cultivated sorghums, recognizes 31 species, 158 varieties and 523 forms. Clearly much too cumbersome, this classification was revised by de Wet and Huckabay (1967). They recognized just 4 races within the cultivated grain sorghums. This was followed by the treatments of Harlan and de Wet (1972) and de Wet (1978), which divided the cultivated taxon (*Sorghum bicolor* subsp. *bicolor*) on the basis of spikelet morphology into 5 basic races (*guinea, kafir, durra, caudatum* and *bicolor*) and 10 intermediate races (*guinea-kafir, durra-caudatum* etc.). They also recognized 9 head types, showing some limited measure of correlation with spikelet morphology. According to the maps provided by Harlan (1975) and Harlan and Stemler (1976), the races *bicolor, guinea, kafir* and (possibly) *caudatum* (plus various intermediates among these) are found in Malawi. These different classifications are summarized and compared by Acheapong et al. (1984).

More recently, the classification of cultivated sorghum into 5 basic races, and the diagnostic power of spikelet characters, were largely confirmed by multivariate analysis of morphological and physiological characters (Chantereau et al., 1989). Only the races *kafir* and *caudatum* could not be adequately separated. In contrast, a study of isozyme polymorphism (Ollitrault et al., 1989) revealed a diversity continuum organized around 3 geographical groups, rather than morphological races: (1) mainly *guinea* types from West Africa; (2) *guinea, kafir, durra-caudatum* and *bicolor* types from Southern Africa; and (3) *durra* and *caudatum* types mainly from Central and East Africa. These results are supported by the isozyme work of Morden et al. (1989). More recently still, however, RFLP studies (Chantereau et al., 1994) have tended to support the racial classification based on spikelet morphology. The *bicolor* and *guinea* races in particular showed considerable variation at the molecular level.

the whole of sub-Saharan Africa. However, if consulting herbaria outside the immediate sub-region were to prove impossible given the resources available, the study could also be limited to White's (1983) Zambezian regional centre of endemism.

Hardcopy and digital maps are crucial to both the ecogeographic study and the subsequent fieldwork. The key mapping reference is *World Mapping Today* (Parry and Perkins, 2000), which provides listings of current topographic and resource mapping on a country-by-country basis and describes the organization and structure of national mapping activities. For example, Parry and Perkins (2000) reproduce much of the information in the *Catalogue of Maps* available for Kenya. This catalogue describes the various maps produced by, or that are available through, the Survey of Kenya, the government department responsible for mapping. The maps listed include small-scale road maps of the whole country, maps of national parks, various thematic maps (e.g. soils), a series of topographic maps at 1:250,000 and 1:500,000 and aerial photographs. These maps (with the exception of the topographic maps and aerial photographs) can be obtained from the Public Map Office in Nairobi, or through the Survey Offices in seven other major cities. Topographic maps and aerial photographs are available for sale only with the permission of the Director of Surveys. The Survey maintains an Aerial Photographic Library in Nairobi, Kenya, where photographs may be inspected and ordered. The *Catalogue* also lists the addresses of a number of agents, both in Kenya and abroad, who can provide the listed maps.

National maps are also available in electronic form (possibly online), as in the case of maps of Namibia[14]. A useful directory of online geographic resources is available on refdesk.com[15]. In addition, the University of Texas at Austin, Perry-Castañeda Library Map Collection web site has lists of online country and regional maps[16] and a list of map dealers[17].

The distribution of crop production and diversity is often as dependent on people as on bio-geographic considerations. Indeed, a case can be made for using the term 'agro-geographic' for crop ecogeographic studies, to highlight the importance of the human dimension. For example, information on population density and the distribution of different cultural, or language, groups within the target region is very useful for defining strata for sampling. This information is often difficult to obtain and interpret as the distributions of cultural groups can be overlapping, inter-digitating and very dynamic, not to mention the fact that the definition of 'cultural group' is itself a complex issue. However, some information may be found in national atlases and similar sources (e.g. see Figure 1). A useful anthropological and ethnographic resource is the *Atlas of World Cultures* (Price, 1990). This atlas has a set of maps with the locations of some 3,500 human cultures in addition to an alphabetical index of the

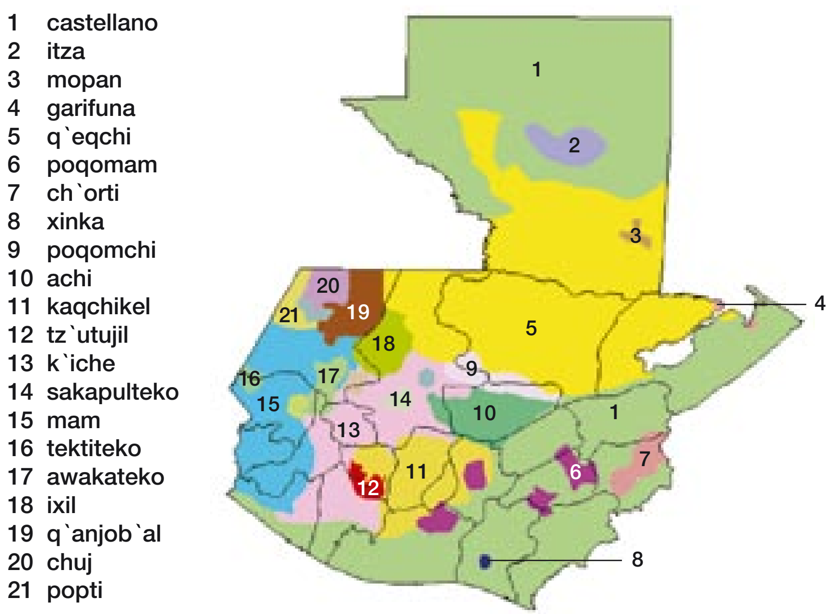

Figure 1. Geographic distribution of the languages of Guatemala. The maps were digitized from a poster (Castillo, 1997).

anthropological and ethnographic literature on each particular group. The SIL International (formerly known as the Summer Institute of Lingustics) Ethnologue website[18] has clickable country maps with language distributions.

Agro-climatic classifications (Box 3) can also be used to delimit and sub-divide the target region for the purpose of stratified sampling. Numerous attempts have been made to classify climate on a global, or regional, basis by combining a range of climatic parameters in some kind of synoptic model. A list of the major classification schemes is given by Young (1987).

- The Köppen (1936) classification, based on mean annual and mean monthly rainfall and temperature
- The Holdridge (1967) life zones system, based on potential evapotranspiration ratio
- The Food and Agriculture Organization of the United Nations (FAO) and International Institute for Applied Systems Analysis (IIASA) (1978-81) agroecological zones (Global - AEZ)[19] system, based on temperature during the growing period, length of growing period and seasonality of rainfall
- Emberger's (1955) classification of Mediterranean environments, based on mean annual rainfall, mean minimum temperature of the coldest month and mean maximum temperature of the warmest month (on a more restricted scale)

Box 3 – Agro-climatic classification of Malawi

Malawi has been divided into a number of agro-climatic regions (e.g., Appa Rao et al., 1989): (1) High-altitude plateaux; (2) High-altitude hills; (3) Tertiary erosion surface; (4) Rift Valley scarp; (5) Upper Shire Valley; (6) Lower Shire Valley. The Lower Shire Valley in the extreme south is low-lying (250 m above sea level), very hot and dry, receiving an average annual rainfall of 700-800 mm, most of it between mid-November and late March. The vegetation is semi-arid savannah and thicket and the main crops sorghum and cotton. The Upper Shire Valley and lakeshore lowlands are at 300-600 masl, hot and wetter in the north than in the south (average annual rainfall 800-1000 mm). Crops include rice, cassava and some maize. A scarp zone leads from these lowlands to the mid-altitude (800-1600 masl) plateau of the Tertiary erosion surface, covering 80% of the country and dominated by miombo woodland with maize, groundnut, tobacco, tea and coffee cultivation. The highland areas are generally isolated tracts rising to about 2000 masl, though Mulanje reaches 3000 masl. The higher altitude areas are mainly used for wildlife and forest conservation. Average annual rainfall varies from <1000 over 51% of the country to over 2500 mm at the highest elevations. The soils, climate and agriculture of the Lower Shire Valley (the main sorghum-growing area) are described in detail by Panje et al. (1987).

Young (1987) recommends the Köppen classification for broad site characterization and the FAO agro-ecological zones system for more specific site characterization. There are also various national systems in use, for example, Kenya's system of agro-climatic zones divides the country into seven regions based on the ratio of mean annual rainfall to mean annual potential evapo-transpiration and nine regions based on mean annual temperature (Kenya Soil Survey, 1982). The International Agricultural Research Centres (IARC) have been very active in agro-climatic and agro-ecological characterization, both of geographic regions and of the growing environments of specific crops (e.g. Carter, 1987). These data are usually available in digital form.

Figure 2 is an example of climatic classification for south-eastern Africa with the location of bean accessions derived from the System-wide Information Network for Genetic Resources (SINGER[20]) database shown superimposed. In addition, Young (1987) lists some major agro-climatic surveys of countries and regions while Martyn (1992) "…examines the climates of the continents and oceans, the continents being treated in considerable detail and the oceans more generally. Each section begins with a climatic review of the whole continent, followed by a detailed discussion of the climatic conditions of large countries or groups of smaller ones." (Publisher's blurb, 1992) The bibliography includes references to climatic atlases and other data sources. The World Meteorological Organization (WMO) also publishes a *Bibliography of Climatic Atlases and Maps*.

Soil is a significant determinant of distribution and production for some crops. Many different classification systems for soils are in use, ranging from local and national schemes to the international

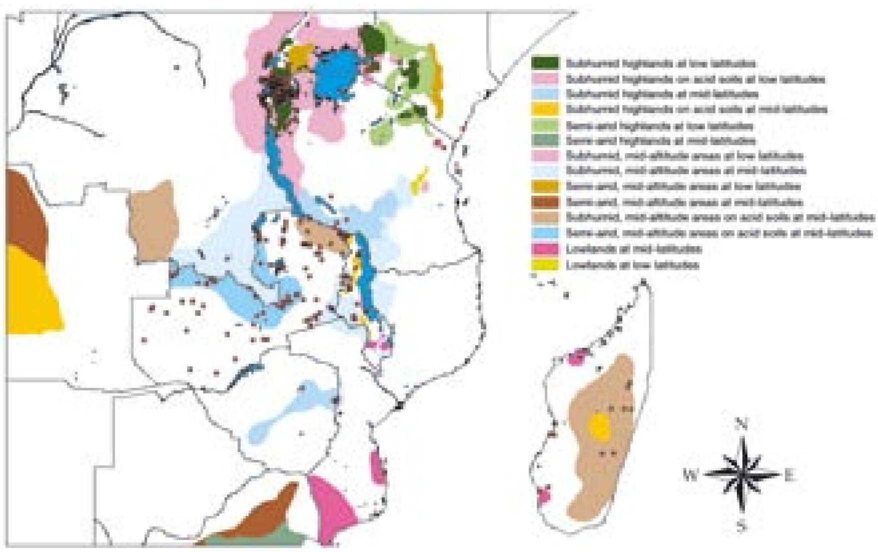

Figure 2. Bean production environments in east Africa.

classifications of FAO-United Nations Educational, Scientific, and Cultural Organization (UNESCO), the United States Department of Agriculture (USDA), and the Commission de Pédologie et de Cartographie des Sols (CPCS). The FAO system (FAO-UNESCO-International Soil Reference and Information Centre (ISRIC), 1988) was initially intended as a legend to the *Soil Map of the World*, but it is, in fact, a soil classification and has been widely treated as such (the map is available in digital form[21]).The US soil taxonomy (USDA, 1975) is widely used throughout the Americas, as is the CPCS (1977) system in Francophone countries. Many countries use their own detailed national classification systems, and publish national soil maps based on these systems, but increasingly such systems are congruent with international classifications. ISRIC[22] is preparing a worldwide digital database for soils and terrain on a scale of 1:1 million, converting existing soil maps to a common format.

Details such as soil profile, texture, depth and colour may be shown on the more detailed soil maps. Specialized soil degradation maps may show the level of salinity, the degree of soil erosion, the presence of toxic substances, fertility and structure decline etc. White (1983) reviews published soil mapping for Africa.

Identify taxon collections

In ecogeographic studies of wild species, the researcher will consult both herbarium and genebank collections of the target taxon. Appropriate herbarium collections can be identified using the New York Botanical Garden web-based *Index Herbariorum*[23] (Holmgren et al., 1990) and by asking experts.

Although there are a few herbaria that accept voucher material for cultivated species, or specialize in cultivated plants (e.g. the Vavilov Institute in St Petersburg, Russia), most have very little such material. The crop conservationist will therefore need to concentrate on genebank holdings for the raw ecogeographic data that will form the basis of the study. Information on genebank holdings worldwide is maintained in IPGRI's Germplasm Holdings Database[24], which is available on the Internet or from IPGRI offices worldwide, and in hardcopy crop germplasm directories[25] (for a list, see Perry and Bettencourt, 1995). It is possible to query this database, to find where specific material is currently being conserved (Box 4). The query findings will include national genebanks and those of regional and international institutes. IPGRI also maintains a separate database of collecting missions it has sponsored that includes an indication of where the material collected is conserved. This database is not available to the general public unless specifically requested. A list of

Box 4 – Conservation of sorghum germplasm from Malawi

The IPGRI conservation database shows that as of December 1993, when the data were last updated, 324 accessions of local sorghum landraces were stored at the Malawi Plant Genetic Resources Centre (MPGRC), duplicated at ICRISAT, at the US National Seed Storage Laboratory (NSSL) at Ft Collins, Colorado, USA and at the SADC Regional Plant Genetic Resources Centre (SPGRC) in Lusaka, Zambia. However, according to the latest information from the MPGRC, 116 accessions of sorghum are currently being held in Malawi, duplicated at SPGRC. These were collected during the course of two multi-crop missions sponsored by SPGRC. The Northern Region was explored in 1993 and the Southern Region the following year. The GRIN database revealed that 521 accessions are stored in the US system, the one with the lowest PI (Plant Introduction) number having been obtained in 1946.

The IPGRI collecting database shows that two missions sponsored by the Institute have collected cultivated sorghum in Malawi. These were carried out in 1979 and 1980 by the country's Department of Agriculture and Natural Resources in collaboration with IBPGR and ICRISAT. A total of 483 sorghum accessions were collected and stored in Malawi, with duplication at ICRISAT and NSSL. The SINGER database shows that 403 sorghum accessions from Malawi are conserved at ICRISAT, collected in 1979 and 1983.

IPGRI's online databases can be accessed by visiting the Institute's web site.[26] The updating and collation of *ex situ* germplasm holding data is done in close collaboration with FAO. In addition, FAO's World Information and Early Warning System on plant genetic resources (WIEWS)[27] provides similar data. Synchronization of common data types is achieved through bi-monthly data exchange.

Similarly, SINGER[28] provides access to information on the collections of genetic resources held by the CGIAR Centres. The CGIAR collections comprise over 500 000 samples of crop, forage and tree germplasm of major importance for food and agriculture. SINGER allows simultaneous searches of the genetic resources databases for information concerning the identity, source, characteristics and transfer of genetic resources in the individual Centre collections. Passport, characterization and evaluation data on the CGIAR collections are also available on SINGER.

Even if the target of conservation is exclusively cultivated material, the crop ecogeographer should consider gathering information on the wild/weedy relatives found in the target region, if any. This may well mean locating and visiting herbarium collections to complement the information gathered from genebanks.

Phase 2. Collect and analyze the data

Inventory conserved germplasm

Once the relevant germplasm collections have been identified, it will be necessary to contact, or visit, the relevant conservation institutes to obtain more detailed information on their holdings. Genebanks often publish basic data on germplasm holdings in catalogues, and most have computerized documentation systems with some publishing their databases on the Internet. Examples of national genebanks and crop networks that make germplasm data available on the Internet are the European Cooperative Programme for Crop Genetic Resources Networks[29] (ECP/GR) and the US National Plant Germplasm System (NPGS) Genetic Resources Information Network (GRIN) database[30].

In ecogeographic surveys of wild taxa, the first step in data analysis is to document the range of diversity currently being conserved, either *ex situ* or *in situ*. One can then compare this with the overall diversity of the target taxon as shown by analysis of ecogeographic data from herbarium collections. Such collections will usually be considerably more extensive and complete than germplasm collections, hence the comparison should highlight geographic, ecological, taxonomic and genetic diversity gaps in the germplasm collections.

In studies of a cultivated species, this comparison will not be possible. However, the crop conservationist will still be able to make listings of the germplasm conserved in genebanks and of on-farm conservation projects involving the target taxon, as is done for sorghum in Malawi in Box 4. The process of extracting ecogeographic data from such sources is described in following section. However, the comparison will be not with data from herbarium collections, but from other sources as described in *Survey other sources of information on the taxon*.

Care must be taken when interpreting information on current genebank holdings (Maxted et al., 1995). The quantities of germplasm available could be misleading in that genebanks typically duplicate their holdings, so the total number of accessions held around the world can give a false impression of the genetic diversity conserved. Although accessions may be held in a genebank, the material may not be available to potential users for various reasons, and so create a false impression of the conservation status of the crop. Finally, material collected in the past may have deteriorated in storage, or it might not have been originally collected according to present recommendations aimed at capturing genetic diversity.

Collate data from taxon collections

The crop conservationist's reliance on genebank collections for accession-specific ecogeographic data is both an advantage and a disadvantage. Most genebanks are relatively new institutions and their records tend to be more fully computerized than those of herbaria. This makes the retrieval of accession-specific data much easier than the laborious transcribing or keying-in of herbarium label data that ecogeographic studies of wild plants usually entail. On the other hand, unless the material is in a field genebank, or happens to have been planted out (e.g. for multiplication), or is accompanied by voucher specimens kept in the genebank's herbarium, conservationists will not be able to familiarize themselves with variation within the target taxon in the way that is possible after several days of looking at herbarium sheets.

Three categories of accession-specific data on germplasm holdings will be relevant to a crop ecogeographic study: passport, characterization and evaluation data.

Passport data is comparable to the herbarium label data that is the centrepiece of ecogeographic studies of wild species. This data is recorded in the field by the collector on 'collecting forms'. Though collectors often use their own specialized forms, many institutes around the world use the IPGRI collecting form, or adaptations thereof. The kinds of data that collectors generally record in the field for individual accessions of crop landraces include (Moss and Guarino, 1995):

- Name(s) of collector(s) and collecting number
- Collection date
- Taxonomic identification
- Brief (perhaps diagnostic) morphological description using standardized characterization descriptor list
- Vernacular names of crop and of landrace (with original language)
- Source of sample (field, store, market etc.)
- Description of sampling method used
- Locality name (include latitude/longitude, if possible)
- Name of farmer
- Ethnic, or language group of farmer
- Agro-ecological zone
- Altitude, slope and aspect
- Soil type
- Farming system, including rotation and inputs used
- Dates of sowing and harvesting
- Source of planting material
- Uses
- Farmer's selection methods

Often, collectors also record their observations on such aspects of phenotypic variation as the presence of interesting morphological variants and the incidence of pests and diseases symptoms. They may also record any comments the farmer made about the accession, for example its tolerance to drought or frost, susceptibility to pests and diseases, or length of growth cycle (Box 5). Such data is a form of characterization and evaluation of the material, akin to making observations on morphological features of herbarium samples during ecogeographic studies of wild species. These comments

Box 5 – Information on sorghum in Malawi from germplasm collections

There are various reports on the 1979 (e.g., Appa Rao, 1979; Denton, 1979; Denton and Appa Rao, 1979) and 1980 multi-crop collecting missions to Malawi (Arora, 1980). These reports include a description of the target region, a schedule of activities and itinerary, summaries of the material collected and maps of collecting localities. Passport data pertaining to the accessions collected during these two missions are available from IPGRI and ICRISAT, and characterization/evaluation data from ICRISAT. An analysis of some characterization data has been published by Obilana et al. (1996). Some of the main observations are summarized below.

Distribution. Sorghum (called 'Mapila' in Chichewa, 'Chidomba' in Tumbuka) was collected from throughout the country, but the crop was particularly common –and variable –in the lowlands along the eastern shore of Lake Malawi (the areas of Salima, Mangochi and between Chiradzulu and Phalombe) and in the Shire Valley. There was less sorghum cultivation in the high-rainfall zone of the north of the country, and also less variation within the crop.

Phenology. The main rains occur between December and April in Malawi, the rainy season generally being somewhat later in the north. Collecting therefore took place in mid-March to mid-April in 1979, commencing in the Shire Valley and progressing northwards, with a second visit to the south for later-maturing landraces. In 1980, collecting took place in May.

Variation. Collectors commented that most landraces were tall, late-maturing *bicolor* types, with some *durra* and *guinea* forms and some hybrids among these (note that the *caudatum* race was not observed, though the landrace 'Masotongo' was classified as *durra-caudatum*). However, a subsequent characterization trial involving 224 accessions from Malawi revealed that some 90% of the material could be classified as guinea or its hybrids, most of the rest being *caudatum*. There was only 1 *durra* and 3 *bicolor* accessions (Obilana et al., 1996). Most fields consisted of mixtures of landraces. Weedy introgression products with *Sorghum verticilliflorum* were also collected ('Nguyu', 'Nkhundi', 'Gugu'). Variation was noted in plant height, tillering, culm thickness, leaf size, nodal length, head size and shape, grain size and colour, glume size and colour, shattering tendency, endosperm texture and palatability. Landraces from the Shire Valley were earlier maturing than ones from higher elevations, which were daylength sensitive. Landraces may be divided into grain (large, loose, droopy panicles; white, corneous, sweet endosperm), beer (red-brown, astringent, starchy endosperm) and chewing types, though some are dual-purpose. Grain was used to make stiff ('Msima') or thin porridge ('Chigodo') or eaten raw ('Mapira awisi'). Arora (1980) records some 13 names of landraces which are distinct morphologically or in terms of use, while Denton (1979) records 17. Interestingly, only 3 names occur on both lists. Some landraces were confined to relatively restricted areas, others were more widely distributed. It seems that 'Thengalamanga' is the most common landrace in the Shire Valley; it is often used as a local check in variety trials (Chintu et al. , 1996). Short descriptions of most landraces are provided by the collectors (see Box 7 for examples).

Genetic erosion. The implementation of an effective national agricultural extension programme was seen as the major threat to landraces of sorghum. This has increased awareness and availability of HYVs, for example Red Swazi, Sereno, Barnard's Red and several hybrids. It was also recorded that introduction of new crops was increasing, with large areas being given over to industrial crops.

need to be verified by the genebank and users such as breeders in formal on-station and on-farm trials. This is particularly true for evaluation descriptors that are, by definition, more prone to environmental influence.

Formal characterization and evaluation is often carried out by following standardized 'descriptor lists'. These are published by IPGRI for a wide range of crops (for a list, see Perry and Bettencourt, 1995[31]). Increasingly, a number of molecular techniques are being used to characterize germplasm at the DNA level, supplementing and complementing more conventional morphological, physiological and biochemical approaches.

As already mentioned, genebanks commonly publish germplasm catalogues listing passport, characterization and evaluation data. In addition, the data is usually computerized. However, genebanks do not necessarily use the same, or even compatible, database management systems, data structures, coding systems etc., though the existence of widely used collecting forms and descriptor lists means that this problem is not as great as it might be. In any case, an ecogeographic study of a crop covering several countries and a number of different genebank collections may well require that the conservationist build a purpose-designed database to copy and collate the data provided by different genebanks.

Some of the problems of data quality identified by Maxted et al. (1995) for herbarium labels are also present in germplasm passport data, though to a much lesser extent due to the fact that genebanks are generally relatively new institutions. Data may be missing, especially latitude/longitude, ecological (e.g. altitude, soil type etc.) and ethno-botanical data, including indigenous knowledge pertaining to the germplasm. It may be possible to infer some features of collecting sites from locality data by utilizing appropriate thematic maps (e.g. agro-ecological zonation, topographic, geological, soil etc.), or by using GIS.

A gazetteer of local geographic names and localities will be very useful in locating collecting sites when latitude/longitude data is not available. Two good geographical dictionaries have been published recently, namely the Houghton Mifflin *Dictionary of Geography: Places and Peoples of the World*, with more than 10,000 entries, and Merriam-Webster's *Geographical Dictionary*, with more than 48,000 entries. However, the 1999 Columbia *Gazetteer of the World*, which contains 165,000 entries, including 30,000 new entries that reflect the dramatic changes in the world over the past 40-plus years, is probably the most comprehensive encyclopaedia of places and geographical features. An *Official Standard Names Gazetteer* is being compiled; country-specific volumes are available from the

US Board of Geographical Names. The *Atlas of the World* (Times Books, 1988) which contains a useful gazetteer would be the least expensive option and is easily obtainable.

Many Internet-based gazetteers exist, including the J. Paul Getty Trust Getty Thesaurus of Geographic Names,[32] which is the first automated global source of hierarchically arranged geographical data. It is comprised of records for approximately 900,000 places. The World Gazetteer web site provides a comprehensive set of population data and related statistics[33]. The United States National System for Geospatial-Intelligence (NSG) GEOnet Names Server[34] (GNS) has a facility for automatically assigning latitude and longitude to locality names (Hijmans et al., 2001). The geographic information system software, DIVA-GIS[35], includes a world gazetteer.

Herbaria and genebanks sometimes develop their own, unpublished gazetteers. Forman and Bridson (1992) list some problems that could be encountered in finding localities in gazetteers: (i) the name of the locality may have changed; (ii) political and administrative boundaries may have moved; (iii) a variant, or incorrect, spelling of the locality name may be used; (iv) the name may be common and, therefore, have more than one entry in the gazetteer. Local experts, as well as old maps, atlases and gazetteers, and even travel books, can be consulted for information on name changes (see also Room, 1979).

In some cases an effort will have to be made to reconstruct, at least in part, the collector's route by referring to mission reports, or the collector's field notebooks. Though these documents may prove time-consuming to decipher, they are often invaluable sources of information, complementing the raw accession-specific passport data with more general observations. Collecting reports are sometimes published in journals such as *Plant Genetic Resources Newsletter*, *Genetic Resources and Crop Evolution* and the crop-specific newsletters of the IARCs. IPGRI keeps copies of the reports of all institute-sponsored collecting missions. Collectors' field notes are often available in the library of their affiliated institute. These notes are often important sources of general information on crops and farming practices. If reports and notebooks are not available, it may be possible to tentatively estimate where a given specimen may have been collected by comparing its collection date and/or collection number with those of specimens whose localities can be recognised.

Survey other sources of information on the taxon

In an ecogeographic survey of a wild plant group, accession-level data from genebank collections (and possibly *in situ* reserves) and from herbarium collections are synthesized and compared. This is the analytical core of the study and is necessary if a coherent and comprehensive conservation strategy is to be developed. However, it must be backed up, supported and complemented by taxon-level information. This information, gleaned mainly from experts and the literature, includes distribution information, phenology, ecological adaptation, reproductive biology (pollination, breeding system, and dispersal), seed storage type, germination requirements, genotypic variation, biotic interactions (pests, pathogens, and herbivores), ethno-botany (e.g. vernacular name, local uses) and conservation status.

In a crop study, the accession-level data is only available from genebank collections (and possibly on-farm conservation projects). The conservationist thus needs data from other sources to develop a complete picture of the crop in the target region to compare with and complement the genebank data. Most of the types of data listed above for wild species will be relevant for crops, but the sources of the data will be very different. The crop ecogeographer will primarily need information on the following:

- Where the crop is grown in the target region;
- The phenology of the crop in different areas within the target region;
- The variation displayed by the crop with regard to characterization and evaluation traits;
- Major agronomic problems faced by the crop (e.g. drought, pests and diseases etc.);
- The contribution the crop makes to income and nutrition;
- How the crop is propagated, cultivated and used (including ritually) by the local populace (both genders);
- How genetic diversity is perceived, managed and maintained by farmers (e.g. folk taxonomy, selection, seed exchange etc.);
- The history of the crop in the target region;
- The threat of genetic erosion the crop faces (e.g. from modern varieties, socioeconomic change);
- The vernacular name(s) of the crop, and of different landraces;
- What wild relatives may be found in the target region.

Starting with general information about the geography of production, the *World Atlas of Agriculture* includes country monographs showing the distribution of major crops. Many countries also have national atlases that include, or specialize in, information on various aspects of agriculture, derived from sources ranging from agricultural censuses to remote sensing. A good example is *An Agricultural Atlas of Nigeria* (Agboola, 1979).

The results of agricultural censuses and household surveys may be published separately by the ministry of agriculture, and will probably be available in the reference library, or documentation centre, of the national agricultural research institute. The Technical Centre for Agriculture and Rural Cooperation (CTA) has co-published *Agricultural Information Resource Centres: A World Directory 1990* (Fisher et al., 1990) and a two-volume directory of *Tropical Agriculture Information Sources* (Keenan and Worteley, 1994). The statistics library at the FAO headquarters in Rome, Italy and the libraries of the IARCs are useful sources of this kind of data.

The methods of data acquisition used by Carter et al. (1992) and Wortmann et al. (1998) in their studies of cassava and common bean production in Africa respectively, may prove instructive. Two main repositories of up-to-date information were tapped by Carter et al. (1992), i.e., the FAO statistics library in Rome, Italy and the Economics Section of CIAT's Cassava Program. The sources used ranged from the *World Atlas of Agriculture* to more detailed national studies. For example, data for total annual production in 1982 for Chad was published in the 1984 edition of *Statistik des Aulandes*, a publication of the German statistics office. These data were converted to hectares using typical yields from a 1985 agricultural census in Mali. For distribution among prefectures, older data from a 1972/73 agricultural census were used. To obtain historical data, extensive searches of pre-independence literature were carried out at the Agricultural University of Wageningen located in The Netherlands; the African Library of Brussels, Belgium; the African Studies Centre at the University of Leiden, The Netherlands; the British Museum located in London, UK; and the Food Policy Research Institute at Stanford University located in Palo Alto, California, USA.

The data on bean production, cropping systems, genetic diversity, abiotic stress and pest/disease incidence in Wortmann et al. (1998) was derived from agricultural censuses, specialised surveys and crop experts. For example, the sources used for Malawi were the National Rural Development Programme of the Ministry of Agriculture for 1988/89; Agrostat files from FAO (1990-1993); and expert opinion.

Crop distribution and production data is increasingly available in digital form from national and international institutions. Such digital datasets can be manipulated, combined and analyzed using GIS. The meta-database of digital spatial datasets held by the CGIAR Centres[36] is a useful starting point. The data in Wortmann et al. (1998), for example, is available in digital form. By way of illustration, Figure 3 shows data on bean producing regions and varietal diversity in eastern Africa, including Malawi.

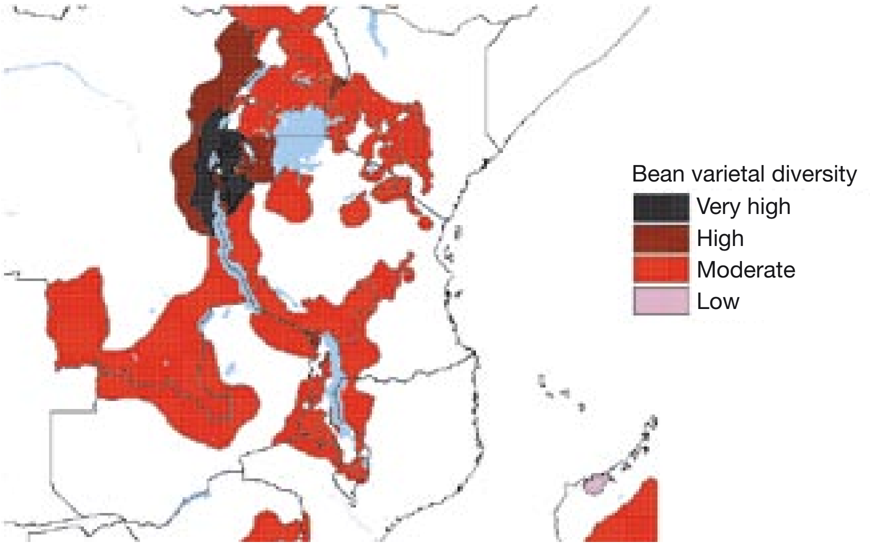

Figure 3. Bean production area in east Africa and varietal diversity (adapted from Wortmann et al. 1998).

Another example is CIP's web-based *World Potato Atlas*[37]. FAO's GeoWeb[38] can be used to display maps of major staples production, an example of which is provided in Figure 4 for sorghum and cassava in Malawi. The USDA Foreign Agricultural Service (FAS) CropExplorer website[39] also has crop production maps on a regional scale together with climatic information for Africa.

Another example of national-level crop production data in digital form is the Australian National University GIS database, Mapping Agricultural Systems in Papua, New Guinea

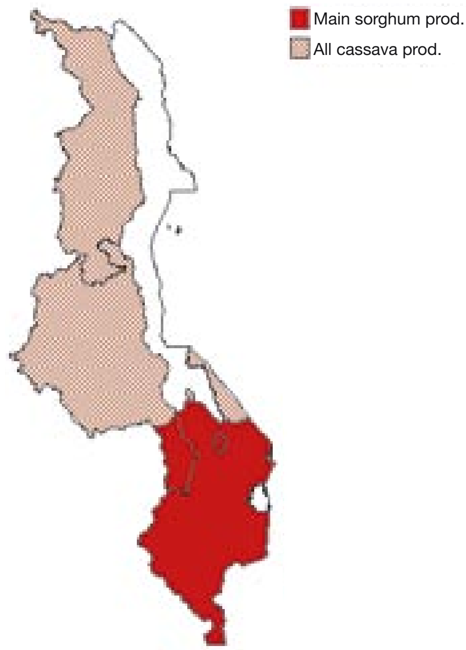

Figure 4. Sorghum and cassava production areas in Malawi according to the FAO Global Information and Early Warning System on Food and Agriculture.

Project[40] (MASP). As was done for the example shown in Figure 2 (beans in east Africa), Figure 5 shows the locality of taro accessions collected in Papua New Guinea superimposed on the areas of taro cultivation derived from the MASP.

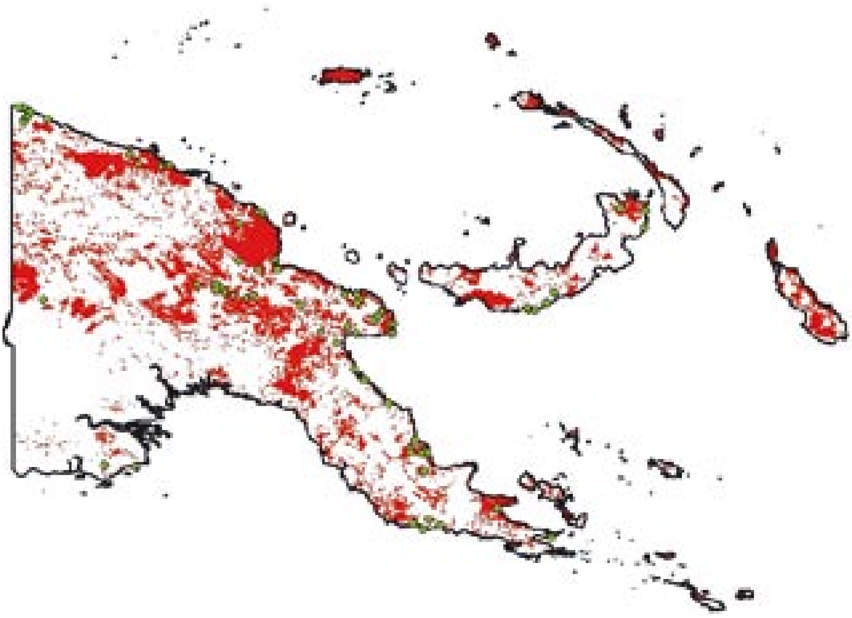

Figure 5. Taro cultivation in Papua New Guinea and taro germplasm accessions.

If production maps are not available, GIS software such as FloraMap and DIVA-GIS can be used to prepare a potential distribution map based on the climatic conditions at collecting sites, or crop growth models (Jones at al., 2001; Hijmans et al, 2002), though clearly these are not likely to be as accurate.

To plan the timing of collecting and exploration, it is important to have near real-time information about the course of a cropping season. FAO's GeoWeb[41] is a web-based application that allows custom access to various information used by FAO's Global Information and Early Warning System analysts to assess the crop and food supply situation worldwide. It is possible to display satellite images including Cold Cloud Duration (CCD) for Africa, Normalized Difference Vegetation Index (NDVI) for Africa and Latin America, and worldwide SPOT-4 images (available only from April 1998) as well as planting and harvesting calendars for normal years and the growing areas for main crops for selected countries.

Satellite image statistics (available for selected African countries only) allow users to see a time series of the average values of CCD, or NDVI, and images over defined zones of the country showing the evolution of rainfall, or vegetation, over time. The USDA-FSA CropExplorer website[42] also has regional maps of key climatic variables, some updated daily, others every 10 days (Figure 6).

General bibliographic databases on agriculture that are available on CD-ROM and on-line include (Dearing and Guarino, 1995), AGRICOLA (USDA), AGRIS (FAO), CAB Abstracts (CAB

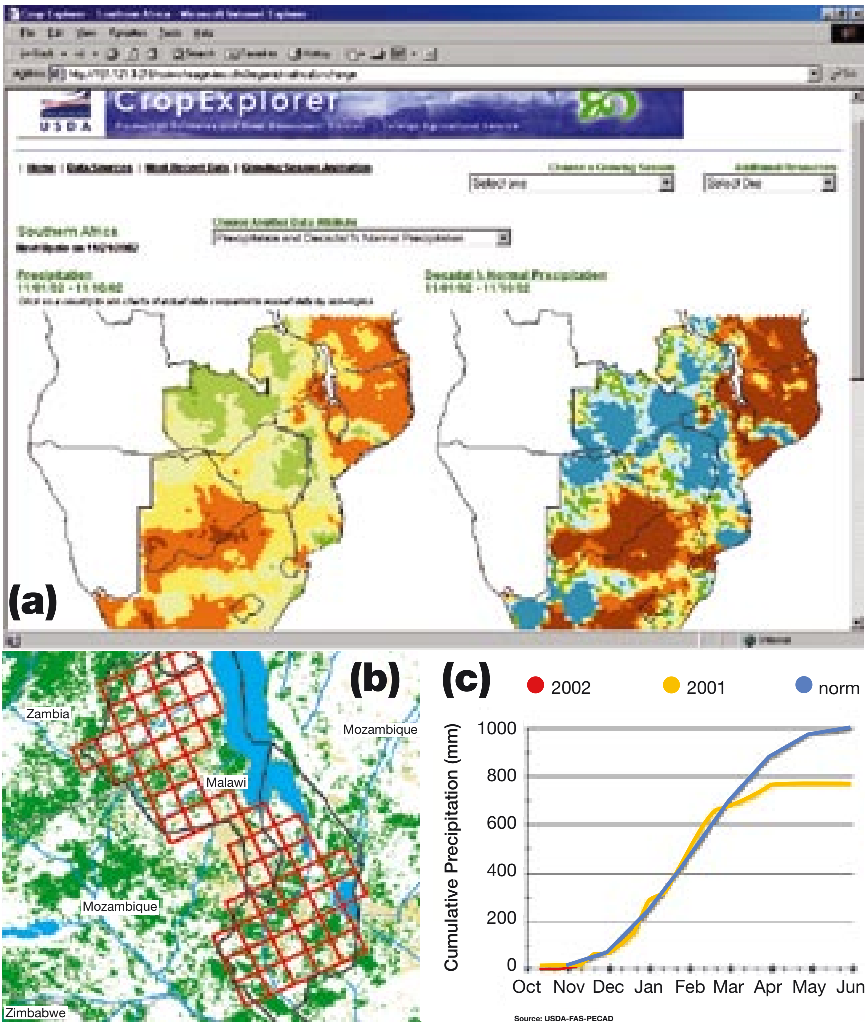

Figure 6. Some resources available on the CropExplorer website: (a) frequently updated regional climatic maps; (b) cropping area for individual countries; (c) statistics on the course of precipitation during past and present cropping season.

International), SESAME (International Cooperation Centre of Agricultural Research for Development - CIRAD) and Tropag & Rural (Royal Tropical Institute, KIT). An excellent addition to the plant genetic resources literature is *Plant Genetic Resources Abstracts* and its CD-ROM version *PlantGeneCD* (CAB International and IPGRI). The IARCs regularly produce specialized bibliographies on their mandate crops; in addition, they run searches and other bibliographic services for their partners (Dearing and Guarino, 1995). *Biodiversity in Trust* (Fucillo et al., 1997), is a useful source of information on the conservation and use of the CGIAR Centres' mandate crops. In addition, this publication has extensive bibliographies. The Info Finder web site[43] allows digital information searches on the CGIAR, FAO and Future Harvest Centers' web sites.

A substantial number of locally- and regionally-important crops remain relatively neglected by agricultural research. Monographs summarizing information on a number of these have been published by IPGRI in collaboration with the Institute of Plant Genetics and Crop Plant Research, Germany (IPK); a list is available on IPGRI's web site[44].

Grey literature rarely reaches bibliographic databases and abstracting journals, but can be extremely useful to crop conservationists in their ecogeographic studies. One way of locating such literature is to consult experts, as mentioned earlier. The unpublished reports and notebooks of past collectors are useful in pointing the conservationist in the right direction. Other sources are the reports of rural development projects, regional research stations, and extension departments in the target region. Richards (1985) quotes examples of colonial departments of agriculture in west Africa recording different aspects of local agricultural practices, including the vernacular names of crops and landraces. The archives of municipal libraries have also proved useful sources of information to plant genetic resources conservationists (Marchenay, 1987).

For specific information on different agronomic problems of the target taxa, pest/disease surveys should be consulted to determine what problems have been recorded in the target region. Unfortunately, such surveys are far from complete in many countries. In many instances the surveys are outdated, or do not cover the entire country, concentrating on the easily accessible areas. Frequently the surveys record pests of crop plants, neglecting wild relatives. Often, the surveys have not been done at all.

There is, of course, extensive published literature on the taxonomy, history, agronomy, breeding, genetic diversity, uses and properties, and ethno-botany of specific crops, and on the farming systems of which they form a part. Holliday (1989) includes a list of major texts, referenced by crop name, on plant pathology, including crop-specific disease compendia. Important sources for pest distributions include *Distribution Maps of Pests* (IIE, 1968 et seq.) and *Distribution Maps of Plant Diseases* (IMI, 1942 et seq.) The ecogeographer should confirm with the relevant institutes that these maps contain the most up-to-date information. Detailed descriptions, including notes on the transmission of many of the pests highlighted on the maps, can be found in the *Descriptions of Fungi and Bacteria* (IMI, 1964 et seq.), *Descriptions of Plant-parasitic Nematodes* (IIP, 1972 et seq.) and *Descriptions of Plant Viruses* (CMI/AA, 1970-1984; AAB, 1985 et seq.) For information on viruses, CAB International (CABI) and the Australian National University have collaborated on the Virus Identification Data Exchange database. *Viruses of Tropical Plants* (Brunt et al., 1990) is an output of the database. The IARCs also publish useful illustrated guides about the pests of their mandate crops. These are particularly useful in the field. Finally, FAO and IPGRI jointly publish a crop specific series of technical guideline booklets, *Technical Guidelines for the Safe Movement of Germplasm*[45]. Each booklet is divided into two parts; the first part makes recommendations on how best to move germplasm of the crop concerned and lists institutions recovering and/or maintaining healthy germplasm; the second part covers quarantinable pests and diseases with descriptions of elimination methodologies.

The information sources on climate and soils mentioned in *Delimit and characterize the target region* can be used to estimate the geographic incidence of abiotic stresses and adapted germplasm. For example, Figure 7 shows data for nitrogen stress in the different bean growing regions of eastern Africa (Wortmann et al., 1998). This data could be used to produce the base map on which to superimpose germplasm collecting localities, allowing the identification of geographic gaps in collection areas and areas likely to harbour material with desired adaptations (see Figure 2). This could also be done with maps of pests and diseases.

Ethnographic literature can provide community-level information on the target region. For example, local language dictionaries can be useful as initial sources of information for local crop names and varieties. Ethnographic and anthropologic research guides and bibliographies are also good information sources. *Ethnographic research: A guide to general conduct* (Ellen, 1984) has a section on "Getting into the literature" that covers the *International Bibliographies of Social Sciences* series and ethnographic archives.

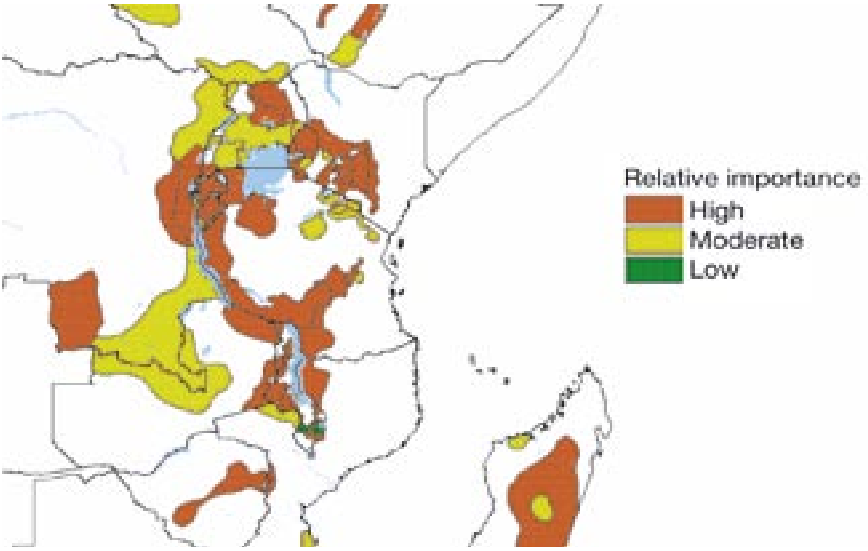

Figure 7. Bean production area in east Africa showing importance of nitrogen stress (adapted from Wortmann et al., 1998).

Atlas of World Cultures (Price, 1990) has a set of maps with the location of some 3,500 human cultures in addition to an alphabetical index of the anthropological and ethnographic literature on that particular group. Each culture in the index is cross-referenced to its listing in the *Ethnographic Atlas* (Murdock, 1967) and the Human Relations Area Files (eHRAF)[46] database (Murdock et al., 1983). For the HRAF, Murdock "…collected detailed data on the incidence and distribution of cultivated plants from over 2,000 ethnographic sources..." for Africa alone (Rhoades, 1988), along with information on technology, social patterns, economics, language, and so on. HRAF is now a large-scale research organization, and publishes the material in its Collection of Ethnography on CD-ROM.

CAB International's *Rural Development Abstracts*[47] and *World Agricultural Economics and Rural Sociology Abstracts*[48] will be useful in accessing the socio-economic and development literature.

Recent literature on the role of women in agriculture is available for most regions of the world. *Rural Women* (Kubisz, 1992) is an annotated bibliography of this literature; *Women in Agriculture and Rural Life: An International Bibliography* (Effland and Gold, 1998) is available on the USDA National Agricultural Library web site[49].

Professional social scientists are not the only sources of information on the cultures of a region of potential usefulness to the ecogeographer. Blench's (1989) work on the Nupe of west-central Nigeria is an interesting example of how almost two centuries of diverse writings of explorers, traders, colonial administrators and missionaries, as well as ethnologists, linguists, anthropologists and historians can be used to assess the changes in crop repertoire and farming systems in an area. One of his medieval sources, the *Bughyat al-fallahin* of Al-Malik Al-Afdal Al-'Abbas (b. 1363 AD), is available in translation (Serjeant, 1974), but this will not always be the case. An interesting use of historical sources to identify areas of high priority for crop germplasm collection is Zizumbo-Villareal's (1996) work on coconut in Mexico. He used a variety of documents from the 16th-18th centuries to identify, "…the sites, dates and origins of the introductions, the initial areas of production, the economic importance of the cultivation and its diffusion during the colonial era." Estimates of coconut production from 1612 to 1760 in Obispado de Michoacan (on the Pacific coast of Mexico), were obtained using documents from the municipal archives of the city of Colima, the diocese report of 1631 and the series of tithes of the diocese for 1636-1810. Although historical texts are sometimes available in modern editions, in some cases the ecogeographer may need to consult original archival material.

Box 6 is an example of the type of results possible using the information available from various published and other sources.

Analyze the ecogeographic data

Analysis of crop ecogeographic data aims to describe the distribution of the crop, of specific character states and of the levels of variation in different characters, or combinations of characters. The first step in such analyzes is usually some sort of mapping.

In studies of wild taxa, population localities of each recognized taxon are commonly shown superimposed on a base map of topography, climate, vegetation or soil, each taxon represented by a different symbol. Herbarium and germplasm accessions might be distinguished by open and closed symbols respectively. Particular morphological or ecological features of each population can be shown by glyphs or other modifications of the basic symbol (Maxted et al., 1995; Guarino, 1995).

Similarly, the crop ecogeographer might use an agro-climatic classification of the target region or of the growing environments of the target crop as a base map, or perhaps an administrative map shaded to reflect the importance of the crop in each district, (e.g. percentage of cultivated area, level of production) as shown by agricultural censuses, or derived from expert sources. Superimposing the location of accessions, as is shown in Figures 2 and 5, will be useful in identifying possible gaps in collections. The locations of different landrace names might also be mapped

Box 6 – Information on sorghum in Malawi from published sources

Distribution. The total area of sorghum production in Malawi varied from 14,000 to 22,000 ha between 1977 and 1987, with average yields of 370-800 kg/ha (compare 2000 kg/ha on station). Though sorghum is widely grown in the country (from 100 to 2000 masl), the main area of cultivation is the Lower Shire Valley, where the crop accounts for up to 60% of the cultivated area. This region accounts for 75% of Malawi's sorghum grain production (though 5-10% of its population). A secondary concentration of sorghum cultivation is the hilly region of the extreme north of the country, near Karonga. In contrast to the relatively dry Shire Valley, here average annual rainfall is 1000-2000 mm.

Cultivation, storage and uses. Bush-fallow-ash shifting cultivation ('visoso') is practiced in the northern hills. In the heavy valley soils of the south, agriculture is more settled. Sorghum and pearl millet are mainly grown as insurance against the failure of the maize harvest, this being the principal staple for at least the last 80 years. These cereals are used during the period when the family has depleted its stock of grain but maize is not yet ready for harvest. After the maize harvest, they are mainly used for brewing beer. Most farmers harvest sorghum between April and May, after a growing season of 100-130 days, depending on the cultivar. The panicles are left outside to dry on raised wooden platforms until June-July, i.e. after the cotton harvest. After threshing, the grain is stored indoors in woven grass baskets, and may be exposed to smoke from the cooking fire. Storage loss was about 2%, possibly because landraces are relatively resistant to storage pests. Sorghum is mainly used to make porridge ('Nsima') and for brewing traditional beer ('Thobwa' or 'Chibuku', depending on whether sweet or sour, respectively). Sweet-stalk types are grown on a very small scale and used exclusively for chewing, the grain being very bitter.

Pests and diseases. Crop loss due to pests (birds) and insects (stem borers and weevils) can be high in the Shire Valley (Chitu et al., 1996). Comprehensive lists of pests and diseases (and some symptoms) are given by Appa Rao et al. (1989), with references. A *PlantGene*CD search revealed various papers in the journal *Plant Disease* reporting on pest/disease surveys in Malawi and neighbouring countries by the SADC/ICRISAT Sorghum and Millet Improvement Program.

Research and breeding. Several sorghum varieties have been released since the 1970s. One of the most popular in the Shire Valley is PN3, a short, white-grained, early-maturing cultivar resistant to common leaf diseases and producing good porridge, but with a soft endosperm vulnerable to weevil attack in storage and liable to heavy mould infestation. Also common is PNR8311, a commercial hybrid from South Africa. After several years of testing in national and SADCC/ICRISAT regional trials, a number of varieties and hybrids from ICRISAT were identified as replacements for PN3 and PNR8311 in the Lower Shire Valley. SPV351 and SPV475 have been released in Malawi as Pirira 1 and Pirira 2 The SACCAR Newsletter publishes lists of germplasm released or about to be released to NARS by regional projects, including the SADC/ICRISAT Sorghum and Millet Improvement Program. The Malawi sorghum breeding programme has been concentrating on the following traits: (i) hard endosperm, (ii) white grain, and (iii) resistance to stem borer. Poor institutional capacity for seed multiplication has prevented the widespread distribution of material produced by the breeding programme. Sorghum material from Malawi has recently been evaluated for resistance to grain mould (Singh et al., 1993) and has revealed a brown midrib mutant (Gupta, 1995).

Genetic erosion. After a sever drought in 1992-93, an NGO mounted a project of emergency sorghum seed provision in the Shire Valley. An early variety from Tanzania was distributed (Seredo). This was not well adapted to local conditions, in particular day length, and farmers did not particularly like it, but despite this it is still widely grown (ICRISAT, 1993).

Useful sources

Agnew (1976)
Appa Rao et al. (1989)
Anon. (1990)
Binns (1968)
Chintu et al. (1996)
Terry (1961)

using different symbols. However, it should be remembered that morphologically or genetically similar material might be given different local names in different areas, or the same local name may be given to different landraces. Therefore, characterization and evaluation data (whether recorded during collecting, or in the course of subsequent formal trials) should also be incorporated into distribution maps (as in Figure 8). One could produce maps showing the overall geographic distribution of crop samples using open symbols, with the occurrence of particular traits of interest—e.g. a given panicle shape, resistance to a disease or drought tolerance—shown by filled-in symbols.

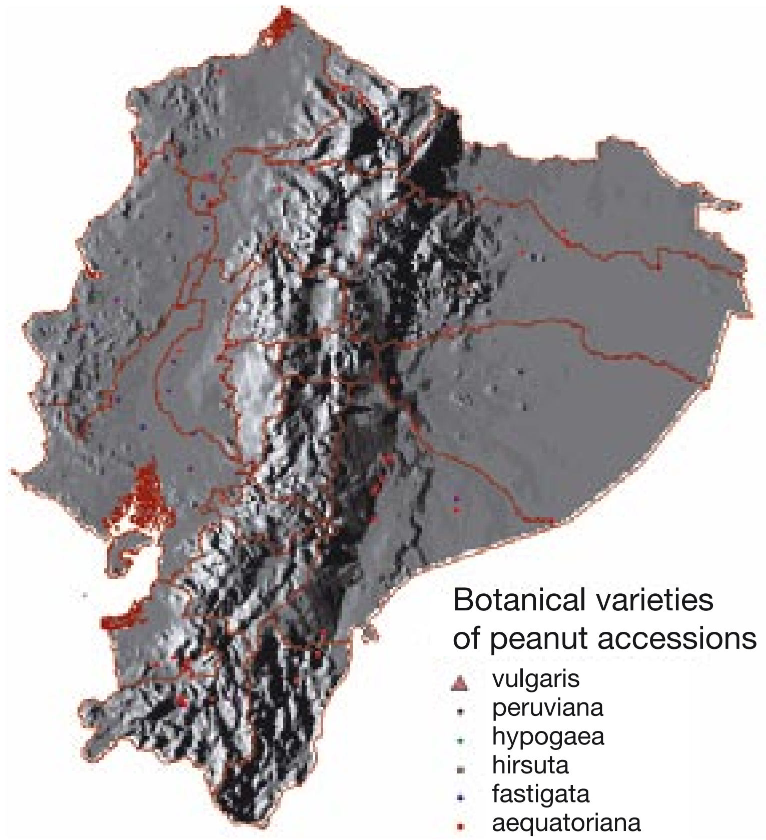

Figure 8. Geographic distribution of botanical varieties of the cultivated peanut in Ecuador.

Such mapping may suggest patterns and associations that could then be explored further using tables and graphs of various sorts, and could also be tested statistically. Examples might include assessing whether a particular landrace is found on a particular soil type or in a particular agro-climatic zone significantly more often than might be expected by chance, or whether the frequency of a character state changes systematically along an environmental gradient, e.g. disease resistance or panicle shape with altitude.

Rather than single characters, combinations of characters could be used. Ordination (e.g. Principal Components Analysis) and classification (e.g. clustering) of landrace accessions according to characterization (morphological, protein, DNA) and evaluation data can be used to identify groups of relatively similar material (Guarino, 1995). The occurrence of material from different clusters in different agro-ecological zones, or the variation of principal component scores with altitude, could then be investigated. Accessions could also be classified in terms of their climatic adaptation by using passport data to describe the climate at the collection site. The FloraMap software developed by CIAT uses an interpolated climate surface to derive the values of 36 climate parameters (monthly means of temperature, daily temperature range and precipitation) from latitude and longitude data. It can then be used to carry out clustering and PCA on the results for a germplasm collection to investigate the existence of climatic differentiation within the material (Jones et al., 2002). DIVA-GIS also provides climatic information for niche analysis (Hijmans et al., 2001).

Another kind of ecogeographic question is whether material from particular areas shows greater genetic diversity than material from others. Such diversity studies usually begin by dividing the target area (or strata within the target area, e.g. agro-climatic, or language zones) into areas of equal size, often in a grid pattern, though administrative subdivisions have also been used. Some index of diversity is then calculated for each area, which can then be compared with each other.

In crop studies, the diversity index could be based on the number of distinct landrace names found in each grid square. In Figure 9, the Shannon-Weaver index is applied to the data used in Figure 8 using the DIVA-GIS software to quantify diversity at the botanical variety level for cultivated peanuts in Ecuador within each grid square. A complementary approach is to calculate diversity not on a grid basis, but around each accession point. This is illustrated in Figure 10, where the Shannon-Weaver index was calculated using DIVA-GIS at the botanical variety level, but for a circle of 1 degree radius around each accession point rather than for each grid square, as in Figure 9. The different styles of Figures 8-10 illustrate the wide range of base maps and presentation approaches that may be used to display geo-referenced plant genetic resources data.

Iterative procedures such as that described by Rebelo and Sigfried (1992) could then be used to choose the smallest number of grid squares such that each landrace will be present in at least one square (or two, three, etc.). Such squares are said to be

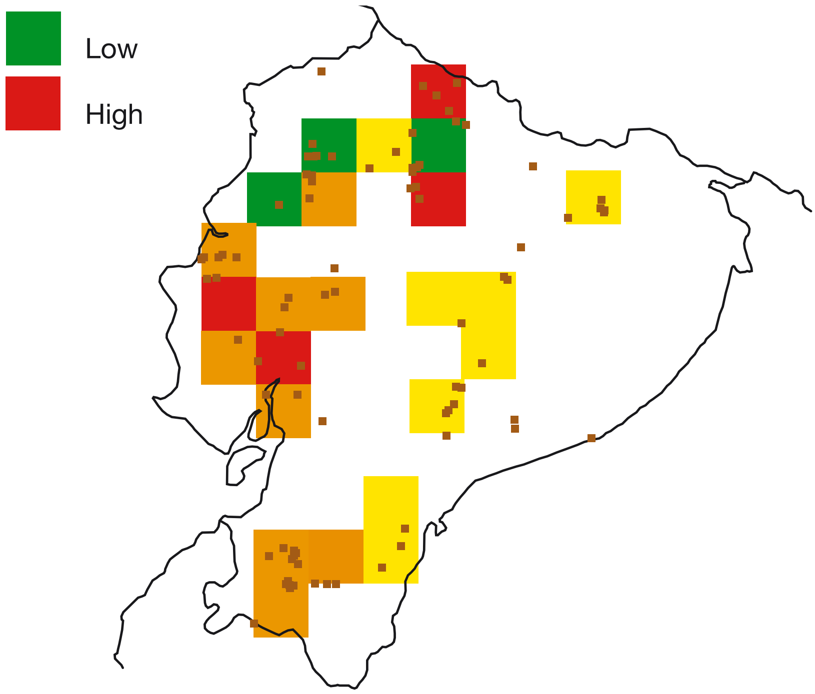

Figure 9. Geographical distribution of diversity at the level of botanical variety in the cultivated peanut in Ecuador.

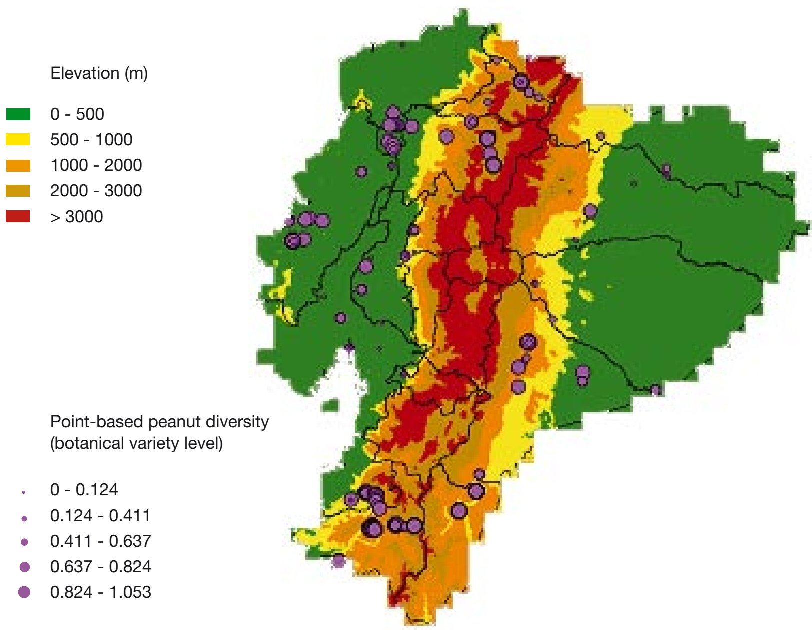

Figure 10. Geographic distribution of cultivated peanut accessions in Ecuador and point-based diversity at the botanical variety level.

'complementary'. This analysis is available in DIVA-GIS. Another, less efficient, approach to identifying areas that are complementary in the diversity they contain is to classify, or ordinate grid squares according to the material found there. Grid squares can then be sampled from each distinct cluster.

In addition to mere numbers of landraces, more formal measurements of the variation in characterization and evaluation traits (taken singly or together) can also be used to identify highly diverse and complementary grid squares. Classification of landraces on the basis of characterization and evaluation data can be used to refine the diversity analysis. Two grid squares may have equal numbers of landraces, but the landraces in one square may be very similar to each other while those in another may be very different. All things being equal, the second grid square would be the higher conservation priority. The procedure described by Vane-Wright et al. (1991) allows grid squares to be weighted for the distinctiveness of the different taxa found there (landraces, in this context).

Phase 3. Generate ecogeographic products

Ecogeographic databases, conspectus, and reports

Maxted et al. (1995) suggest that the main products generated by ecogeographic studies of wild taxa may be characterized as the database, the conspectus and the report:

- Database: Contains the raw ecogeographic data, as derived from herbarium labels and the passport data of germplasm accessions;
- Conspectus: Provides brief notes on the taxonomy, distribution, ecology and phenology of the various taxa recognized by the accepted classification of the target group;
- Report: Presents the analysis of the data in the database and conspectus and uses it to recommend priorities and strategies for conservation.

These products have close counterparts in crop studies. The database will probably have different fields and structure to that of a study of wild taxa and will consist of germplasm accession data. However, it will still hold the basic raw data of the study. In the case of a multi-crop study, the conspectus should consist of an annotated checklist of crops of the type suggested by Hammer (1991), with annotated landrace checklists for each crop. It may be useful to prepare separate checklists for the different language groups present within the target region. Notes on each crop and landrace could include such information as vernacular names (perhaps with translations), distribution, morphological description, agronomic characteristics, phenology, associated cultivation practices, uses, farmers' comments etc. (Box 7).

In addition, 'profile memos' could be developed for other topics of general interest. An example on gender and agriculture in Malawi is given in Box 8 (Guarino, 1995), but other topics could include:

- The history and distribution of different ethnic and language groups in the target region;
- The different agro-climatic zones of the target region, and their associated farming systems/practices;
- Significant places and geographical features;
- Important people, social groupings and traditional institutions;
- Significant occasions (e.g. market days);
- Relevant laws, customs, taboos and restrictions, particularly those dealing with access to natural resources, including plant genetic resources;

Box 7 – Part of a sorghum landrace checklist for Malawi

Checklist arranged in alphabetical order of local name:

Name	Use	Head	Grain	Comments
Beri	grain	loose, small	white	near Lilongwe
Kanchiwere	grain	compact	white, bold	common in eastern lowlands
Misale	beer, chewing	semi-compact	brown	widely distributed, very variable
Ndikhwa	grain	compact	cream, bold	durra, high-yielding
Wayawaya	grain	loose, small	white	bicolor, early, grey awned glumes
Zambia	grain	compact	purple	durra, Shire Valley
etc.				

Alphabetical checklist sorted by head type:

Name	Use	Head	Grain	Comments
Kanchiwere	grain	compact	white, bold	common in eastern lowlands
Ndikhwa	grain	compact	cream, bold	durra, high-yielding
Zambia	grain	compact	purple	durra, Shire Valley
Misale	beer, chewing	semi-compact	brown	widely distributed, very variable
Beri	grain	loose, small	white	near Lilongwe
Wayawaya	grain	loose, small	white	bicolor, early, grey awned glumes
etc.				

Landraces listed by use:

Beer/grain	*Masotongo*
Small-grain porridge	*Tongo*
	Tsumburi
Grain	*Kanchiwere*
	Ndikhwa
	Beri
	Wayawaya
Early-maturing	*Kachansane*
	Wayawaya

Box 8 – Outline profile memo: Gender and agriculture in Malawi

- Matrilineage (husband leaves his home to live with his wife, who inherits cultivation rights) is common in the central and southern regions, patrilineage in the north (Appa Rao et al., 1989).
- Women subordinated to the interests of men and of the wider society (Akeroyd, 1991).
- Women use sung poetry as a strategy to “define, redefine, evaluate and interpret their position” (Timpunza, 1988).
- Women have a more important role in subsistence production than men (Engberg et al., 1988).
- Women play an important decision-making role in adoption of HYVs of beans (Due, 1988).
- Gender and commodity production during the colonial period (Vaughan, 1985).
- Men farmers produce hybrid maize and tobacco for export and women produce the subsistence food crop, local maize: evidence for and against (Smale and Heisey, 1994).

Source: *PlantGene*CD , Effland and Gold (1998)

- How gender, age, class, social status, ethnicity etc. relate to access to, and control of, natural resources, including plant genetic resources.

Some of these profile memos could actually be prepared separately for each language or cultural group in the region.

Finally, the report will include the results of the analyses described in the previous section. In particular, the following kinds of geographical areas should be described and mapped, if possible:

- Areas of high (and complementary) diversity in the crop;
- Areas where the crop and wild/weedy relatives co-exist;
- Areas harbouring (or suspected to harbour) specific traits of interest;
- Areas harbouring morphological phenotypes (specific landraces or cultivar groups) which are under-represented in collections;
- Areas representing ecogeographic gaps in collections;
- Areas at risk of (or already suffering from) genetic erosion.

The report should then suggest a conservation strategy for the crop within the target region. Various kinds of interventions could be recommended on the basis of the results of the various analyzes carried out as part of the ecogeographic survey. An important possible intervention will be germplasm collecting for *ex situ* conservation. Any recommendation for collecting should be accompanied by an indication of the most appropriate sampling strategy (e.g. targeted on specific traits, landraces or localities) and timing to achieve stated objectives. Different kinds of on-farm conservation activities might also be recommended; for example, activities that complement existing *ex situ* conservation activities in areas where high genetic diversity coincides with high and continuing pest/disease pressure, or the presence of wild/weedy relatives of the crop. Possible interventions that have been classified as community-based, economic, public awareness and policy initiatives, and are discussed in detail in Jarvis et al. (1999), include: participatory crop improvement, community genebanks, adding value through processing, diversity fairs and incorporating local crop resources into agricultural extension packages. The restoration of landraces to specific communities from which they have disappeared could also be recommended on the basis of the results of an ecogeographic study.

Another possible conclusion of the work could be that more information is needed before specific, detailed conservation suggestions can be made. One possibility might be that the available phenological data is insufficient to determine the best time for collecting, which will necessitate a preliminary field visit, or further consultations with locally-based experts. There might be recommendations for a more thorough assessment of genetic diversity to be carried out, either on existing collections, perhaps using molecular markers, or in the field, for example using ethno-botanical methodologies. There might also be the need for a better assessment of past genetic erosion, and of the risk of future losses, to be done in key areas.

References

AAB. 1985, et seq. Description of Plant Viruses. Association of Applied Biologists.19:296-309.

Acheapong E, Murthi Anishetty N, Williams JT. 1984. A World Survey of Sorghum and Millets Germplasm. IBPGRI, Rome, Italy.

Agboola SA. 1979. An Agricultural Atlas of Nigeria. Oxford University Press, Oxford, UK.

Agishi EC, Heering H. 1991. A bibliography of *Sesbania* species. Working Document No. A4. ILCA, Addis Ababa, Ethiopia. Agnew S. 1976. World Atlas of Agriculture - Malawi. pp. 333-345. Istituto Geografico Agostini, Novara, Italy.

Akeroyd AV. 1991. Gender, food production and property rights: constraints on women farmers in southern Africa. In: Afshar, H. (ed.) Women, Development and Survival in the Third World. pp. 135-171. Longman, Harlow, UK.

Anon. 1990. Agriculture, Forestry and Natural Resources Sector Review and Programming Mission. Malawi. Mission Findings and Recommendations. Report prepared in close collaboration between Government of Malawi, UNDP and FAO. Unpublished FAO report DD: DP/RAF/89/B37.

Appa Rao S. 1979. Germplasm collecting mission to Malawi. Genetic Resources Programme Progress Report No. 2. ICRISAT.

Appa Rao S. House LR. Gupta SC, 1989. Review of Sorghum, Pearl Millet and Finger Millet Improvement in the SADCC Countries. SACCAR and SADCC/ICRISAT Sorghum and Millet Improvement Program, Bulawayo, Zimbabwe.

Arora RK. 1980. Report of IBPGR crop germplasm collecting mission to Malawi and Zambia, 1980. Unpublished. IBPGR, Rome, Italy. report AGP: IBPGR/80/62. Australian National University GIS database [Homepage of Mapping Agricultural Systems in Papua, New Guinea Project (MASP)] [online]. 2002 August 12 last update. Available from: http://rspas.anu.edu.au/lmg/masp/. Date accessed: 31 March 2005

Binns B. 1968 Crop Plants of Malawi. University of Malawi, Zomba, Malawi.

Brunt AA. Crabtree K, Gibbs A. 1990. Viruses of Tropical Plants. CAB International. Slough, UK. pp. 707

CABI Publishing – Rural Development Abstracts [Homepage of CABI Publishing – Rural Development Abstracts] [online]. 2005 last update. Available from: http://www.cabi-publishing.org/AbstractDatabases.asp?SubjectArea=&PID=62. Date accessed: 1 April 2005

Carter SE, Bunting AH (ed). 1987. Collecting and organising data on the agro-socio-economic environment of the cassava crop: case study of a method. Workshop on Agro-Ecological Characterization, Classification and Mapping. Rome, Italy, 14-18 April 1986. CABI, Wallingford, UK. pp. 11-29

Carter SE, Fresco LO Jones PG, Fairbairn JN. 1992 An Atlas of Cassava in Africa: Historical, Agroecological and Demographic Aspects of Crop Distribution. Centro internacional de agricultura tropical (CIAT), Cali, Colombia. pp. 85

Castillo MCS. 1997. Idiomas de Guatemala. Poster published (w/ copyright) by Editorial Piedra Santa, Guatemala City, Guatemala.

CGIAR SPATIAL DATA CATALOGUE [Homepage of CGIAR Meta-data Catalogue] [online]. 1997 June. Available from: http://www.grida.no/cgiar/htmls/mdindex.htm. Date accessed: 31 March 2005

Chantereau J, Arnaud M, Ollitraut P, Nabayaogo P, Noyer JL. 1989. Study of morphophysiological diversity and classification of cultivated sorghums. Agronomie Tropicale 44:223-232.

Chantereau J, Deu M, Glaszmann JC, Gonzalez de Leon D, Hamon P. 1994. RFLP diversity in cultivated sorghum in relation to racial differentiation and heterosis in hybrids. In: Use of Molecular Markers in Sorghum and Pearl Millet Breeding for Developing Countries. Proceedings of an ODA Plant Sciences Research Programme Conference. 29 March-1 April 1993. pp. 38-45. ODA, Norwich, UK.

Chintu EM, Chigwe CFB, AB Obilana AB, Chirwa RW, Msiska FS. 1996. Sorghum variety release in Malawi: the case of Pirira 1 and Pirira 2. In: Leuschener K, Manthe CS. (eds) Drought-Tolerant Crops in Southern Africa. Proceedings of the SADC/ICRISAT Regional Sorghum and Pearl Millet Workshop, 25-29 July 1994. Gaborone, Botswana. pp. 19-25. ICRISAT.

CMI/AAB (1970-1984) Description of Plant Viruses. (Sets 1-18). CABI and Association of Applied Biologists.

de Wet JMJ. 1978 Systematics and evolution of *Sorghum* sect. *Sorghum*. American Journal of Botany. 65:477-484.

de Wet JMJ, Huckaby JP. 1967. The origin of *Sorghum bicolor*. 2. Distribution and domestication. Evolution 21:787-802.

Dearing JA Guarino L. 1995. Bibliographic databases for plant germplasm collectors. In: Guarino L, Ramanatha Rao V, Reid R. (eds) Collecting Plant Genetic Diversity. pp. 229-254. CABI.

Denton IR. 1979. Report on FAO/IBPGR/ICRISAT sorghum and millet collecting mission to Malawi, 1979. Unpublished IBPGR report AGPE: IBPGR/79/29.

Denton, IR, Appa Rao S. 1979 Sorghum and millets in Malawi. FAO/IBPGR Plant Genetic Resources Newsletter 38:20-22.]

Development Gateway: The Gender and Development page. [Homepage of the gender and development topic within the Development Gateway] [online]. 2005 last update. Available from: http://www.developmentgateway.org/gender. Date accessed: 29 March 2005

DIVA-GIS [Homepage of DIVA-GIS] [online]. 2005 March 23 last update. Available from: http://www.diva-gis.org/. Date accessed: 10 May 2005

Due, JM. 1988. Intra-household and gender issues in farming systems in Tanzania, Zambia and Malawi. In: Poats SV, Schmink M, Spring A. (eds) Gender Issues in Farming Systems Research and Extension. pp. 331-344. Westview Press, Boulder, Colorado, USA.

Eldis Gateway to Development Information. [Homepage of Eldis] [online]. 2005 last update. Available from: http://www.eldis.org/. Date accessed: 29 March 2005

Ellen RF. (ed) 1984. Ethnographic research: a guide to general conduct. Academic, London, UK. pp. 319-377

Engberg LE, Sabry JH, Beckerson SA. 1988. A comparison of rural women's time use and nutritional consequences in two villages in Malawi. In: Poats SV,Schmink M, Spring A. (eds) Gender Issues in Farming Systems Research and Extension. pp. 99-110. Westview Press, Boulder, Colorado, USA.

Ethnologue.com - Ethnologue country index [Homepage of Ethnologue.com] [online]. 2005 April last update. Available from: http://www.ethnologue.com/country_index.asp. Date accessed: 30 March 2005

European Cooperative Programme for Crop Genetic Resources Networks (ECP/GR) {Homepage of ECP/GR] [online] 2005 last update. Available from: http://www.ecpgr.cgiar.org/Databases/Databases.htm. Date accessed: 30 March 2005

Flora Zambesiaca – Royal Botanic Gardens, Kew [Homepage of about Flora Zambesiaca] [online]. 2005 February last update. Available from: http://www.rbgkew.org.uk/floras/fz/intro.html. Date accessed: 10 May 2005

Flora of Tropical East Africa - Royal Botanic Gardens, Kew [Homepage of Flora of Tropical East Africa] [online]. 1999 December last update. Available from: http://www.rbgkew.org.uk/herbarium/ftea/fteaindx.html. Date accessed: 10 May 2005

Food and Agriculture Organization of the United Nations (FAO) [Homepage of FAO-AGL] [online] 2005 last update. Available from: http://www.fao.org/waicent/Faoinfo/agricult/agl/agll/dsmw.htm. Date accessed: 30 March 2005

Fisher RC, Peterson JC, JW Beecher JW, Johnson JS, Boast C. 1990. Agricultural Information Resource Centres: A World Directory.

IAALD, Urbana-Champaign, Illinois,USA.
Forman L,. Bridson D.1992. The Herbarium Handbook. Revised ed. Royal Botanic Gardens, Kew, UK. pp. 303
Fuccillo D, Sears L, Stapleton P. (ed.) 1997. Biodiversity in Trust. Cambridge University Press, Cambridge, UK. pp. 371GIEWS - Global Information and Early Warning System on Food and Agriculture [Homepage of GeoWeb Home Page] [online]. 2005 last update. Available from: http://www.fao.org/giews/english/about.htm. Date accessed: 10 May 2005
Guarino L. 1995. Secondary sources on cultures and indigenous knowledge systems. In: Guarino L, Ramanatha Rao V, Reid R. (eds) Collecting Plant Genetic Diversity. pp. 195-228. CABI.
Guarino L. 1995. Published sources of information on wild plant species. In: Guarino L Ramanatha Rao V and Reid R (eds). Collecting Plant Genetic Diversity. Technical Guidelines. CABI.
Gupta SC. (1995). Allelic relationships and inheritance of brown midrib trait in sorghum. Journal of Heredity 86: 72-74.
Hammer K. 1991. Checklists and germplasm collecting. FAO/IBPGR Plant Genetic Resources Newsletter 85:15-17
Hanelt P, Hammer K. 1995. Classification of intraspecific variation in crop plants. In: Guarino L, Ramanatha Rao V, Reid R. (eds) Collecting Plant Genetic Diversity. pp. 113-120. CABI
Hanelt P, Fritsch R, Hammer K, Kruse J, Pistrick K, Schultze-Motel J. 1993b. Taxonomy and evolution of cultivated plants: literature reviews. FAO/IBPGR Plant Genetic Resources Newsletter 91/92:24.
Harlan JR. 1975. Crops and Man.(ed. 1) American Society of Agronomy and Crop Science Society of America, Madison, Wisconsin, USA. pp. 295
Harlan JR, Stemler A. 1976. The races of sorghum in Africa. In: Harlan JR, de Wet JMJ, Stemler ABL. (eds) Origins of African Plant Domestication. Mouton, The Hague, The Netherlands. pp. 465-478
Harlan JR, de Wet JMJ. 1972. A simplified taxonomy of cultivated sorghum. Crop Science 12:172-176.
Hijmans RJ, Guarino L, Cruz M, Rojas E. 2001. Computer tools for spatial analysis of plant genetic resources data: 1. DIVA-GIS. Plant Genetic Resources Newsletter 127:15-19.
Holliday P. 1989. A dictionary of plant pathology. Cambridge University Press, Cambridge, UK. pp. 369
Holmgren PK, Holmgren NH, Barnett LC. 1990 Index Herbariorum I: The Herbaria of the World (ed. 8) International Association for Plant Taxonomy and New York Botanical Garden, New York, New York, USA. pp. 693

Holmgren PK, Holmgren NH. 1992. Plant specialists index. Regnum Vegetabile 124:1-394.

Human Relations Area Files, Inc. (HRAF) [Homepage of eHRAF] [online]. Last update not known. Available from: http://www.yale.edu/hraf/index.html. Date accessed: 1 April 2005

IBPGR (1985) Ecogeographic surveying and *in situ* conservation of crop relatives. Report of an IBPGR task force meeting held at Washington DC. IBPGRI, Rome, Italy.

ICRISAT (1993) SADC/ICRISAT 1992 drought relief emergency production of sorghum and pearl millet seed: impact assessment. ICRISAT Southern and Eastern Africa Region Working Paper 93/01. ICRISAT, Bulawayo.

IIE (1968 et seq.) Distribution Maps of Pests. Series A (Agriculture). International Institute of Entomology (formerly Commonwealth Institute of Entomology) and CABI.

IIP (1972 et seq.) IIP Descriptions of Plant-parasitic Nematodes. International Institute of Parasitology (formerly Commonwealth Institute of Helminthology) and CABI.

IMI (1942 et seq.) IMI Distribution Maps of Plant Diseases. International Mycological Institute (formerly Commonwealth Mycological Institute) and CABI .

IMI (1964 et seq.) IMI Descriptions of Fungi and Bacteria. International Mycological Institute (formerly Commonwealth Mycological Institute) and CABI.

IISRIC [Homepage of ISRIC] [online] 2004 February 5. Available from: http://www.isric.nl/. Date accessed: 30 March 2005

InfoFinder {Homepage of InfoFinder] [online]. 2005 last update. Available from: http://waicent.fao.org/cgiar/. Date accessed: 31 March 2005

International Legume Database & Information Service (ILDIS) [Homepage of ILDIS] [online] 2005 23 March last update. Available from: http://www.ildis.org/. Date accessed: 29 March 2005

International Plant Genetic Resources Institute (IPGRI) [Homepage of IPGRI] [online] 2005 last update. Available from : http://www.cgiar.org/ipgri/publicat/direcveg.pdf. Date accessed: 29 March 2005

J. Paul Getty Trust – Getty Thesaurus of Geographic Names Online [Homepage of TGN] [online]. 2004 last update. Available from: http://www.getty.edu/research/conducting_research/vocabularies/tgn/index.html. Date accessed: 31 March 2005

Jarvis DI, Meyer L, Klemick H, Guarino L, Smale M, Brown AHD, Sadiki M, Sthapit B, Hodgkin T.1999. A Training Guide for *In Situ* Conservation On-farm. Version 1. IPGRI, Rome, Italy.

Jones PG, Guarino L, Jarvis A. 2002. Computer tools for spatial analysis of plant genetic resources data: 2. FloraMap. Plant Genetic Resources Newsletter 130:6-10.

Karp A, Kresovich S, Bhat KV, Ayad WG Hodgkin T. 1997. Molecular tools in plant genetic resources conservation: a guide to the technologies. IPGRI Technical Bulletin No. 2. IPGRI, Rome, Italy.

Keenan S, Worteley P. 1994. Directory of agricultural bibliographic information sources. CTA, Ede, The Netherlands. pp. 142

Lampinen R, Liu S, Brach A R, McCree K. 1996.-. The Internet Directory for Botany. - [http://www.botany.net/IDB/]. Date accessed: 29 March 2005

Lock JM. 1989. The Legumes of Africa. A Checklist. Royal Botanic Gardens, Kew, UK.

Marchenay P. 1986.A la recherche des variétés locales de plantes cultivées; guide methodologique. PAGE-PACA, Conservatoire Botanique de Porquerolles. Hyères, France. pp. 211

Martyn D. 1992. Climates of the world. Developments in Atmospheric Science (Netherlands) No. 18 [out of print]. Elsevier, Amsterdam, The Netherlands. pp. 446

Maxted N, Kell S. 1998 Ecogeographic techniques and *in situ* conservation: a case study for the legume genus *Vicia* in Turkey. In: Zencirci N, Kaya Z, Anikster Y,Adams WT. (eds) Proceedings of an International Symposium on *In situ* Conservation of Plant Diversity 4 – 8 November, 1996. pp. 323-344. Central Research Institute for Field Crops, Ankara, Turkey.

Maxted N, van Slageren MW, Rihan JR. 1995. Ecogeographic surveys. In: Guarino L, Ramanatha Rao V, Reid R. (eds) Collecting Plant Genetic Diversity. pp. 255-285. CABI.

McKiernan G. 1990. The CIKARD international documentation unit and library of indigenous knowledge for agriculture and rural development. In: Warren DM, Slikkerveer LJ, Oguntunji Titilola S (eds) Indigenous Knowledge Systems: Implications for Agriculture and International Development. pp. 86-90. Iowa State University, Ames, Iowa, USA.

Ministry of Environment & Tourism, Namibia - Atlas of Namibia [Homepage of Atlas of Namibia] [online] 2005 7 April last update. Available from: http://www.dea.met.gov.na/data/Atlas/Atlas_web.htm#4Vegetation. Date accessed: 29 March 2005

Morden CW, Doebley JF, Schertz KF. 1989. Allozyme variation in Old World races of Sorghum bicolor. American Journal of Botany 76:247-255.

Moss H, Guarino L. 1995. Gathering and recording data in the field. In: Guarino L, Ramanatha Rao V, Reid R. (eds) Collecting Plant

Genetic Diversity. Technical Guidelines. CABI Wellesbourne, UK. pp. 367-417

Muchena FN, van de Weg RF. 1982 Soil survey and land evaluation in Kenya. Soil survey and land evaluation. May 1982. v. 2 pp. 42-47

Murdock GP. 1967. Ethnographic atlas. University of Pittsburgh Press, Pittsburgh, PA, USA. pp. 128

US National Plant Germplasm System (NPGS) Genetic Resources Information Network (GRIN) [Homepage of USDA-NPGS-ARS (GRIN)] [online]. 2004 September 23. Available from: http://www.ars-grin.gov/npgs/. Date accessed: 31 March 2005

Netherlands organization for international cooperation in higher education (Nuffic). [Homepage for Nuffic] [online]. 03 March 2005 last update. Available from: http://www.nuffic.nl/index-en.html. Date accessed: 29 March 2005

New York Botanical Gardens - Index Herbariorum [Homepage of NYBG- Index Herbariorum] [online]. 2003 last update. Available from: http://sciweb.nybg.org/science2/IndexHerbariorum.asp. Date accessed: 30 March 2005

Obilana AB, Prasada Rao KE, Mangombe N, House LR. 1996. Sorghum variety release in Malawi: the case of Pirira 1 and Pirira 2. In: Leuschener K, Manthe CS. (eds) Drought-Tolerant Crops in Southern Africa. Proceedings of the SADC/ICRISAT Regional Sorghum and Pearl Millet Workshop, 25-29 July 1994. Gaborone, Botswana. pp. 113-118. ICRISAT.

Ollitrault P, Arnaud M, Chatereau J. 1989. Enzyme polymorphisms in sorghums. II. Genetic and evolutionary constitution of cultivated sorghum. Agronomie Tropicale 44:211-222.

Panje P, Matabwa CJ, Kumwenda JTD. 1987. Soils of the drier areas of Malawi which are prone to drought: present agriculture on these soils and research that may increase the agricultural potential. In: Agronomic Adjustment to the Environment of the 400-600 mm rainfall zone of Southern Africa. Proceedings of a SACCAR workshop held in Harare, Zimbabwe, September 1983. pp. 47-61. SACCAR Workshop Series No. 1. SACCAR, Gaborone.

Parry RB, Perkins CR. 2000. World Mapping Today. 2nd ed. K.G. Saur Verlag, Munich, Germany.

Perry MC, Bettencourt E. 1995. Sources of information on existing germplasm collections. In: Guarino L, Ramanatha Rao V, Reid R. (eds) Collecting Plant Genetic Diversity. pp. 121-130. CABI.

Prendergast JB. 1995. Published sources of information on wild plant species In: L. Guarino, V. Ramanatha Rao & R. Reid (eds) (1995). *Collecting Plant Genetic Diversity. Technical Guidelines.* CAB International, Wellesbourne, UK.

Price DH. 1990. Atlas of World Cultures. Sage Publications, London, UK.
Rebelo AG, Sigfried WR. 1992. Where should nature reserves be located in the Cape Floristic Region, South Africa? Models for the spatial configuration of a reserve network aimed at maximising the protection of diversity. Conservation Biology 6:243-252.
refdesk.com MY FACTS PAGEATLAS AND MAPS [Homepage of refdesk.com] [online]. 2005 last update. Available from: http://www.refdesk.com/factmaps.html. Date accessed: 29 March 2005
Richards P. 1985. Indigenous agricultural revolution: exology and food production in West Africa. Unwyn Hyman, London, UK. pp. 192
Room A. 1979. Place Name Changes Since 1900. The Scarecrow Press, London, UK. pp. 202
Rural Sociological Society. [Homepage of the Rural Sociological Society] [online]. 2005 March 28 last update. Available from: http://ruralsociology.org/. Date accessed: 29 March 2005
Schultze-Motel J. (ed.) (1986) Rudolf Mansfeld. Verzeichnis Landwirtschaftlicher und Gärtnerischer Kulturpflanzen (2 ed.). Springer-Verlag, Berlin, Germany.
Singh SD, Rao KEP, Navi SS, Satyanarayana MV. 1993. Identification of resistance to grain mould in white grain sorghum. Sorghum Newsletter 34:24.
Smale M, Heisey PW. 1994. Gendered impacts of fertilizer subsidy removal programs in Malawi and Cameroon. Agricultural Economists 10: 95-99.
Snowden JD. 1936. The Cultivated Races of Sorghum. Adlard , London, UK. pp. 273 System-wide Information Network for Genetic Resources (SINGER) [Homepage of SINGER] [online] 2005 last update. Available from: http://www.singer.cgiar.org/. Date accessed: 30 March 2005
Terry PT. 1961. African agriculture in Nyasaland. Nyasaland Journal 14:1858-1864.
Times Books (1988) *Atlas of the World* (ed. 7). Times Books, London, UK
Timpunza ESM. 1988. Women's oral poetry as a social strategy in Malawi [dissertation] CCL-MC, Chancellor College, Zomba, Malawi. Abstracts International. Humanities and Social Sciences 48:2420.
United States Department of Agriculture (USDA) Foreign Agricultural Service [Homepage of CropExplorer] [online] 2004 last update. Available from: http://151.121.3.218/rssiws/#. Date accessed: 31 March 2005
United States Department of Agriculture (USDA) National Agricultural Library [Homepage of Women in Agriculture and Rural Life]

[online]. 1998 June 8 last update. Available from: http://www.nal.usda.gov/afsic/wia/women.htm. Date accessed: 1 April 2005

United States National System for Geospatial-Intelligence (NSG) GEOnet [Homepage of GEOnet Names Server (GNS)] [online]. 2005 March 25 last update. Available from: http://earth-info.nga.mil/gns/html/index.html. Date accessed: 31 March 2005

University of East Anglia, Norwich School of Development Studies. [Homepage of UEA ODG] [online]. 2004 6 December last update. Available from: http://www.uea.ac.uk/dev/. Date accessed: 29 March 2005

University of Texas at Austin - Perry-Castañeda Library Map Collection [Homepage of UT at Austin Perry-Castañeda Library Map Collection] [online]. 2005 April 5 last update. Available from: http://www.lib.utexas.edu/maps/map_sites/country_sites.html. Date accessed: 30 March 2005

Vanderbilt University Jean and Alexander Heard Library. [Homepage of the VU Jean and Alexander Heard Library] [online]. 2004 last update. Available from: http://www.library.vanderbilt.edu/ Date accessed: 29 March 2005

Vane-Wright RI, Humphries CJ, Williams PH. 1991. What to protect? Systematics and the agony of choice. Biological Conservation 55:235-254.

Vaughan M. 1985. Household units and historical process in southern Malawi. Review of African Political Economy 34:34-45.

White F. 1983. The Vegetation of Africa. A Descriptive Memoir to Accompany the UNESCO/AETFAT/UNSO Vegetation Map of Africa. UNESCO, Paris, France.

World Gazetteer [Homepage of World Gazetteer] [online]. 2004 December 25 last update. Available from: http://www.world-gazetteer.com/. Date accessed: 31 March 2005

World Potato Atlas [Homepage of World Potato Atlas] [online]. 2002 September 27 last update. Available from: http://www.cipotato.org/wpa/index.htm. Date accessed: 31 March 2005

Wortmann CS, Kirby RA, Eledu CA, Allen DJ. 1998. Atlas of Common Bean (*Phaseolus vulgaris* L.) Production in Africa. CIAT, Cali, Colombia. pp. 133

Young A. 1987. Methods developed outside the international agricultural research system. In: Agricultural environments. Characterization, classification and mapping. Bunting AH (ed). CABI, Wallingford, UK. pp. 43-63

Zeven AC, de Wet JMJ. 1982. Dictionary of Cultivated Plants and their Regions of Diversity. PUDOC, Wageningen, The Netherlands.

Zizumbo-Villareal D. 1996. History of coconut in Mexico: 1539-1810. Genetic Resources and Crop Evolution 43:505-515.

(Endnotes)

Phase 1: Design the project

1 http://www.botany.net/IDB - Accessed 29 March 2005
2 http://www.cgiar.org/ipgri/publicat/direcveg.pdf - Accessed 29 March 2005
3 http://www.eldis.org/
4 http://www.developmentgateway.org/gender - the original link inactive 29 March 2005 [Note to Author: please confirm that I have inserted the correct web address]
5 http://www.nuffic.nl/ik-pages/addresses.html - Accessed 29 March 2005
6 http://www.nuffic.nl/ciran/ikdm/index.html - Accessed 29 March 2005
7 http://ruralsociology.org – Accessed 29 March 2005
8 http://www.developmentgateway.org/node/130625 - link inactive 29 March 2005
9 http://www.uea.ac.uk/dev - Accessed 29 March 2005
10 http://www.library.vanderbilt.edu/central/anthro.html - Accessed 29 March 2005
11 http://www.rbgkew.org.uk/floras/fz/intro.html - Accessed 10 May 2005
12 http://www.rbgkew.org.uk/herbarium/ftea/fteaindx.html - Accessed 10 May 2005
13 http://www.ildis.org – Accessed 29 March 2005
14 http://www.dea.met.gov.na/data/Atlas/Atlas_web.htm#4Vegetation – Accessed 30 March 2005
15 http://www.refdesk.com/factmaps.html - Accessed 30 March 2005
16 http://www.lib.utexas.edu/maps/map_sites/country_sites.html - Accessed 30 March 2005
17 http://www.lib.utexas.edu/maps/map_dealers.html - Accessed 30 March 2005
18 http://www.ethnologue.com/country_index.asp - Accessed 30 March 2005
19 http://www.fao.org/waicent/faoinfo/agricult/agl/agll/gaez/index.htm
20 http://www.singer.cgiar.org - Accessed 30 March 2005
21 http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGL/agll/gaez/index.htm - Accessed 30 March 2005
22 http://www.isric.nl – Accessed 30 March 2005
23 http://sciweb.nybg.org/science2/IndexHerbariorum.asp - Accessed 30 March 2005

[24] http://www.ipgri.cgiar.org/publications/pubseries.asp?ID_SERIE=14 – Accessed 30 March 2005
[25] http://www.ipgri.cgiar.org/germplasm/dbintro.htm - Accessed 30 March 2005
[26] http://www.ipgri.cgiar.org/catalogue/theme.asp?theme=7 - Accessed 30 March 2005
[27] http://apps3.fao.org/wiews/wiews.jsp?i_l=EN - Accessed 30 March 2005
[28] http://www.singer.cgiar.org

Phase 2: Collect and analyze the data

[29] http://www.ecpgr.cgiar.org/Databases/Databases.htm - 30 March 2005
[30] http://www.ars-grin.gov/npgs/acc/acc_queries.html - Accessed: 30 March 2005
[31] http://www.ipgri.cgiar.org/publications/pubseries.asp?ID_SERIE=13 – Accessed
[32] http://www.getty.edu/research/tools/vocabulary/tgn/index.html - Accessed 31 March 2005
[33] http://www.world-gazetteerr.com/links.htm - Accessed 31 March 2005
[34] http://164.214.2.59/gns/html/index.html - Accessed 31 March 2005
[35] www.diva-gis.org – Accessed 10 May 2005
[36] http://www.grida.no/cgiar/htmls/mdindex.htm - Accessed 31 March 2005
[37] http://www.cipotato.org/wpa/index.htm - Accessed 31 March 2005
[38] http://www.fao.org/giews/english/about.htm - Accessed 10 May 2005
[39] http://151.121.3.218/rssiws/ - Accessed 31 March 2005
[40] http://rspas.anu.edu.au/lmg/masp - Accessed 31 March 2005
[41] http://www.fao.org/giews/english/about.htm - Accessed 10 May 2005
[42] http://151.121.3.218/rssiws/ - Accessed 31 March 2005
[43] http://waicent.fao.org/cgiar - 31 March 2005
[44] http://www.ipgri.cgiar.org/publications/pubseries.asp?ID_SERIE=37 – 31 March 2005
[45] http://www.ipgri.cgiar.org/publications/pubseries.asp?ID_SERIE=11 – Accessed 31 March 2005
[46] http://www.yale.edu/hraf/ - Accessed 1 April 2005
[47] http://www.cabi-publishing.org/AbstractDatabases.asp?SubjectArea=&PID=62 – Accessed 1 April 2005

48 http://www.cabi-publishing.org/AbstractDatabases.asp?SubjectArea=&PID=83 – Accessed 1 April 2005

49 http://www.nal.usda.gov/afsic/wia/women.htm

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