Valuation and Sustainable Management of Crop and Livestock Biodiversity: A Review of Applied Economics Literature

Adam G. Drucker, Melinda Smale, and Patricia Zambrano
September 5, 2005

Published for the CGIAR System-wide Genetic Resources Programme (SGRP) by the International Food Policy Research Institute (IFPRI), the International Plant Genetic Resources (IPGRI), and the International Livestock Research Institute (ILRI).

* Adam G. Drucker is an environmental economist with the International Livestock Research Institute, and Melinda Smale and Patricia Zambrano are agricultural economists at the International Food Policy Research Institute. The authors gratefully acknowledge the comments and ideas of Daniel Debouck, International Center for Tropical Agriculture, as well as Linda Collette and other reviewers from the Food and Agriculture Organization of the United Nations including Leslie Lipper, Irene Hoffman, Brad Fraleigh, and Elcio Guimaraes. This paper and its accompanying bibliography were supported by the System-wide Genetic Resources Program of the Consultative Group on International Agricultural Research (CGIAR).

Valuation and Sustainable Management of Crop and Livestock Biodiversity: A Review of Applied Economics Literature

List of Abbreviations

AnGR	Animal Genetic Resources
GR	Genetic Resources
IFPRI	International Food Policy Research Institute
ILRI	International Livestock Research Institute
IPGRI	International Plant Genetic Resources Institute
PGR	Plant Genetic Resources
SGRP	System-wide Genetic Resources Program

EXECUTIVE SUMMARY

Background

This paper is part of the follow-up to the workshop "Managing Agricultural Biodiversity for Sustainable Development" organized by the International Plant Genetic Resources Institute (IPGRI) for the CGIAR System-wide Genetic Resources Programme (SGRP) and hosted by the World Agroforestry Centre (ICRAF), Nairobi, Kenya (23-25 October, 2003, Nairobi, Kenya). Subsequently SGRP agreed to support:

1) a background paper assessing the state of the art of valuation methods for crop and livestock components of agricultural biodiversity, with particular emphasis on developing agricultural economies;
2) a thematic bibliography of selected economics literature about valuing crop and livestock components of agrobiodiversity; and
3) an expert workshop entitled "Valuation tools for managing agricultural biodiversity: state of the art and future directions" (scheduled for October 2005).

This paper covers item 1. Item 2 has been produced separately for website posting. Both prepare some of the groundwork for the workshop (item 3).

Agricultural biodiversity refers to all diversity within and among species found in domesticated crop, tree, aquatic, and livestock systems. Here, crop and livestock components are addressed. "Crop biodiversity" refers to the biological diversity of crops, encompassing both phenotypic and genotypic variation, including cultivars or varieties recognised as agro-morphologically distinct by farmers and genetically distinct by plant breeders. Similarly, livestock biological diversity encompasses both phenotypic as well as genotypic variation. Although much less talked about, genetic erosion in farm animal genetic resources (AnGR) is much more serious than in crops because the gene pool is much smaller.

The motivation for this paper was the notion that scientific research about agrobiodiversity could be advanced by a holistic[1] approach to valuing its components. As a first step, a review of findings, methodologies and their limitations might reveal common approaches and contrasts, enabling researchers to exploit synergies and work toward an integrated research agenda. The hypothesis is that the costs, benefits, and policy recommendations differ when interactions among biodiversity components are taken into account. As a second step, this hypothesis could be tested by undertaking a pilot project with a joint research design.

Several observations support this hypothesis in the case of crops and livestock, taken as an initial example. First, many small-scale farmers, especially in subsistence-oriented

[1] i.e. one that includes all the major components of (farm) agroecosystem diversity including wild relatives – i.e. crops and other plants, including trees; livestock; aquatic resources, etc. Furthermore, a holistic approach would include a focus on interactions between components, rather than simply considering the economic values of more than one individual component at a time.

agriculture, integrate the production of crops and livestock. Policy and development interventions at the local level often deal with the same people. Second, livestock and crops compete for some of the same lands, crop products serve as inputs for livestock production, and manure and animal power serve as an input to crop production. Thus, policies and development interventions that affect crop GR often affect livestock GR, and vice versa. Finally, some of the most significant forces driving change in crop and livestock biological diversity are the same—intensification of production, mechanization, certain forms of commercialization, and product uniformity.

General Findings

Economics has in fact contributed relatively little to the debate about the value of crop or livestock genetic resources and their diversity. One reason why is that most of them are not traded in markets and their prices are not observable. All sources of economic value associated with crop and livestock biodiversity, as with other goods and services, emanate from human preferences; as compared to wild species, most of the value associated with the diversity of these resources in agriculture probably stems from their use values, as compared to non-use, or existence values.

The review indicates that advances in economic valuation for both crop and livestock GR have eased some methodological/analytical constraints, and that in some respects, data constraints may now be more binding. A wide range of tools and analytical approaches have been successfully applied to a number of crops/species and breeds, in a number of production systems and locations. Application of these methods can provide useful estimates of the market and non-market value of variety/breed attributes. Such data are crucial for:

- Identifying trait values in breeding programs
- Demonstrating the benefits, as well as the costs of conservation
- Identifying cost-efficient, diversity maximising, or optimal conservation strategies
- Orienting policies aimed at genetic resources (GR) conservation and sustainable use

The field of economics of AnGR conservation and sustainable use has developed rapidly during recent years, although the applied economics literature about the value of PGR for agriculture has a longer history and is therefore more extensive, especially in developing economies.

Methodological advances continue to be important, in several ways. First, a number of strategic areas have not yet been addressed with adapted tools in either the crops or livestock literature. Second, there are advantages and disadvantages associated with both revealed and stated preference approaches to valuation, so that a combination of approaches will often prove more satisfactory. Still, greater accuracy could come at a price of greater respondent burden and research expenditures. Third, there are obvious limitations to what can be accomplished solely through valuation exercises, since management of genetic resources involves crucial institutional and organizational decisions. Institutional analysis is generally lacking.

Since economics research on the value of crop and livestock components of agricultural biodiversity has been undertaken separately, the review provides few clues about the gains that might be achieved through a more holistic approach to GR valuation. Typically, economics studies undertaken with respect to one component have treated the goods or services provided by the other component as "exogenous," or external. Clearly, an integrated approach will be more complex since it will encompass the interactions among diversity components, also implying greater research investment. While many of the techniques developed for assessing the value of PGR are appropriate for AnGR and vice versa, they are not interchangeable because livestock provides a number of services that are not provided by crops. Integrating the research would require new approaches. The choice of study sites will require careful attention, especially given the location-specificity of findings that is apparent in case studies already conducted.

With respect to the goals of the System-wide programme, it should be borne in mind that defining a System-wide agenda on valuing agricultural biodiversity for sustainable management of components (crops, livestock, trees, aquatic resources) will require information and insights from a much wider range of literature and disciplines than economics alone.

Specific Findings: Crops

- The marginal commercial value expected from an individual plant genetic resource in agricultural use will not be high enough, in general, to fund national innovation or conservation efforts at levels desirable for society.
- The commercial value of plant genetic resources is a relatively small component of their total use value because of incomplete markets, especially in developing or transitional agricultural economies.
- There is ample evidence that the successive, continuous releases of improved varieties by plant breeding programs, many of them publicly-financed, have generated economic returns that far outweigh the costs of investment.
- The expected marginal value of exploiting an individual accession in commercial agricultural use justifies the cost of conserving it in a gene bank.
- Studies testing the relationship of crop genetic diversity to productivity, vulnerability, and efficiency are so far inconclusive because methodologies require further development and validation. Associations are sometimes positive and sometimes negative.
- Three of the overriding determinants of crop biodiversity levels on farms are geographical location, cultural cohesion, and environmental heterogeneity.
- Another common determinant is relative isolation from physical market infrastructure, which induces farmers to rely on their own production to meet the food and fodder needs of their families. Despite this persistent finding, the relationship of market development and commercialisation to crop biodiversity on farms appears more complex when specific market features, other than sheer isolation from physical infrastructure or road density, are analyzed.

- Many of the case study findings suggest that in marginal environments, factors associated with economic development may not, in the short-term, detract from intra-crop and in particular inter-crop diversity on farms, whether observed at the farm level or at higher levels of aggregation, such as village, settlement, district, or region.
- Trade-offs were hypothesised between conservation objectives such as maintaining richness, evenness, relative abundance, rare or heterogeneous landraces. Not many trade-offs were evident in case studies—perhaps as a reflection of the bluntness of the tools applied. Differential impacts of the same factors across crops were pronounced, however. Programs designed to encourage infra-specific diversity in one crop might have the opposite effect on another.
- Statistical profiles of households most likely to sustain crop biodiversity suggest that conservation programmes can be designed to address social equity concerns. On one hand, often it is not the poorest within communities who maintain diversity. On the other hand, programmes to support the maintenance of diversity in some locations might benefit economically marginalized members of society.
- The more sophisticated the crop diversity index in terms of genetics and mathematics, the farther it is removed from farmer decision-making. Farmer decision-making units must be linked through genetics to metrics that are more meaningful for conservation programmes at a higher scale of analysis.
- Across a range of crops, national income levels, and agro-ecological environments, case studies support the notion that farmers value various dimensions of crop biodiversity.
- A number of methods and tools have been applied to assess value, tapping many fields of inquiry. Most are data-intensive and because of the nature of human and environmental interactions with crops and species reproduction systems, findings are often location-specific, with implications for research cost. Although the conceptual and theoretical literature about sources of value in crop genetic resources and their diversity is extensive, and literature about rates of return to breeding for commercial agriculture is comprehensive, literature guiding practical decisions about the conservation of crop biodiversity *ex-situ* and *in-situ* is relatively scant. Theoretical, conceptual, and methodological advances are required to introduce interactions of crop biodiversity with other components of agricultural biodiversity, and assess the extent to which it supports the provision of ecosystem services.

Specific Findings: Livestock

- Conventional productivity evaluation criteria are inadequate to evaluate subsistence livestock production and have tended to overestimate the benefits of crossbreeding and breed substitution.
- Adaptive traits and non-income functions form important components of the total value of indigenous breed animals to livestock keepers.
- The costs of implementing an *in-situ* breed conservation programme may be relatively small, both when compared with the size of subsidies currently being

provided to the commercial livestock sector and with regard to the benefits of conservation.

- However, few such conservation initiatives exist and even where the value of indigenous breeds has been recognised and support mechanisms implemented, significant shortcomings can be identified.
- Similar work regarding the costs and benefits of the *ex-situ* (cryo)conservation of livestock remains limited. However, under the assumption that technical feasibility brings cryoconservation of livestock species to within the same level of magnitude as that of plants, extensive conservation efforts would be justified on economic grounds.
- Household characteristics play an important role in determining differences in farmer breed preferences. This additional information can be of use in designing cost-effective conservation programmes.
- While the impact of policy factors on AnGR are readily discernable in broad terms, little is known about their relative importance.
- Conservation policy needs to promote cost-efficient strategies and this can be achieved through the development of "Weitzman-type" decision-support tools. Such tools permit the allocation of a given budget among a set of breeds such that the expected amount of between-breed diversity conserved is maximised.
- Opportunity/Least cost approaches reveal that, in a number of cases, only minimal incentives and interventions would in fact be needed to ensure continued indigenous breed sustainable use, as the costs of implementing an *in-situ* breed conservation programme in certain areas are relatively low.

Chapter I.
Overview

Adam G. Drucker and Melinda Smale

I.1. Introduction

This report forms part of the follow-up to the SGRP/IPGRI workshop entitled "Managing Agricultural Biodiversity for Sustainable Development" (23-25 October, 2003, Nairobi, Kenya). The overall aim of the workshop was to explore connections and interactions between different components of the agroecosystem from the perspective of biodiversity management and use, and to provide opportunities to develop linkages between research groups.

Under the broad heading of "costs, value and benefits of agricultural biodiversity", a working group was formed to discuss "methods for assessing the private and public value of agrobiodiversity." The working group noted that valuation of agrobiodiversity is not an end in itself. Valuation methodologies need to be incorporated into decision-support tools that can be applied in contexts where they can be used to inform policy decisions and support poor farmers, toward the goal of conserving agrobiodiversity for sustainable use. In this regard there is a need to promote research collaboration among those involved with economics research about biodiversity of animal, plant, tree and aquatic genetic resources.

Collaboration would enable researchers to learn more from each other and take advantage of synergies and common approaches. There is potential to benefit from an improved understanding of the interactions between these components, especially given the fact that interventions may deal with the same people at the community level. The existence of plant diversity has, over the millennia, led to the development/evolution of livestock breeds adapted to particular environment. At the same time, livestock grazing, forage and veterinary plant use directly influences plant diversity. Harnessing such interactions may be one of the best ways to conserve regional biodiversity.

The working group made the following recommendations for future activities to plenary:

- Make use of existing approaches and develop them further;
- Incorporate approaches into decision-support tools;
- Identify key researchable questions that are common across components; and
- Identify an area appropriate for joint research of components as a pilot study.

Subsequently SGRP agreed to support:

1) a background report assessing the status of methods for valuing crop and livestock components;
2) a thematic bibliography of selected economics literature about valuing crop and livestock components of agrobiodiversity;
3) an expert workshop entitled "Valuation tools for managing agricultural biodiversity: state of the art and future directions" (October 2005).

The current paper covers item 1. Item 2 has been produced separately for website posting. Both items contribute to the realization of the workshop (Item 3).

I.2. Definitions and perspective

All chapters of this manuscript employ the following definitions of agricultural biodiversity and crop biodiversity. Agricultural biodiversity refers to all diversity within and among species found in domesticated systems, including wild relatives, interacting species of pollinators, pests, parasites, and other organisms. Domesticated biodiversity (crops, trees, aquaculture fish, livestock), is a consequence of deliberate human intervention, serving both as a production component and as a source for genetic improvement (Cassman et al., 2005). Located within cultivated landscapes, domesticated biodiversity is linked outside these landscapes with the biodiversity found in protected reserves or maintained in the *ex-situ* collections of breeders and gene banks. Wild relatives are interspersed within both cultivated landscapes and *ex-situ* collections.

"Crop biodiversity" refers in this paper to the biological diversity of crops, encompassing both phenotypic and genotypic variation, including cultivars recognized as agro-morphologically distinct by farmers and varieties recognized as genetically distinct by plant breeders. The terms "cultivars" and "varieties" are used to describe either farmers' varieties or those bred by plant breeders. Typically, farmers' varieties do not satisfy UPOV definitions of variety because they are heterogeneous, exhibit less uniformity, and segregate genetically. Where it is necessary to distinguish between varieties selected and managed by farmers and those bred by professional plant breeders, the terms "landraces" and "modern varieties" are assigned. Definitions and concepts of landraces are numerous in the crop science literature (Zeven, 1998). Harlan (1992) defined landraces broadly as variants, varieties, or populations of crops, with plants that are often highly variable in appearance, whose genetic structure is shaped by farmers' seed selection practices and management, as well as natural selection processes, over generations of cultivation.

Similarly, for livestock, biological diversity encompasses both phenotypic as well as genotypic variation. The Food and Agriculture Organization of the United Nations (FAO, 1999) defines "breed" as: "either a subspecific group of domestic livestock with definable and identifiable external characteristics that enable it to be separated by visual appraisal from other similarly defined groups within the same species; or a group for which geographical and/or cultural separation from phenotypically similar groups has led to acceptance of its separate identity". A combination of phenotypic (including classical morphometric) studies, biochemical (e.g. protein polymorphism, blood group) analyses and, more recently, DNA-level molecular genetic studies, are the main sources of data on genetic relationships among breeds, varieties and strains (Rege and Gibson, 2003). Populations within each species can be classified as wild and feral populations, landraces or primary populations, standardized breeds, selected lines and any conserved genetic material (FAO, 2000).

Crop and livestock genetic resources are managed sustainably when they satisfy the present needs of farm families while also retaining their genetic integrity for the longer term needs of society. The "sustainable management" of GR is defined as the combined set of actions (and policies) by which a sample, or the whole, of a plant/animal population is subjected to processes of genetic and/or environmental manipulation with the aim of sustaining, utilizing, restoring, enhancing and understanding (characterizing) the quality and/or quantity of the GR and its products.

I.3. Importance of crop and livestock genetic resources in domesticated biodiversity

Managing the biological diversity of crop and livestock genetic resources on farms is of fundamental importance: 1) as a means of survival for the world's rural poor; 2) as a mechanism for buffering against output losses due to emerging pests and diseases, even in fully commercialized agricultural systems; 3) as an input into locally sustainable, indigenous technology systems; 4) as a biological asset for the future genetic improvement on which the global supply of food and agricultural products depends, and 5) as a means of satisfying the evolving tastes and preferences of consumers as economies change.

For example, some 70% of the world's rural poor depend on livestock as a component of their livelihoods (LID, 1999). Crops and livestock with different agronomic and product characteristics suit a range of local community needs. Empirical research has documented that in harsh, isolated environments where climatic and soil conditions are variable, farmers often depend on the cultivation of multiple crops and varieties to meet their food and cash needs. For farm households to be food secure, they require stable supplies for consumption from either their own production or market purchases. As markets develop, they generally specialize in fewer products oriented toward the demands of distant consumers, relying less on a portfolio of crop varieties and more on a portfolio of income sources to smooth their consumption. Nevertheless, those in isolated areas continue to face heavy transactions costs because they have limited and uncertain options for buying and selling in markets. They have a "demand" for crop biological diversity that is derived from the range of production traits and consumption attributes they need.

Livestock, in particular, serves needs beyond output functions. Livestock provide manure to enhance crop yields, and transport for inputs and products, serving also for traction. Where rural financial and insurance markets are not well developed, they enable farm families to smooth variation in income and consumption levels over time. Livestock constitute savings and insurance, buffering against crop failure and cyclical patterns in crop-related income. They enable families to accumulate capital and diversify, serving a range of socio-cultural roles related to status and the obligations of their owners (Anderson, 2003).

By contributing in multiple ways to human survival and well-being, crop and livestock diversity supports sustainable agricultural practices. Sustainable agriculture involves the integrated use of a range of regenerative technologies, combined with farmers' knowledge and skills, to conserve and improve existing resources on farms, and so substitute for some or all external inputs (Pretty, 1995). The diversity of genetic resources constitutes a sustainable and indigenous technology with a crucial role to play in integrated farming systems, particularly in the face of climate change, the challenges of new diseases, changes in production systems and consumer tastes (Drucker et al., 1999).The same is true for fully commercialized cropping systems, as evidenced by the historical investments made in breeding for genetic resistance to emerging pathogens and pests, and as markets have been more differentiated, the attention paid to breeding for product attributes.

Geneticists often hypothesize that rare, locally adapted genotypes may be found among the varieties and breeds maintained by farmers in extreme or heterogeneous environments. Some genotypes are thought to contain tolerance or resistance traits that are not only valuable to the farmers who grow them but also to the global genetic resource endowment on which future crop improvement depends. Rare alleles are often discovered in known centres of origin, though depending on the crop, valuable diversity can often be found elsewhere.

For this reason, managing crop and livestock genetic resources in sustainable ways will entail careful husbandry within domesticated landscapes as well as banks and breeding programs, at local, national and international scales.

I.4. Rates and causes of loss

I.4.1 Livestock

<u>Rates of loss:</u> Although much less talked about, genetic erosion in farm animal genetic resources (AnGR) is much more serious than in crops because the gene pool is much smaller[2] (6,000 – 7,000 breeds/strains of some 40 species) and only very few wild relatives remain (Rege and Gibson, 2003). An estimated 82% of the total contribution of AnGR to the global food and agricultural production comes from only 14 of these species (FAO, 2000). Additionally, ‘fire brigade’ type rescue operations are much more difficult to undertake for animals than for crops. Thus, during civil strife or severe drought and famine, farmers may successfully keep seeds buried underground, but they will most likely lose all their livestock. Moreover, most crops can be conserved *ex-situ* (e.g. as seeds or vegetative forms in genebanks), but, due to technological constraints, only very few animal species can be cryopreserved at present. Since the turn of the last century, some 16% of uniquely adapted breeds have become extinct (Hall and Ruane, 1993). A further 32% are at risk of becoming extinct and the rate of extinction continues to accelerate (FAO, 2000). In Africa, for example, some 22% of indigenous cattle breeds

[2] The difference in gene pool sizes is related to differences in reproduction between plants and animals. Plants can reproduce in bulk, and can self-pollinate without requiring another plant to ensure replacement of the generation. Furthermore, plant genetic material can be effectively preserved and transmitted through tiny seeds from generation to generation often under conditions that can be too harsh for the whole plant, but for animals the whole organism has to survive and reproduce to generate the next generation. Additionally, more plants than animals can 'hibernate' during times difficult for survival. These comparative advantages provide far greater opportunities for more frequent gradual evolutionary genetic changes (mutation) i.e. wider genetic diversity in plants than animals.

have become extinct in the last 100 years and 27% of the remainder are at varying degrees of risk (Rege, 1999). In Europe, where currently nearly two-fifths of existing breeds are at risk, one-third of breeds existing at the turn of the twentieth century have already been lost (Hammond and Leitch., 1996a). Out of the global farm animal breeds existing today, an estimated 70% are in developing countries where the risk of loss is highest.

Although information about genetic distances for extinct and at risk livestock breeds is limited, there is strong evidence that breed loss leads to a significant reduction in genetic diversity. Hammond and Leitch (1996b) observe that the genetic variance between breeds accounts for approximately 30%-50% of the total variance. The loss of a given breed is therefore associated with a significant decline in genetic diversity, especially since such losses tend to be of breeds adapted to specific localities. Hence, the resulting genetic loss is not likely to be of a redundant genetic resource (E. Rege, personal communication, 2000). In addition, the technology to recreate a breed once lost does not yet exist.

Causes of loss: Factors that threaten indigenous AnGR include: crossbreeding with and/or replacement by, exotic breeds in programmes designed to improve animal productivity; neglect arising from shifts in social settings, production systems and/or market demand of certain animal products; urbanization and its impact on traditional animal agriculture; drought; civil strife/conflicts; and famines (Rege and Gibson, 2003).

I.4.2 Crops

Rates of loss: Though much more talked about, quantifiable global evidence regarding crop genetic erosion is not so easy to find. There are methodological challenges in measuring losses comparably across crop reproduction systems and locations, over time, and on such a large scale. Many detailed studies have been conducted on particular crops, in specific locations or time periods. FAO's 1997 report "The State of the World's Plant Genetic Resources for Food and Agriculture," is considered one of the most comprehensive sources of information. FAO reported the widespread loss of genetic diversity based on reports from the 143 participating countries, but the underlying data used was largely anecdotal or descriptive. Nearly all countries reported that genetic erosion had occurred, and the Annex of the report lists specific examples of loss of genetic diversity in a number of crops. FAO concluded that "there have been few systematic studies of the genetic erosion of crop genetic diversity which have provided quantifiable estimates of the actual rates of genotypic or allelic extinction," calling for "the development of better indicators and measurements" (FAO, 1997). New initiatives are under development in order to improve measurement techniques, including the establishment of genetic baselines.

Causes of loss: According to FAO (1997), 81 countries reported that the main cause for genetic erosion was replacement of local varieties by modern varieties. During the early phases of the Green Revolution in Asia, the late Jack Harlan (1972) coined the term "genetic erosion" to describe what he viewed as a diminishing stock of "landraces," or traditional forms of cultivated crop plants. By referring to the stock of crop germplasm as resource economists refer to a non-renewable natural resource, he drew attention to the economic value associated with rare alleles or unique gene complexes that may be found in such landraces. "Genetic erosion" became synonymous with the displacement of landraces by modern varieties (Frankel, 1970; Hawkes, 1983). Broader causes are clearly associated with the industrialization of agriculture, including: mechanization; use of irrigation, fertilizer and other inputs; crop processing and marketing requirements as agriculture industrializes. This perspective notwithstanding, FAO recognizes that modern varieties do not necessarily imply a reduction in genetic diversity at local or global scales.

I.4.3. Assessing rates of loss

Some caveats are important to bear in mind when interpreting data about crop and livestock genetic erosion. The first is that counting units that represent genetic variation always requires the imposition of taxonomy, or a system for classifying individuals, over another. Plant populations can be sorted or grouped by any one of numerous taxonomies. Outside the legal realm of distinct, uniform, and stable (DUS), the units counted are not standardized since the delineation of the unit managed by farmers is specific to a crop and location. The evolutionary relationship between farmers and plants, the extent of local adaptation, and genetic heterogeneity of these locally-bred varieties means that "counting" them is in some respects a futile endeavour.

One extreme example is maize landraces in Mexico, the known centre or origin of this heavily cross-pollinating species. Some have argued that each physical lot of seed planted by a Mexican farmer is unique—e.g., there are as many local varieties of maize as there are maize farmers in Mexico (Soleri and Cleveland., 2001; Louette and Smale, 2000; Louette et al, 1997). Using neutral molecular markers to assess genetic diversity, Pressoir and Berthaud (2004) found high levels of diversity within farmers' maize populations but low levels of variation between farmers and villages in the State of Oaxaca. The high level of variation within a single farmer's population makes it difficult to differentiate among farmers. The authors conclude that "a maize landrace should not be considered as a separate entity, but rather as an open genetic system." Similar findings have also been reported by Rice (2004) in the State of Nayarit.

A second caveat is that counts are generally insufficient indicators of diversity because they fail to account for relative abundance (Magurran, 1998). Geneticists and social scientists would also agree that not all farmers' varieties and livestock breeds are "equal." In a given region of reference, farmers' varieties/breeds are unequal in terms of their contribution to genetic diversity (for example see Simianer et al's (2003) diversity index as applied to African zebu cattle). They are also unequal in terms of their importance to local farmers or to different segments of global society[3].

Despite these caveats, large, observable changes in utilization of crop genetic resources were sufficient to cause scientists to raise public concern about their loss over thirty years ago. For livestock the recognition of genetic erosion has been much more recent. In 1980

[3] This is an important factor that should be accounted for when determining breed conservation priorities, as biodiversity conservation is carried out to maximize human welfare rather than genetic diversity *per se*.

a joint FAO/UNEP consultation on Animal Genetic Resources referred to "close relatives of domestic species" in its recommendations but it was not until the early 1990s that farm AnGR loss began to be widely recognized, particularly within the context of the Convention on Biological Diversity and Agenda 21.

I.4.4. Implications

Concerns about genetic erosion in crops and livestock had two ramifications of significance for economics applications described in this paper. First, they led to conservation. In crops, they led to a genuine effort to "insure" against losses by sampling and storing large numbers of landraces and wild relatives of cultivated plants *ex-situ* (out of place or origin, or source) in collections, or gene banks. Some experts consider that a large proportion of genetic variation in a number of major crop plants is conserved *ex-situ*, in gene banks or plant breeders' collections (Evenson et al., 1998). Most of the world's crops, especially those that may be critical to the livelihoods of marginalized people, are not represented, however. Moreover, the number or count of accessions is not a reliable proxy for genetic diversity among accessions, and while some duplication is necessary for safety, over-duplication is a familiar issue for genebank managers (Fowler and Hodgkin, 2004). In the past decade or so, the notion of conserving crop plants *in-situ* regained scientific attention (Brush, 2000; Maxted et al., 1997), but far less is known about it, especially for domesticated species that cannot be held in protected reserves.

By contrast, farm AnGR have been conserved to date largely through *in-situ* approaches. Not only is this the preferred method under the CBD, but because the technology for *ex-situ* cryopreservation of livestock is only well-developed for a handful of species, it is often more cost-effective, while also allowing for co-evolution of production systems and disease/climate challenges. Nevertheless, both *ex-situ* and *in-situ* approaches have their own merits. For example, *ex-situ* animal material is more likely to be utilized in emergency restoration but it is much less likely to find use in long-term animal improvement programmes. Therefore, there is need for an integrated conservation approach, which combines a range of available *ex-situ* and *in-situ* options (Rege 2003).

As a consequence of these divergent paths, applied economics research on crop biodiversity has treated both *ex-situ* and *in-situ* (on farm, for domesticated species) conservation, while research addressing livestock genetic diversity has concentrated largely on *in-situ* (on farm, or on rangeland) conservation. Technological advances mean that this situation is gradually changing (for example see upcoming workshop entitled "Option and strategies for the conservation of animal genetic resources"[4]).

The second ramification was a preoccupation with modern varieties and breeds. In the case of crops, the dominant perspective was that modern crop varieties would inevitably lead to the abandonment of landraces, regardless of the fitness of the modern variety relative to the landrace, the agro-ecological niche it is intended to fill, the objective of the farmer, or the structure of the seed industry and product market. For some time, the

[4] Montpellier, 7-10 November 2005. SGRP, FAO and AGROPOLIS

substantial productivity and income benefits of the Green Revolution in Asia obscured the recognition that seed technical change of that magnitude might not happen in all crops or locations of the world. Literally speaking, landraces were viewed in the applied economics literature as an omitted category. Applied economists have only recently begun to investigate the value of increasingly scarce, local varieties to the farmers who grow them. Cultivation of both modern and landrace varieties on the same farm is common outside the historical regions of the Green Revolution; within the historical regions of the Green Revolution such as the high potential, irrigated environments of the Asian subcontinent, the deleterious consequences for productivity of health and environmental externalities have been documented (e.g., Ali and Byerlee, 2001). A different analytical approach and way of thinking about the problem is therefore needed.

With respect to an emphasis on modern breeds, the situation has been similar. Drucker et al. (2001) note that the causes of AnGR erosion often stem from the "misguided development policies initiated in developing countries over the last one-hundred years which have largely ignored the vast majority of AnGR adapted to the lower input mixed farming and pastoral production systems[5] found throughout the developing world. Instead, the focus has been on the introduction of higher-yielding exotic breeds that were developed for high-input, comparatively benign production environments" (ILRI, 1999, p.4). The Intermediate Technology Development Group (ITDG, 1996) notes that such policies are generally oriented toward short-term productivity gains. They often involve substituting local breeds with exotic ones, and then multiplying and distributing them. Such programmes can threaten the conservation and sustainable use of local breeds. Not only has inadequate attention been given to the advantages of indigenous breed use and to the impact of breed replacement on such populations, but also the approach has proved unsustainable in terms of the "improved" breeds being able to reproduce themselves in harsh environments and the apparent comparative advantage in terms of productivity not being realized (Ayalew et al. 2003; Vaccaro, 1973; Vaccaro, 1974; Cunningham and Syrstad, 1987).

I.5. The contribution of economics

I.5.1 Concepts

All classes of economic value have a basis in human preferences. Crop and livestock genetic resources have several classes of economic value that markets fail to capture completely. The conventional classification of total economic value consists in use and non-use values. Use value may be direct or indirect, reflecting the contribution of crop or livestock genetic resources to surrounding habitats or ecosystems. Both direct and indirect use values have current and expected future dimensions. Current use value derives from the utility gained by an individual from consuming a good or service or its consumption by others. Expected future use value is based on known probabilities. Option value is the value associated with retaining an option to a food or service for

[5] Only a few governments are supportive of pastoralists while some countries such as Kenya actively promote sedentarisation which can lead to the loss of local livestock breeds. One exception is Mongolia where the government actively supports traditional nomadic pastoralism. (ITDG, 1996, p.15)

which future demand is uncertain. Non-use value includes existence value, reflecting the satisfaction of knowing that a resource exists, unrelated to any use to which the resource may be put.

Many experts would argue that, as compared to a picturesque, endangered wild species, most of the value associated with domesticated crop varieties and livestock breeds stems from their use rather than their existence. Clearly, genebanks were established to safeguard future use and option values associated with genetic resources. Strategies of breeding horizontal resistance to pests and disease, or maintaining variety mixtures in farmers' fields, are intended to support the flexibility of local farming systems to adapt to changes in pathogens. On farm conservation projects typically aim to enhance the current use value recognized by farmers as incentive for their continued management of local genetic resources.

Markets generally fail to capture all classes of economic value, especially when a resource has public good properties (non-rival, non-excludable, or non-transparent), as do genetic resources. A consequence of market "failure" is that economic incentives are distorted in favour of the economic activities that erode such resources, rather than conserving them.

Genetic resources (GR) erosion can thus be seen in terms of the replacement of the existing slate of diverse GR with a selection from a small range of specialized "improved" varieties/breeds. This bias towards investment in such specialized varieties/breeds results in under-investment in a more diverse set of breeds in a world where human investments are now necessary for the survival of the latter (Brown et al., 1993). Economic theory suggests that decisions such as the replacement of a local variety/breed with an exotic one will be determined by the relative private rates of return the farmer realizes from the two options. To the farmer, abandoning production of a local variety/breed may appear to be economically rational if returns are higher than those obtained from activities compatible with genetic resources conservation. Other incentives, such as subsidized inputs and services (e.g. fertilizers, extension advice, artificial insemination), might also be for the exotic variety or breed, particularly where they are being actively promoted by externally biased agents of change (e.g. national extension workers, foreign donors).

Goods that are not traded on markets tend to be undervalued. Crop and livestock biodiversity are such goods. Conserving them involves non-market benefits that accrue to people other than the farmer. Economic theory predicts that as long as they are "good" for society, farmers will tend to under-produce them relative to the national, regional, or global needs. Policy interventions are therefore necessary to support their production if society's goals are to be met. An example of a social goal is the sustainable management of crop and livestock biodiversity.

Mendelsohn (2003) argues that the primary challenge facing the conservation of genetic resources is identifying sound reasons why society should preserve crops and animals that farmers have abandoned. Given that the market will preserve valuable varieties/breeds, conservationists must focus on what the market will not do. This includes identifying and quantifying the potential social benefits of PGR/AnGR that have been abandoned by the market. So conservationists first must make a case for why society should be willing to pay to protect apparently ‘‘unprofitable’’ PGR/AnGR resources and then must design conservation programs that will effectively protect what society treasures.

Economic analysis can therefore help in understanding the incentives farmers face in making the choice between raising local and/or exotic varieties/breeds, as well as the interventions necessary in order to ensure that the on-going agricultural development process will be compatible with the conservation and sustainable use of local GR diversity. At the international level, economics can support the formulation and implementation of GR access and benefit-sharing mechanisms/agreements, as per the requirements of the 1992 Convention on Biological Diversity (CBD), which stresses the importance of “the fair and equitable distribution of the benefits arising out of the utilization of genetic resources” (Article 1).

I.5.2 Practical constraints

Relative to other areas of public policy, economics has in fact contributed relatively little to the debate about the value of crop and livestock genetic resources and their diversity, primarily because most of them are not traded in markets and prices are not observable (Brown, 1990). There are methodological challenges associated with measuring the value of goods that are not traded on markets, despite continued advances in theory and applications.

Measuring the benefits of germplasm diversity to crop development is extremely difficult, even with advanced methods for estimating the rate of return to investments in plant breeding programs (Pardey et al., 2004; Evenson, 1991). Improved crop and livestock genetic resources are often the product of generations of informal innovations. Thus, identifying the contribution of a particular local variety/breed to the success of an improved variety/breed is complicated. Furthermore, the base materials used for breeding are themselves the result of a production function and identifying the returns to respective factors (e.g. labour, on-farm technology, intellectual inputs, etc.) is likely to be possible only in the most general terms (Evenson, 1991; Pearce and Moran, 1994).

Price data continue to be sparse for many types of crop genetic resources. In recent years, those who supply crop genetic resources, including private companies, public research institutions, non-governmental organizations, and other interest groups have sought to strengthen the intellectual property rights over crop varieties, isolated genes, and enabling tools such as promoters and markers. Economic theory predicts that stronger proprietary regimes will decrease the costs of excluding others from using the same resources, providing an incentive for innovation and market formation.

The lack of information related to the value of crop and livestock genetic resources *in-situ* arises from the fact that most of the farmers who supply them also use them as production inputs. Typically they are located in the more marginal or heterogeneous production environments, often with local markets that function poorly, consuming at least some of their harvest directly. For example, they frequently save the seed of their crop varieties, entering into seed transactions with other farmers within their community or a relatively limited radius. When this is the case, seed prices are unobservable and determined by the internal supply and demand conditions within farm households. Neither the value of the seed nor of the genetic resources embodied in it is visible in the marketplace.

Economists have tools that can be of use in designing these policy interventions, and some of these have been applied to value crop and livestock genetic resources and their diversity. They are summarized in Chapters II and III, in terms of the questions posed, the tools the have been applied, findings, and limitations. The research has to date been carried out separately, although there is congruence in methods. PGR valuation started earlier and AnGR valuation work drew on relevant techniques/approaches from that body of studies; some recent studies in the PGR literature have since drawn on methods applied in AnGR valuation research. Despite advances in the AnGR valuation field since the ILRI/FAO workshop (1999), plants/crops continue to have a higher international profile relative to farm animals, both in terms of international regulatory frameworks (i.e. the International Treaty on Plant Genetic Resources[6] - ITPGR), as well as with regard to research funding (e.g. the CGIAR system has approximately 55-60 international scientists working on PGR issues and less than five working on AnGR issues).

Some have argued that using economics to assign values to species is inherently unethical (Ehrenfeld, 1988); others have viewed valuation as self-serving, seeking to justify, rather than explain or predict. Thus, the focus in this paper is the use of economic analysis to explain and predict how existing levels of genetic variation in crop and livestock species can be sustained for the benefit of current and future society. Valuation is viewed not as a goal in and of itself but a tool that can assist in designing policies to support the sustainable management of crop and livestock genetic resources.

References

Ali, M., and D. Byerlee. (2001). Productivity Growth and Resource Degradation in Pakistan's Punjab. In E.M. Bridges, I.D. Hannam, L.R. Oldeman, F.W.T. Penning de Vries, S.J. Scherr, and S. Sombatpanit (eds.), *Response to Land Degradation*, Enfield, NH: Science Publishers, pp. 186-199.

Anderson, S. (2003) Animal genetic resources and sustainable livelihoods. *Ecological Economics* 45, 331-339.

[6] The need for a similar treaty for AnGR is increasingly being discussed in international fora. However, Wollny (2003) questions whether a government policy claiming general property rights over AnGR will be of benefit to developing countries, particularly given limited means and infrastructure to implement/enforce such legislation. Drucker and Gibson (2003) identify a range of issues that would need to be researched before the relative costs and benefits of such an international regulatory instrument for AnGR can be determined. These include an improved understanding of the importance of continued access and trade in livestock germplasm for research and development purposes; the nature of the costs and benefits arising from AnGR research; and the many national level policy factors affecting AnGR conservation and sustainable use.

Ayalew, W., King J. M., Bruns E., and Rischkowsky B. (2003) Economic evaluation of smallholder subsistence livestock production: lessons from an Ethiopian goat development program. *Ecological Economics* 45, 473-485.

Brown, G. M.(1990) Valuing Genetic Resources. In: Orians, G. H. Brown, G. M. Kunin, W. E. and Swierzbinski J.E (ed.) *Preservation and Valuation of Biological Resources.* University of Washington Press, Seattle, pp. 203-226

Brown, K., Pearce, D., Perrings, C., and Swanson, T. (1993) *Economics and the conservation of global biological diversity*. Working Paper - Global Environment Facility, Washington DC: The World Bank.

Brush, S. B. (ed.) (2000) Genes in the field: on-farm conservation of crop diversity. IDRC/IPGRI/Lewis Publishers, Boca Raton, USA.

Cassman, K. G., S. Wood, P. S. Choo, C. Cooper, C. Devendra, J. Dixon, J. Gaskell, S. Khan, R. Lal, L. Lipper, J. Pretty, J. Primavera, N. Ramankutty, E. Viglizzo, K. Weibe, S. Kadungure, N. Kanbar, Z. Khan, R. Leakey, S. Porter, K. Sebastian, and R. Tharme. 2005. Cultivated Systems. In *Millennium Ecosystem Assessment. Condition Working Group Report.* Washington D.C.: Island Press, *forthcoming*.

Cunningham, E. P. and Syrstad, O. (1987) *Crossbreeding bos indicus and bos taurus for milk production in the tropics*. FAO Animal Production and Health Paper 68.Rome: FAO.

Drucker, A. G. and Gibson, J.P. (2003). A Legal and Regulatory Framework for AnGR? Issues for Consideration. Paper presented at: Workshop on Farm AnGR Legal and Regulatory Framework, Maputo, Mozambique, 19-23 May 2003. FAO/UNDP/GTZ/CTA/SADC.

Drucker, A. G., Gómez V., and Anderson S. (2001) The economic valuation of farm animal genetic resources: a survey of available methods. *Ecological Economics* 36, 1-18.

Drucker, A. G., Gómez, V., Ferraes-Ehuan, N., Rubio, O. and Anderson, S. (1999) Comparative economic analysis of *criollo*, crossbreed and imported pigs in backyard production of Yucatan, Mexico. FMVZ-UADY Mimeo.

Ehrenfeld, D. (1988) Why put a value on biodiversity? In: Wilson, E. O. and Peter F.M. (ed.) *Biodiversity.* National Academic Press., Washington, D.C, pp. 212-216.

Evenson, R. E. (1991) Genetic resources: assessing economic value. In: Vincent, J. Crawford, E. and Hoehn, J. (ed.) *Valuing Environmental Benefits in Developing Economies. Proceedings of a seminar series held February-May 1990 at Michigan State University, Special Report No. 29.*

Evenson, R. E., Gollin, D., and Santaniello (ed.) (1998). *Agricultural values of plant genetic resources,* CABI, FAO, University of Tor Vergara, and CABI Publishing, Wallingford, UK.

FAO. (1997). *The State of the World's Plant Genetic Resources for Food and Agriculture*.

--------. (1999). *The global strategy for the management of farm animal genetic resources,* Food and Agriculture Organisation of the United Nations (FAO), Rome.

--------. Food and Agriculture Organisation of the United Nations (FAO) (ed.) (2000). *World Watch List for Domestic Animal Diversity,* FAO, Rome.

Fowler, C., and T. Hodgkin. (2004). *Plant Genetic Resources for Food and Agriculture: Assessing Global Availability*. Annual Review of Environmental Resources. 20: 143-79.

Frankel, O.H.. (1970) The genetic dangers of the Green Revolution. *World Agriculture* 19, 9-13.

Hall, S. J. G. and Ruane J. (1993) Livestock breeds and their conservation - global review. *Conservation Biology* 7, 815-825.

Hammond, K. and Leitch, H. (1996a) The FAO global program for the management of farm animal genetic resources. In: Miller, R. Pursel, V. and Norman, H. (ed.) *Biotechnology's Role in the Genetic Improvement of Farm Animals.* American Society of Animal Science., pp. 24-42

-------- (1996b) The FAO global program for the management of farm animal genetic resources. In: Miller, R. Pursel, V. and Norman, H. (ed.) *Beltsville Symposia in Agricultural Research. XX. Biotechnology's Role in the Genetic Improvement of Farm Animals.* American Society of Animal Science., Illinois, pp. 24-42

Harlan, J. R. (1972) Genetics of disaster. *Journal of Environmental Quality* 1, 212-215.

--------. 1992). *Crops and Man. 2nd edn,* American Society of Agronomy and Crop Science Society of America, Madison, Wisconsin, USA.

Hawkes, J. G. (1983). *The Diversity of Crop Plants,* Harvard University Press, Cambridge.

Heisey, P. W., Smale M., Byerlee D., and Souza E. (1997) Wheat rusts and the costs of genetic diversity in the Punjab of Pakistan. *American Journal of Agricultural Economics* 79, 726-737.

ILRI Rege, J. E. O. (ed.) (1999) Economic valuation of animal genetic resources. Proceedings of a FAO/ILRI Workshop on Economic Valuation of Animal Genetic Resources, Rome (Italy), 15-17 March 1999. ILRI, Nairobi, Kenya

ITDG. Mulvaney, P. (ed.) (1996) *Livestock keepers safeguarding domestic animal diversity through their animal husbandry*. Dynamic Diversity Series.Rugby, England.: ITDG (Intermediate Technology Development Group).

LID. (1999). *Livestock in poverty-focused development.,* Livestock in Development - LID, Crewkerne, UK.

Louette, D. and Smale M. (2000) Farmers' seed selection practices and traditional maize varieties in Cuzalapa, Mexico. *Euphytica* 113, 25-41.

Louette, D., Charrier, A., and Berthaud, J. 1997. *In situ* conservation of maize in Mexico: genetic diversity and maize seed management in a traditional community. *Economic Botany* 51, 20-38.

Magurran, A. E. (1998). *Ecological diversity and its measurement,* Princeton University Press, Princeton, New Jersey.

Maxted, N., Hawkes J. G., Guarino L., and Sawkins M. (1997) Towards the selection of taxa for plant genetic conservation. *Genetic Resources and Crop Evolution* 44, 337-348.

Mendelsohn, R. (2003) The challenge of conserving indigenous domesticated animals. *Ecological Economics* 45, 501-510.

Pardey, P., Alston, J. M., Chan-Kang, C., Magalhães, E. C., and Vosti, S. (2004) *Assessing and Attributing the Benefits from Varietal Improvement Research in*

Brazil. Research Report 136Washington, DC: International Food Policy Research Institute.
Pearce, D. and Moran, D. (1994). *The economic value of biodiversity,* Earthscan, London.
Pretty, J. (1995). *Regenerating agriculture: policies and practice for sustainability and self-reliance.,* Earthscan, London.
Pressoir, G., and J. Berthaud. (2004) Population Structure and Strong Divergent Selection Shape Phenotypic Diversification in Maize Landraces. Heredity 92, 95-101.
Randall, A. 1988. What Mainstream Economists have to say about the Value of Biodiversity. In E.O.Wilson *(*ed.) *Biodiversity*, Washington, D.C. National Academy Press. pp 217-223.
Rege, J. E. O. and Gibson J. P. (2003) Animal genetic resources and economic development: issues in relation to economic valuation. *Ecological Economics* 45, 319-330.
Rege J. E. O. 2003. *In-situ* conservation of farm animal genetic resources. In: CIP-UPWARD. Conservation and sustainable use of agrobiodiversity: A source book. Los Banos, Laguna, The Philippines. pp. 434-438.
Rege, J. E. O. (ed.) (1999) Economic valuation of animal genetic resources. Proceedings of a FAO/ILRI Workshop on Economic Valuation of Animal Genetic Resources, Rome (Italy), 15-17 March 1999. ILRI, Nairobi, Kenya .
Rice, E.B. 2004. Conservation and Change: A Comparison of In-situ and Ex-situ Conservation of Jala Maize Germplasm in Mexico. Ph. D. thesis. Cornell University, Ithaca.
Simianer, H., Marti S. B., Gibson J., Hanotte O., and Rege J. E. O. (2003) An approach to the optimal allocation of conservation funds to minimize loss of genetic diversity between livestock breeds. *Ecological Economics* 45, 377-392.
Smale, M., Bellon M. R., and Aguirre Gómez J. A. (2001) Maize diversity, variety attributes, and farmers' choices in Southeastern Guanajuato, Mexico Maize diversity, variety attributes, and farmers' choices in Southeastern Guanajuato, Mexico. *Economic Development and Cultural Change* 50, 201-225.
Soleri, D. and Cleveland D. A. (2001) Farmers' genetic perceptions regarding their crop populations: an example with maize in the Central Valleys of Oaxaca, Mexico. *Economic Botany* 55, 106-128.
Vaccaro, L. P. d. (1973) Some aspects of the performance of European pure bred and crossbred dairy cattle in the tropics: Part I: Reproductive efficiency in females. *Animal breeding Abstracts* 41, 571-589.
-------- (1974) Some aspects of the performance of European pure bred and crossbred dairy cattle in the tropics: Part II: Mortality and culling rates. *Animal breeding Abstracts* 42, 93-103.
Wollny, C. B. A. 2003. The need to conserve farm animal genetic resources in Africa: should policy makers be concerned? *Ecological Economics* 45, 341-351.
Zeven, A. C. (1998) Landraces: A review of definitions and classifications. *Euphytica* 104, 127-139.

Chapter II.
Economics literature about crop biodiversity: Findings, methods, and limitations

Melinda Smale

Chapter Overview

In this chapter, a summary of the findings, methods and tools applied are organised by research question. There is a large literature about the economic benefits of improved crop varieties in commercial agriculture, and an extensive amount of conceptual and theoretical literature concerning the sources of value in crop genetic resources and biodiversity. Far less research has been intended to solve the practical problems of crop genetic resource conservation *ex-situ* or *in-situ* (on farms) using economics methods applied to empirical data. A more complete annotated bibliography of related literature will be posted on the SGRP, IFPRI, and ILRI websites.

II.1. What is the commercial value from exploiting an individual plant species or crop genetic resource?

Findings

The marginal commercial value expected from an individual plant genetic resource in agricultural use will not be high enough, in general, to fund national innovation or conservation efforts at levels desirable for society. The perception that individual plant genetic resources have great commercial value is based largely on anecdotal cases in which substances identified in wild, indigenous plants have generated profits for pharmaceutical companies. Economics research has cast doubt on the likelihood that the willingness to pay for prospecting these resources in the pharmaceutical industry would be sufficient to promote the conservation of their habitats (Craft and Simpson 2001; Simpson, Sedjo and Reid 1996; Koo and Wright 2000a). Evidence to suggest that any one landrace or improved variety will generate large commercial returns in agricultural use—and therefore huge benefits through restricting access to it—is even more modest. Gollin and Smale (1998, 244-6) cautioned against “the myth of enormous value” associated with an individual crop genetic resource. Though there are instances in which a single plant genetic resource has proved extremely valuable, these cannot be generalised. There are three reasons why economists are sceptical:

(1) The first reason is the process of plant breeding. In plant breeding, numerous genetic resources are continually shuffled and reshuffled in an uncertain search for traits that are well expressed in a crop variety destined for highly differentiated production conditions. Economically important traits are distributed statistically across plant genetic resources, with varying likelihood of encountering useful levels. The traits demanded by societies, such as resistance to plant pests and diseases, and quality attributes preferred by consumers, also change frequently in response to environmental stress and economic changes, keeping plant breeders on a treadmill to surpass past

accomplishments. Breeding products (crop varieties) contain many "ingredients" that are also genetic resources and these products are in turn combined with others to produce the next variety. The marginal contribution of the last resource used may be slight. Attributing value to each ingredient is difficult.

(2) A second reason is the nature of crop production. Changes in productivity that underlay economic benefits from new varieties involve multiple factors in interaction with the seed. A well-known example is the Green Revolution in wheat. The economic benefits associated with the Green Revolution cannot be ascribed solely to the dwarfing genes, the landrace that contained them, or the scientist who initially bred them into another cultivar. An estimated 1749 spring bread wheat cultivars were recorded as released by national breeding programs in low- and middle-income countries from 1966 to 1997, with an growing proportion carrying the semidwarf genes; in 1997, 88% of all spring bread wheat grown by farmers in these countries was sown to semidwarf types (Byerlee and Moya 1993; Heisey, Lantican and Dubin 2002). A number of agroecological, social, economic, and policy factors influenced the widespread adoption of those cultivars, generating economic benefits through yield gains. Concurrently, major changes in the growing environments for varieties enhanced those yield gains, such as increased water use, fertiliser application and the expertise of farmers. Production benefits were then transmitted via prices and distributed to society through effects on producers' and consumers' incomes.

(3) A third reason is the existence of substitutes, although they are not always available. To what extent are the traits and gene complexes embodied in seed unique to one plant genetic resource? The same trait may be apparent to one degree or another in many other plant genetic resources. Seed samples of the same genetic resource may also be found in more than one *ex-situ* collection, in more than one political jurisdiction. Even when rare in a given collection, accessions carrying useful traits might be duplicated among seed samples (accessions) in multiple collections. Similarly, though locally rare in farmers' fields, they could be globally abundant.

The commercial value of plant genetic resources is a relatively small component of their total use value in agriculture because of market imperfections, particularly in developing and transitional economies. Many values are not captured well in market prices (and this is not likely to change in the near future), so that public investments in innovation and conservation will continue to be needed for social welfare (Brown 1990; Swanson 1996). Since the potential usefulness of any single genetic resource is often highly uncertain, and time horizons for developing products from genetic resources are long, private investors typically under-invest in conserving them at the levels needed by society. Furthermore, each market-based analysis is generally fixed in time, and projections are based on assumptions that might not be borne out. Tastes and preferences are dynamic; and unforeseen production shocks occur. As a consequence, the public sector has played a pivotal role in conserving these resources and will continue to do so in the foreseeable future.

Methods

Overviews and surveys discussing the sources of economic value in plant genetic resources have been numerous, including Pearce and Moran (1994), Swanson (1996) and Gollin and Smale (1998). The value of diversity in crop or animal species has been modelled theoretically, supported in some cases by empirical data (Brown and Goldstein 1984; Weitzman 1993; Polasky and Solow 1995; Evenson and Lemarié 1998; Simpson, Sedjo and Reid 1996; Craft and Simpson 2001; Rausser and Small 2000). The global values of genetic resources, along with other ecosystem services have been assessed in an ecological economics framework with large-scale secondary databases (Costanza et al. 1997). The values of plant genetic resources and their diversity in crop breeding have been estimated by applying a combination of production economics and forms of hedonic analysis (Evenson, Gollin and Santaniello 1998). Hedonic analysis relates explicit prices for marketed goods to the implicit prices of the attributes of the goods, revealing their marginal value.

Limitations

This literature has advanced the theoretical and conceptual understanding of issues. More conceptual and theoretical work is needed to develop a better understanding of feasible, cost-effective approaches to valuing multiple components of agricultural biodiversity and services (see, for example, Ceroni et al. 2005).

II.2. What is the rate of return to improvement of crop genetic resources?

Findings

There is ample evidence that the successive, continuous releases of improved varieties by plant breeding programs, many of them publicly-financed, have generated economic returns that far outweigh the costs of investment. The important role of plant genetic resources in the development of world agriculture is clear, both historically (Cox, Murphy and Goodman 1988; Fowler 1994) and more recently (Fowler, Smale and Gaiji 2001). Economists have repeatedly demonstrated that rates of return to investment in plant breeding programs are high (Byerlee and Traxler 1995; Morris and López-Pereira 1999; Alston et al. 2000; Evenson 2001; Heisey, Lantican and Dubin 2002; Evenson and Gollin 2003). Research on farm-level adoption of these varieties was also extensive, reviewed in 1985 by Feder, Just and Zilberman, and in 1993 by Feder and Umali. Although the marginal benefit that can be attributed to a single gene or genetic resource in plant breeding is likely to represent a relatively small proportion of the total, the productivity benefits accruing to society as a whole and especially to consumers in terms of lower food prices are large relative to the costs of investing in plant breeding. This is particularly true in less advanced agricultural economies where consumers spend a much larger proportion of their budgets on food. Successful innovation has depended on access to a wide range of materials (for example, Smale et al. 2002).

Methods

The compendium and state-of-the-art of methods used to assess the economic benefits or productivity gains are found in Alston, Norton, and Pardey (1998). Economic surplus or econometric methods are commonly used. Methodological challenges within the framework of assessing the commercial economic benefits of agricultural research are explored in a large body of literature, including Alston, Norton and Pardey (1998), Alston et al. (2000), and Morris and Heisey (2003).

Limitations

This literature is extensive and advanced. Methods for attributing the economic benefits of crop improvement by plant breeding programs continue to be refined (Pardey et al. 2004). Methods for apportioning the economic benefits of crop improvement among ancestors and progenitors require the imposition of unrealistic assumptions, however—even in highly-bred crops. For example, the use of Mendelian rules of inheritance ignores the effects of selection in breeding. In general, estimates are only as reliable as the pedigree that has been recorded. Examples in the literature include Gollin (1998), Gollin and Evenson (1998), and Johnson, Pachico and Voysest (2003). Moreover, assessing the economic benefits from genetic resources in crops that are not highly bred or minor crops would require the applications of other methods since these crops do not have pedigrees.

II.3. What is the effect of crop biodiversity on productivity, vulnerability, and efficiency?

Findings

Studies testing the relationship of crop genetic diversity to productivity, vulnerability, and efficiency are so far inconclusive because methodologies require further development and validation. Associations are sometimes positive and sometimes negative. Findings cannot be generalised because they are specific to location, time period, and cropping system. Several studies have tested the relationship of crop biodiversity to productivity, yield variability, and economic efficiency, particularly in farming systems dominated by modern varieties. Heisey et al. (1997) demonstrated that higher levels of latent genetic diversity in modern wheat varieties would have generated costs in terms of yield losses in some years in the Punjab of Pakistan. In other years, the mix of varieties and their spatial distribution across the region generated both lower overall yields and less diversity than was feasible. Smale et al. (1998) found that the production environment determines the sign of the relationship between diversity and productivity, in a different study about wheat varieties in the Punjab of Pakistan. For instance, among rainfed districts, genealogical distance and a greater number of different varieties grown of smaller areas were associated with both higher mean yields and more yield stability. In the irrigated areas, instead, a high spatial concentration of wheat area among fewer varieties, or greater genetic uniformity, had an important, positive effect on expected yields. Applying a similar approach, Widawsky and Rozelle (1998) concluded that rice variety diversity reduced both the mean and the variance of yields in townships of Zhejiang and Jiangsu Provinces of Eastern China. Testing the relationship of wheat variety diversity to productivity and economic efficiency in China, Meng et al. (2003) found that although evenness in morphological groups contributed to higher per hectare costs of wheat produced, potentially important cost savings were apparent for some inputs, such as pesticides. A greater concentration of cooperative market associations in regions of southern Italy contributed to greater diversity of durum wheat varieties, with positive effects on productivity (Di Falco 2003).

Methods

Initial attempts linked diversity in modern varieties in a partial productivity, production function framework, expanding to a mean-variance framework (Just and Pope 1979) and a simultaneous equation system with cost shares. Data have been largely secondary, measured at the township, provincial, or regional level. Applications have focused on modern varieties. Most diversity indices have been constructed from pedigree data, including a Herfindahl index, a Solow-Polasky index, and others based on the number of landrace progenitors or unique parental combinations in the genealogy. Temporal diversity indices (the area-weighted average age of varieties, an indicator of the rate of variety change) and Shannon indices from agro-morphological groups calculated with biometric techniques have also been constructed (Franco et al. 1998).

Limitations

More general approaches require a more complete theoretical framework of decision-making under risk with multiple outputs and differentiated genetic inputs, estimated structurally where data permit, perhaps including higher moments. A wider cross-section of case studies conducted in commercially-oriented, as well as mixed and or subsistence-oriented systems, are required in order to generalise and validate empirical findings. The role of crop genetic diversity in mitigating production and consumption vulnerability in marginal environments and its contribution to system resilience have not been explored. The shortcoming of the primal (production function) approach applied so far is that it enables statistical tests about technical efficiency effects but not about the effects of crop biodiversity on allocative or economic efficiency (cost function approach). Production frontier approaches have not yet been applied.

II.4. What are the costs and benefits of *ex-situ* conservation?

Findings

<u>The expected marginal value of exploiting an individual accession in commercial agricultural use justifies the cost of conserving it in a gene bank.</u> The costs of conserving accessions in gene banks are relatively easy to tabulate compared to the expected benefits from the accessions they conserve. If, as is shown in a set of recent studies compiled by

Koo, Pardey and Wright (2004), the costs of conserving an accession are shown to be lower than any sensible lower-bound estimate of benefits, undertaking the expensive and challenging exercise of benefits estimation is not necessary to justify its conservation. Zohrabian et al. (2003) found that the expected marginal benefit from exploring an additional unimproved gene bank accession in breeding resistant varieties of soybean more than justified the costs of acquiring and conserving it. It has been suggested that many gene bank resources are primarily used when other options have failed, with low probabilities of success (Cox, Murphy and Goodman 1988). Since the payoff can be large for problems of economic importance when the desired traits are rare, conserving some categories of materials "untapped" for years can be justifiable; infrequent use of individual accessions by plant breeding programs does not, in itself, imply that an additional accession will have low value (Gollin, Smale and Skovmand 2000). A recent study of a large national gene bank indicates higher rates of direct utilization in plant breeding than suggested earlier, secondary use through sharing within and outside respondents' institutions, and proportionately higher use rates among respondents in low- and middle-income countries (Day-Rubenstein and Smale 2004). Most plant genetic resources conserved in gene banks reach commercially-oriented farmers when they are bred into improved varieties, though there are outstanding examples of direct distribution of gene bank materials to farmers, including those that are more subsistence-oriented (Hawkes, Maxted and Ford-Lloyd 2000; King 2003).

Methods

To estimate the benefits expected from using an additional gene bank accession in crop breeding, studies have employed mathematical programming, Monte Carlo simulations, and maximum entropy methods in a search theoretic framework, combined with partial equilibrium estimates of the productivity impact of the bred materials in farmer's fields. Findings cannot be broadly generalised and tools for widespread application have not yet been developed. Costs of conserving accessions have been estimated by applying the microeconomic theory of the firm and capital investment decisions. Based on these methods, tools could be developed and directly applied with spreadsheet analysis to gene bank cost data.

Other than this literature, sample surveys have been conducted to assess the extent of gene bank utilization by plant breeders, other scientists, and farmers (Brennan et al. 1999; Smale and Day-Rubenstein 2002; Duvick 1984; Rejesus, Smale and Ginkel 1996). These do not apply economics analysis frameworks, though they are motivated by notions of use value, breeder demand for and supply of materials.

Limitations

Costs and benefits estimated from detailed studies of large national and international gene banks cannot be generalised for all gene banks. The range in benefits is extremely sensitive to assumptions concerning the lag until variety release, and the discount rate, or time value of money. Though the statistical theory used in the search models accounts for relative abundance and the genetic differences among accessions with respect to the trait of interest, the range in simulated benefits is too wide for confidence. The cost analyses distinguish between crops and types of collections, but treat each accession as genetically equivalent.

It is not always the case that active breeding programs are linked to genebanks. Still, the fact that there are uses outside plant breeding for accessions kept in genebanks should be underscored. For example, the economic value through improved livestock production of introducing a few accessions of African grasses (*Panicum maximum, Brachiaria humidicola*) in the lowlands of Colombia, Venezuela and Brazil has been calculated as over hundreds of thousands of dollars. This is also an example of a linkage between crops and livestock (D. Debouck, personal communication).

Few studies have addressed the value of knowledge and information functions of genebanks and of crop genetic resources, although applied economics methods are available to estimate them. With theory, Koo and Wright (2000b) explored the timing of the evaluation of accessions, an important issue for genebank managers who face chronic funding problems. Day-Rubenstein and Smale (2004) tested the effect of accompanying data on the share of accessions received that were reported "useful" by recipients of germplasm samples. One recent PhD thesis estimated the value of seed-related information conveyed to farmers through field days and on-farm trials in West Africa (Horna, 2005).

II.5. Which factors predict variation in crop biodiversity on farms as economies change? Which farmers are most likely to maintain it?

Findings

On farm conservation is defined as the *choice* by farmers to continue cultivating genetically diverse crops, in the agricultural systems where the crops have evolved historically through processes of human and natural selection (from Bellon, Pham and Jackson 1997; Jarvis et al. 2000)[7]. The premise of recent empirical studies (compiled in a volume edited by Smale, forthcoming in 2005) is that the highest benefit-cost ratios for on farm conservation of crop biodiversity will occur where both society and the farmers who maintain it benefit (Smale and Bellon 1999), similar to a concept originally advanced by Krutilla (1967). According to this concept, the highest benefit-cost ratios for on farm conservation of crop genetic resources will occur where the private benefits or utility farmers earn from managing them as well as the public value associated with their biological diversity are high. In these areas, since farmers are already bearing the costs of maintaining diversity and reveal a preference for doing so, the costs of public interventions to support them will be least. As economic development occurs, a necessary

[7] By contrast, with current technologies, all domesticated breeds of livestock are conserved on farms and rangelands. As a consequence of these divergent paths, applied economics research on crop biodiversity has treated both *ex-situ* and on farm conservation, while that addressing livestock genetic diversity concerns only *in-situ* conservation.

condition for this outcome is that consumers demand products arising from crop biodiversity, so that the costs of maintaining it are paid through the market channel. In locations where both the public value and private value of crop biodiversity are known to be relatively low, there is no need to invest in any form of conservation. Where crop biodiversity is great but farmers derive little private value from it, *ex-situ* conservation is the best strategy. Where there is little crop biodiversity but farmers care a lot about it, there is no need for public investment at all since no value is associated with conservation.

So far, a major aim of case studies about on-farm conservation has been to characterise candidate sites for on farm conservation, and within these locations, farmers with high probabilities of maintaining it during economic change (Meng 1997; Van Dusen 2000; Birol 2004; Gauchan 2004). Researchers have sought to identify the factors that increase and decrease the likelihood that farmers will continue to manage crop biodiversity, and develop statistical profiles of those most likely to maintain it. These profiles can be used to design targeted programs in centres of crop biological diversity.

Two of the overriding determinants of crop biodiversity levels on farms are geographical location and environmental heterogeneity, as suggested by theories of population genetics (Marshall and Brown, 1975) and island biogeography (MacArthur and Wilson, 1967). In most of the studies undertaken in low income countries, agricultural production is accomplished with limited use of purchased inputs. Farm technology consists largely of family labour, and in some cases, animal traction, in combination with land and soil quality. Across almost all income levels and crops studied, the larger the physical extent of the farm, the higher is the probability of finding more crops or varieties, more evenly distributed. Where measured, higher numbers of plots, fragments and slopes, are positively associated with crop biodiversity on farms. The direction of land quality relationships (soil erosion and fertility, moisture content) depends on the context.

Another common determinant is relative isolation from physical market infrastructure, which induces farmers to rely on their own production to meet the food and fodder needs of their families. Nonetheless, the relationship of market development and commercialisation to crop biodiversity on farms appears more complex in these studies when specific market features, other than sheer isolation from physical infrastructure or road density, are disengaged. For example, market participation as a seller enhances the range of endemic banana varieties grown in Uganda, while participating as a buyer has the opposite effect (Edmeades, Karamura and Smale 2005). On the hillsides of Ethiopia, different types of markets or road access, such as walking distance from household to road, from the farm to the nearest input shop or dealer, or from the village to the district market, seem to influence the richness (numbers) of varieties grown in different ways (Benin et al. 2004; Gebremedhin, Smale and Pender 2005). Markets clearly provide incentives for farmers to grow aromatic quality landraces, but not to coarse-grained landraces grown in Nepal, though farmers preferred coarse-grained landraces for their adaptation to stress and agronomic traits (Gauchan 2004). Nagarajan (2004) found that seed system characteristics are significant determinants of millet biodiversity at the farm and community levels in southern India.

Another key determinant is cultural richness and cohesiveness, or cultural autonomy, as these relate to the selection pressures applied on the plant materials. The originality and duration of the selection pressures will result in genetically different, stable and uniform landraces across a human community. Because of plant demography considerations, a single farmer will hardly make a tremendous difference over his/ her lifetime (30-40 years) but a human community will (D. Debouck, personal communication). For obvious reasons, this determinant has been more fully analysed in the anthropological and ethnobotanical literature than in the applied economics literature (e.g., Brush, 2002).

Many of the case study findings suggest that in marginal environments, factors associated with economic development may not, in the short-term, detract from intra-crop and in particular inter-crop diversity on farms, whether observed at the farm level or at higher levels of aggregation, such as village, settlement, district, or region. Education of men and women almost uniformly has a positive effect, if at all. In environments with local seed shortages, the introduction of modern varieties broadens the range of materials grown, or has no appreciable effect. Unexpectedly, seed supply interventions through disaster relief and extension programs, including the introduction of modern varieties, did not appear to diminish the richness or evenness of potatoes grown in Cajamarca, Peru (Winters, Hintze and Ortiz 2005) or crop diversity in Eastern Ethiopia (Lipper, Cavatassi and Winters 2005). Access to animal traction, credit, land, and other assets enhance rather than detract from crop biodiversity in most of these studies. Assets are often denominated in livestock, with some consumer durables, few tractors, cars, or other farm machinery.

On the other hand, those households currently maintaining crop biodiversity are generally older, regardless of empirical context. As the population of farmers ages and declines as a proportion of the total population, public investments must be made to encourage the retention of local knowledge in crops and varieties—in some form. Labour effects are multiple and counteracting. It is evident that diversification in any form studied is most often associated with relatively labour-intensive production. Non-farm cash transfers and income contributes to sustaining intra- and inter-crop diversity in several of the cases, but the Mexico case (Van Dusen 2005) reveals the negative impact of long-term, international migration.

A case study in Peru (Winters, Hintze and Ortiz 2005) illustrates how the rapid uptake of a more remunerative, labour-intensive activity—dairy farming—may lead to the decline of intra-crop diversity. There will often be better ways to relieve poverty than through either the introduction of crop varieties or the diversification of crop varieties. A staple food crop in a subsistence-oriented farming system does not tend to be highly remunerative, unless—as in the case of durum wheat in southern Italy—a highly differentiated, commercial market emerges. Typically, there are social costs associated with developing such markets and strong consumer demand is a prerequisite for their success.

Statistical profiles of households most likely to sustain crop biodiversity suggest that conservation programs can be designed to address social equity goals. Though most farmers on the hillsides of Nepal may be ranked as poor by global standards, targeting the households relatively more likely to maintain valuable landraces in those locations is by no means equivalent to targeting the poor. In Hungary, targeting the households most likely to maintain agrobiodiversity at least cost is equivalent to targeting the poor, or relatively disadvantaged rural populations (Birol 2004). Effectively, the poorer regions of southern Italy have been targeted to sustain durum wheat diversity on farms as a consequence of national and European Union policies, whether deliberately or not.

Methods

Seminal approaches that initiated this work (Brush, Taylor and Bellon 1992; Meng 1997) built on the literature about the adoption of agricultural innovations in developing economies (Feder, Just and Zilberman 1985; Feder and Umali D.L. 1993). Later, Van Dusen (2000) developed a farmer decision-making model in the theoretic framework of the agricultural household (Singh, Squire, and Strauss 1986; de Janvry, Fafchamps and Sadoulet 1991). Several trait- or attribute-based approaches have been advanced (Wale and Mburu 2005; Edmeades, Karamura and Smale 2005), based on Lancaster's theory of consumer choice (1966). The theoretical model is applied econometrically in a reduced form equation. Dependent variables are diversity indices constructed over optimal choices, as observed on farms. Crop biodiversity is generally treated as an outcome, or indirect choice, of farmer decision-making rather than a deliberate choice.

Limitations

Less well analysed in the published economics literature are species sometimes known as "orphan crops," which are of minor economic importance globally but have also benefited less from public or private research investments. Too much research has focused on the crop while treating other crops and economic activities as exogenous or given, rather than tackling the question within a whole-farm or whole-household farm decision-making framework.

The smallest social unit for agrobiodiversity conservation is the village or community rather than the farm household, because of the mixed goods nature of biodiversity, the social dilemma involved, and population genetics. Analysis at the household level does not provide sufficient information about diversity in larger biological units, even when explanatory economic variables measured in larger units can be introduced into the equation. Moreover, variation across communities may be more important for programme design than variation within any single community.

An economics conceptual framework will need to be developed to relate analyses based on the household model to larger scales of aggregation. In particular, the role of seed supply and demand factors must be better understood. Few institutional approaches are apparent in the literature so far.

II.6. What is the value of crop genetic resources to farmers?

Findings

Across a range of crops, national income levels, and agro-ecological environments, case studies support the notion that farmers value various dimensions of crop biodiversity. Yet, the predictions of economic theory are confirmed, even among regions in relatively rich nations, like Hungary. Farmers in the less productive, most remote regions of this high-income country value agrobiodiversity the most. As the settlements in which farmers reside develop and the physical infrastructure of their markets becomes denser, they will rely less on their home-produced goods for food and the value they ascribe to agrobiodiversity on their farms will diminishes (Birol 2004). Farmers in southern Italy enjoy an historical endowment of local wheat diversity, producing durum wheat in a challenging environment for controlled, highly articulated and differentiated markets. Durum wheat diversity and crop diversification appear to contribute positive to crop productivity and farmer revenues (Di Falco 2003).

Methods

Predictions from econometric models described in question 5 represent the preferences farmers reveal for crop varieties and attributes given their production technology, cash expenditures, and other constraints. They provide one means of ranking locations, farmers, or the sets of varieties according to their private value, in terms of current, direct use. Stated preference approaches can be used to generate either ordinal or cardinal estimates of value for non-market goods such as crop biodiversity. These can be elicited with any one of a number of marketing research tools or related methods used to value environmental goods that are not traded in markets.

Stated preference methods have varying degrees of sophistication. Matrix ranking, utility scores and other approaches have been used in focus group and household interviews (Gauchan 2004; Bela, Balázs and Pataki 2005; Gauchan 2004; Lipper, Cavatassi and Winters 2005). Econometric methods have been applied to data from choice experiments conducted with sample surveys to estimate the value farmers assign to components of agrobiodiversity, including the richness of crop varieties, cultivation of landraces, use of organic methods, and integrated crop and livestock production (Birol 2004; Birol, Smale and Gyovai 2004). The choice experiment approach exhibits some operational advantages. The theoretic framework of the choice experiment draws from the Lancaster theory of consumer choice (1966), as well as the random utility model.

Limitations

These approaches, like those based on the household farm model of on farm diversity, rely on intensive, primary data collection. In the case of the choice experiment, the apparent simplicity of the survey instruments relative to household surveys disguises the complexity involved in data manipulation of choice sets. Moreover, as in any household survey, the design of the survey instrument is critical since measurement error in operational variables may be great, generating biased estimates.

Additional applications of stated preference methods, with different survey instruments, are needed in order to assess the advantages and disadvantages of the research tool for valuing agrobiodiversity and its components in poorer countries with less literate populations. The well-known limitation of all stated preference approaches is their hypothetical nature compared to revealed preferences, though both stated and revealed preferences have advantages and drawbacks. Combining choice experiment and farm household data analysis could strengthen the reliability of results. In addition, the roles of production and consumption risk are relevant to both revealed and stated preference formulation but have not yet been investigated with a theoretic framework in this literature. These may also be compared to valuation findings from institutional analyses. (Bela, Balázs and Pataki 2005).

II.7. Which diversity index is appropriate to use in applied economics analyses?

Findings

Authors have tested a range of diversity indices or metrics as dependent variables in econometric analysis. Their construction, relative advantages and disadvantages for social scientists are reviewed by Meng et al. (1998). Indices are scalars constructed from any one of several types of data, including agro-morphological, genealogical and taxonomic information. Some examples of criteria that have been used in choosing dependent variables for applied economic analysis are shown in Table II.1. Diversity indices can reflect various conservation goals, such as rarity, heterogeneity (intra-variety or intra-population diversity), or adaptation. They might also represent various types of use value. For example, rarity may represent option value. A diversity index constructed for heterogeneity might express local, impure (private and public) goods, such as resistance to biotic or abiotic stress. Inferences of this type must be decided in consultation with crop scientists and genetics experts.

One conclusion of the recent literature is that the more sophisticated the diversity index in terms of genetics and mathematics, the farther removed it is from the units that farmers recognize as varieties and about which they make decisions. At the household level, simple indices of richness and relative abundance have a stronger overlap with social science and are more easily interpreted in terms of farmer behaviour—given that they are based on a careful taxonomy that is comprehensible to both farmers and professional scientists. Other indices may provide more information and explanatory power at other levels of scales of analysis, such as the breeding program, the gene bank collection, or the on-farm conservation site (village or region). If a thorough taxonomy of farmer-managed units and genetic units has been completed for the site, however, these more sophisticated measurements can be linked to household-level diversity indices.

Krutilla (1967) suggested that when little is known about the cardinal value of non-market benefits, scientific estimates could be used as proxies for ranking the potential value of candidate sites for conservation. Metrics for assessing the public value of crop biodiversity can be based on criteria that plant breeders and geneticists employ to identify useful genetic materials for future crop improvement. For example, greater public value might be associated with genes that are locally common but globally rare, on the supposition that these carry both the greatest potential for adaptation and scarcity value. Values can also be elicited from urban consumers. In Nepal, Gauchan (2004) developed prototypes of the farmers most likely to continuing growing rice landraces that conservationists and plant breeders also ranked as important for future crop improvement. Greater public value is associated in his analysis with such criteria as rare genes or gene variants, genetic diversity or heterogeneity, and adaptive traits.

Limitations

Analysis is based on cross-sectional data collected with sample surveys conducted in each location, and panel data is needed. A problem that has plagued empirical studies thus far is that the strength of the economics data typically is not matched in any individual case by the genetic diversity data, and vice versa. In addition, results are not easy to generalise given the high degree of location-specificity in cropping systems and other variables measured.

Table II.1. Crop biodiversity: Criteria to consider when choosing a diversity index

Criteria	**Examples**
Crop reproduction	Self
	Cross
	Vegetative
Farming system	Modern
	Traditional
	Mixed
Diversity concept	Latent/apparent
	Spatial/temporal
	Inter-infra variety/inter-infra species
Level or scale	Household
	Community
	Region
	Nation
Conservation goal	Rarity
	Heterogeneity
	Adaptation
Data used to construct index	Molecular analysis
	Agro-morphological characterization
	Pedigrees
	Ecological maps
	Taxonomies from focus groups with farmers or plant breeders

Source: Smale (ed.) 2005.

References

Alston, J. M., Chan-Kang, C., Marra, M. C., Pardey, P. G., and Wyatt, T. J. (2000) *A meta-analysis of rates of return to agricultural R&D: ex pede herculem?* IFPRI Research Report No 113. Washington DC: International Food Policy Research Institute

Alston, J. M., Norton, G. W., and Pardey, P. G. (1998). *Science under scarcity: principles and practice for agricultural research evaluation and priority setting,* CAB International, Wallingford, UK

Bela, G., Balázs, B., and Pataki, G.(2005) Institutions, stakeholders, and the management of crop genetic sources on Hungarian family farms. In: Smale, M. (ed.) *Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change.* CABI Publishing (forthcoming), Wallingford, UK, pp.

Bellon, M. R., Pham, J. L., and Jackson, M. T.(1997) Genetic conservation: a role for rice farmers. In: Maxted, N. Ford-Lloyd, B. and Hawkes, J. G. (ed.) *Plant genetic conservation: the in situ approach.* Chapman & Hall, London; New York, pp. 263-289

Benin, S., M. Smale, J. Pender, B. Gebremedhin and S. Ehui. 2004. The economic determinants of cereal crop diversity on farms in the Ethiopian Highlands. *Agricultural Economics* 31: 197-208.

Birol, E. (2004) Valuing agricultural biodiversity on home gardens in Hungary: An application of stated and revealed preference methods, PhD Thesis University College London, University of London, UK.

Birol, E., Smale, M., and Gyovai, A. (2004) *Agri-Environmental Policies in a Transitional Economy: The Value of Agricultural Biodiversity in Hungarian Home Gardens*. EPTD Discussion Paper - Environment and Production Technology Division, International Food Policy Research Institute., Washington DC: International Food Policy Research Institute.

Brennan, J. P., Godden D., Smale M., and Meng E. (1999) Breeder demand for and utilisation of wheat genetic resources in Australia. *Plant Varieties & Seeds* 12, 113-127

Brown, G. and Goldstein J. H. (1984) A model for valuing endangered species. *Journal of Environmental Economics and Management* 11, 303-309.

Brown, G. M.(1990) Valuing Genetic Resources. In: Orians, G. H. Brown, G. M. Kunin, W. E. and Swierzbinski J.E (ed.) *Preservation and Valuation of Biological Resources.* University of Washington Press, Seattle, pp. 203-226

Brush, S. B., Taylor J. E., and Bellon M. R. (1992) Technology adoption and biological diversity in Andean potato agriculture. *Journal of Development Economics* 39, 365-387.

Brush, S.B. (ed.). 2002. *Genes in the Fields*: *On-Farm Conservation of Crop Diversity.* International Plant Genetic Resources Institute (IPGRI), Rome, International Development Research Centre (IDRC), Ottawa, and Lewis Publishers, Boca Raton, USA.

Byerlee, D. and Moya, P. (1993). *Impacts of international wheat breeding research in the developing world, 1966-1990,* CIMMYT, Mexico D.F.

Byerlee, D. and Traxler G. (1995) National and international wheat improvement research in the post-Green Revolution period: evolution and impacts. *American Journal of Agricultural Economics* 77, 268-278.

Ceroni, M, S. Liu, and R. Costanza. (2005). The Ecological and Economic Roles of Biodiversity in Agroecosystems. In Jarvis, DI, C Padoch, and D Cooper (eds). *Managing Biodiversity in Agroecosystems*. Columbia University Press, NY USA.

Costanza, R., d'Arge R., de Groot R., Farber S. C., Grasso M., Hannon B., Limburg K., Naeem S., O'Neill R. V., Paruelo J., Raskin R. G., Sutton P., and van den Belt M. (1997) The value of the world's ecosystem services and natural capital. *Nature* 387, 253-260.

Cox, T. S., Murphy, J. P., and Goodman, M. M.(1988) The contribution of exotic germplasm to American agriculture. In: Kloppenburg, J. R. Jr. (ed.) *Seeds and Sovereignty : The Use and Control of Plant Genetic Resources.* Duke University Press., Durham, N.C., pp. 114-144

Craft A.B. and Simpson R. D. (2001) The Value of Biodiversity in Pharmaceutical Research with Differentiated Products. *Environmental & Resource Economics* 18, 1-17.

Day-Rubenstein, K. and Smale, M. (2004) *International Exchange of Genetic Resources, the Role of Information and Implications for Ownership: The Case of the U.S. National Plant Germplasm System*. EPTD Discussion Paper 119 - Environment and Production Technology Division, International Food Policy Research Institute. Washington DC: International Food Policy Research Institute

de Janvry, A., Fafchamps M., and Sadoulet E. (1991) Peasant Household Behaviour With Missing Markets - Some Paradoxes Explained. *Economic Journal* 101, 1400-1417.

Di Falco, S. (2003) Crop Genetic Diversity, Agroecosystem Production and the Stability of Farm Income. Ph.D. dissertation Environment Department University of York, UK.

Duvick, D. N. (1984) Genetic diversity in major farm crops on the farm and in reserve. *Economic Botany* 38, 161-178.

Dyer Leal, G. A. (2002) The Cost of *In Situ* Conservation of Maize Landraces in the Sierra Norte de Puebla, Mexico. PhD. Dissertation, University of California - Davis.

Edmeades, S., Karamura, D., and Smale, M.(2005) Demand for cultivar attributes and the biodiversity of bananas in Uganda. In: Smale, M. (ed.) *Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change.* CABI Publishing, Wallingford, UK, pp.

Evenson, R. E.(2001) Economic impacts of agricultural research and extension. In: Gardner, B. and Rausser, G. (ed.) *Handbook of Agricultural Economics.* Elsevier Science, Amsterdam, pp.

Evenson, R. E. and Gollin, D. (ed.) (2003). *Crop variety improvement and its effect on productivity: the impact of international agricultural research,* CABI Publishing, Wallingford, UK.

Evenson, R. E., Gollin, D., and Santaniello, V. (ed.) (1998). *Agricultural values of plant genetic resources,* CABI, FAO, University of Tor Vergara, and CABI Publishing, Wallingford, UK.

Evenson, R. E. and Lemarié, S.(1998) Crop Breeding Models and Implications for Valuing Genetic Resources. In: Smale, M. (ed.) *Farmers, gene banks and crop breeding: economic analyses of diversity in wheat, maize, and rice.* Kluwer Academic Publishers, Boston, Massachusetts, pp. 79-92

Feder, G., Just R. E., and Zilberman D. (1985) Adoption of agricultural innovations in developing countries: a survey. *Economic Development and Cultural Change*, 255-298.

Feder, G. and Umali D.L. (1993) The adoption of agricultural innovations: A review. *Technological Forecasting and Social Change*, 215-239.

Fowler, C. (1994). *Unnatural selection: Technology, politics, and plant evolution,* Gordon and Breach Science Publishers, Yverdon, Switzerland.

Fowler, C., Smale M., and Gaiji S. (2001) Unequal exchange? Recent transfers of agricultural resources and their implications for developing countries. *Development Policy Review* 19, 181-205.

Franco, J., Crossa J., Villasenor J., Taba S., and Eberhart S. A. (1998) Classifying genetic resources by categorical and continuous variables. *Crop Science* 38, 1688-1696.

Gauchan, D. (2004) Conserving Crop Genetic Resources On-Farm: The Case of Rice in Nepal. PhD dissertation, University of Birmingham.

Gebremedhin, B., Smale, M., and Pender, J.(2005) Determinants of cereal diversity in villages of Northern Ethiopia. In: Smale, M. (ed.) *Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change.* CABI Publishing (forthcoming), Wallingford, UK, pp.

Gollin, D.(1998) Valuing farmers' rights. In: Evenson, R. E. Gollin, D. and Santaniello, V. (ed.) CAB International; Wallingford, pp. 233-245

Gollin, D. and Evenson, R. E.(1998) An application of hedonic pricing methods to value rice genetic resources in India. In: Evenson, R. E. Gollin, D. and Santaniello, V. (ed.) *Agricultural values of plant genetic resources.* CAB International., Wallingford, U.K., pp. 139-150

Gollin, D. and Smale, M.(1998) Valuing Genetic Diversity: Crop Plants and Agroecosystems. In: Collins, W. W. and Qualset, C. O. (ed.) *Biodiversity in Agroecosystems.* CRC Press, London, pp. 237-265

Gollin, D., Smale M., and Skovmand B. (2000) Searching an *Ex Situ* Collection of Wheat Genetic Resources. *American Journal of Agricultural Economics* 82, 812-827.

Hawkes, J. G., Maxted, N., and Ford-Lloyd, B. (2000) *The ex situ conservation of plant genetic resources*. Dordrecht: Kluwer.

Heisey, P. W., Lantican, M. A., and Dubin, H. J. 2002). *Impacts of international wheat breeding research in developing countries, 1966-97,* CIMMYT (International Maize and Wheat Improvement Centre), Mexico D.F.

Heisey, P. W., Smale M., Byerlee D., and Souza E. (1997) Wheat rusts and the costs of genetic diversity in the Punjab of Pakistan. *American Journal of Agricultural Economics* 79, 726-737.

Horna, D. 2005. Evaluating Private Participation in Agricultural Extension: The Case of Rice in Nigeria and Benin. PhD dissertation. University of Hohenheim.

Jarvis, D. Sthapit, L. and Sears, L. (ed.) (2000). *Conserving agricultural biodiversity in situ: A scientific basis for sustainable agriculture.,* International Plant Genetic Resources Institute, Rome, Italy.

Johnson, N. L., Pachico D., and Voysest O. (2003) The distribution of benefits from public international germplasm banks: the case of beans in Latin America. *Agricultural Economics* 29, 277-286.

Just, R. E. and Pope R. D. (1979) Production Function Estimation and Related Risk Considerations. *American Journal of Agricultural Economics* 61, 276-284.

King, A. Productive Partnerships - Gene banks Working in In-situ Conservation. 2003. An unpublished report solicited by the Global Conservation Trust. Rome, Italy

Koo, B., Pardey, P. G., and Wright, B. D. (2004). *Saving seeds: The economics of conserving crop genetic resources ex situ in the Future Harvest Centres of the CGIAR,* CABI Publishing, Wallingford, UK.

Koo, B. and Wright B.D. (2000a) The role of biodiversity products as incentives for conserving biological diversity: Some instructive examples. *The Science of the Total Environment* 240, 21-30.

Koo, B. and Wright, B.D. (2000b). The optimal timing of evaluation of genebank accessions and the effects of biotechnology. *American Journal of Agricultural Economics* 82(4).

Krutilla, J. V. (1967) Conservation Reconsidered. *The American Economic Review* 57, 777-786.

Lancaster, K. (1966) A new approach to consumer theory. *Journal of Political Economy* 74, 132-157.

Lipper, L., Cavatassi, R., and Winters, P.(2005) Seeds supply and on farm demand for diversity: a case study of Eastern Ethiopia. In: Smale, M. (ed.) *Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change.* CABI Publishing (forthcoming), Wallingford, UK, pp.

Luce, R. 1959). *Individual choice behaviour,* Wiley, New York. McFadden, D.(1974) Conditional *logit* analysis of qualitative choice behaviours. In: Zarembka, P. (ed.) *Frontiers in Econometrics.* Academic Press, New York, pp.

MacArthur, R. and Wilson, E. (1967) The Theory of Island Biogeography. Princeton University Press, New Jersey.

Marshall, D.R. and Brown, A.H.D. 1975. Optimum sampling strategies in genetic conservation. In O. H. Frankel and J.G. Hawkes (eds), Crop Genetic Resources for Today and Tomorrow, Cambridge University Press, Cambridge, pp. 53-80

Meng, E. C. H. (1997) Land allocation decisions and *in situ* conservation of crop genetic resources: The case of wheat landraces in Turkey. Ph.D. dissertation Davis, California, USA: University of California.

Meng, E. C. H., Smale, M., Bellon, M. R., and Grimanelli, D.(1998) Definition and measurements of crop diversity for economic analysis. In: Smale, M. (ed.) *Farmers, Gene Banks and Crop Breeding: Economic Analyses of Diversity in Wheat, Maize, and Rice.* Kluwer Academic Publishers, Boston, pp. 19-31

Meng, E. C. H., Smale, M., Rozelle, S. D., Hu, R., and Huang, J.(2003) Wheat genetic diversity in China: measurement and cost. In: Rozelle, S. D. and Sumner, D. A. (ed.) *Agricultural trade and policy in China: issues, analysis and implications.* Ashgate, Burlington, Vermont, USA, pp. 251-267

Morris, M. L. and Heisey P. W. (2003) Estimating the benefits of plant breeding research: methodological issues and practical challenges. *Agricultural Economics* 29, 241-252.

Morris, M. L. and López-Pereira, M. A. (1999). *Impacts of maize breeding research in Latin America, 1966-1997,* International Maize and Wheat Improvement Centre (CIMMYT), Mexico D.F.

Nagarajan, L. (2004) Managing Millet Diversity: Farmer's Choices, Seed Systems and Genetic Resource Policy in India. PhD thesis. Department of Applied Economics, University of Minnesota.

Pardey, P., Alston, J. M., Chan-Kang, C., Magalhães, E. C., and Vosti, S. (2004) *Assessing and Attributing the Benefits from Varietal Improvement Research in Brazil*. Research Report 136Washington, DC: International Food Policy Research Institute.

Pearce, D. and Moran, D. (1994). *The economic value of biodiversity,* Earthscan, London.

Polasky, S. and Solow A. (1995) On the Value of a Collection of Species. *Journal of Environmental Economics and Management* 29, 298-303.

Rausser, G. C. and Small A. A. (2000) Valuing research leads: bioprospecting and the conservation of genetic resources. *Journal of Political Economy* 108, 173-206.

Rejesus, R. M., Smale M., and Ginkel M. v. (1996) Wheat breeders' perspectives on genetic diversity and germplasm use: findings from an international survey. *Plant Varieties & Seeds* 9, 129-147.

Simpson, R. D., Sedjo R. A., and Reid J. W. (1996) Valuing biodiversity for use in pharmaceutical research. *Journal of Political Economy* 104, 163-185

Singh I., Squire L., and Strauss J. (1986) A Survey of Agricultural Household models : Recent Findings and Policy Implications. *World Bank Economic Review* 1, 149-179.

Smale, M. and Bellon, M. R.(1999) A conceptual framework for valuing on-farm genetic resources. In: Wood, D. and Lenné, J. M. (ed.) *Agrobiodiversity: characterization, utilization and management.* CABI Publishing, Wallingford, UK, pp. 387-408

Smale, M. and Day-Rubenstein K. (2002) The demand for crop genetic resources: international use of the US National Plant Germplasm System. *World Development* 30, 1639-1655.

Smale, M., Hartell J., Heisey P. W., and Senauer B. (1998) The contribution of genetic resources and diversity to wheat production in the Punjab of Pakistan. *American Journal of Agricultural Economics* 80, 482-493.

Smale, M., Reynolds M. P., Warburton M., Skovmand B., Trethowan R., Singh R. P., Ortiz-Monasterio I., and Crossa J. (2002) Dimensions of diversity in modern spring bread wheat in developing countries from 1965. *Crop Science* 42, 1766-1779.

Smale, M. (ed.) 2005. *Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change.* CABI Publishing, Wallingford, UK.

Swanson, T. (1996) Global values of biological diversity: the public interest in the conservation of plant genetic resources for agriculture. *Plant Genetic Resources Newsletter*, 1-7.

Van Dusen, E.(2005) Missing markets, migration and crop biodiversity in the Mexican *milpa* system: A household farm model. In: Smale, M. (ed.) *Valuing Crop*

Biodiversity: On-Farm Genetic Resources and Economic Change. CABI Publishing, Wallingford, UK, pp.

-------- (2000) *In situ* conservation of Crop Genetic Resources in the Mexican *Milpa* System. PhD Thesis University of California at Davis.

Wale, E. and Mburu, J.(2005) Demand for attributes and on farm conservation of coffee in Ethiopia. In: Smale, M. (ed.) *Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change.* CABI Publishing, Wallingford, UK, pp.

Weitzman, M. L. (1993) What to Preserve? An Application of Diversity Theory to Crane Conservation. *The Quarterly Journal of Economics* 108, 157-183.

Widawsky, D. and Rozelle, S. D.(1998) Varietal diversity and yield variability in Chinese rice production. In: Smale, M. (ed.) *Farmers, Gene Banks, and Crop Breeding: Economic Analyses of Diversity in Wheat, Maize and Rice.* Kluwer Academic Press and CIMMYT., Dordrecht, pp. 159-172

Winters, P., Hintze, L. H., and Ortiz, O.(2005) Rural development and the diversity of potatoes on farms in Cajamarca, Peru. In: Smale, M. (ed.) *Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change.* CABI Publishing, Wallingford, UK, pp.

Zohrabian, A., Traxler G., Caudill S., and Smale M. (2003) Valuing pre-commercial genetic resources: a maximum entropy approach. *American Journal of Agricultural Economics* 85, 429-436.

Chapter III.
Economics literature regarding livestock biodiversity:
Findings, methods and limitations

Adam G. Drucker

Chapter Overview

In this chapter, a summary of the findings, methods and tools applied are organised by research question. Although there is a large literature about the economic benefits of improved breeds in intensive (largely developed country) commercial agriculture, the importance of indigenous breeds and trait values in the subsistence production systems typical of developing countries have been studied much less. Despite an extensive amount of conceptual and theoretical literature concerning the sources of value in genetic resources and biodiversity in general (but usually referring to plants and wild animals), it is in fact only since the FAO/ILRI workshop (1999) identified potential AnGR valuation methodologies, combined with the subsequent initiatives of ILRI (Economics of AnGR Conservation and Sustainable Use Programme) and its partners to test such methodologies, that significant research of this type has been carried out. The application of such tools and their findings still remains to be carried out in contexts that have an influence on policy-making and farmer livelihoods.

A more complete annotated bibliography of related literature, prepared by Zambrano, Smale and Drucker, will be posted on the SGRP, IFPRI, and ILRI websites.

III.1 What is the value of livestock genetic resources to farmers?

Findings

Conventional productivity evaluation criteria are inadequate to evaluate subsistence livestock production and have tended to overestimate the benefits of breed substitution. Adaptive traits and non-income functions form important components of the total value of indigenous breed animals to livestock keepers.

Tano et al. (2003) and Scarpa et al. (2003[a&b]) use stated preference choice experiments (CE) to value the phenotypic traits expressed in indigenous breeds of livestock. Adaptive traits and non-income functions are shown to form important components of the total value of the animals to livestock keepers. In W. Africa, for example, the most important traits for incorporation into breed improvement program goals were found to be disease resistance, fitness for traction and reproductive performance. Beef and milk production were less important. The studies' results also show that not only do these techniques (adapted from other areas of environmental economic analysis) function for AnGR research but can be used to investigate values of genetically-determined traits currently not widely recognised in livestock populations, but desirable candidates for breeding or conservation programs (e.g. disease resistance).

Karugia et al. (2001) use an aggregate demand and supply approach covering both national and farm levels. They argue that conventional economic evaluations of crossbreeding programmes have overestimated their benefits by ignoring subsidies, the increased costs of management such as veterinary support services, and the higher levels of risk and socio-environmental costs associated with the loss of the indigenous genotypes. Applied to Kenyan dairy farmers, results suggest that at the national level crossbreeding has had a positive impact on Kenyan society's welfare (based on a consumer/producer surplus measure), although taking into account important social cost components substantially lowers the net benefits. Farm-level performance is, however, little improved under certain production systems by replacing the indigenous zebu with exotic breeds.

In comparing the performance of different genotypes (indigenous goats vs. exotic crosses), Ayalew et al. (2003) comes to a similar conclusion. The secondary importance of meat and milk production traits in many production systems leads them to argue that conventional productivity evaluation criteria are inadequate to evaluate subsistence livestock production, because 1) they fail to capture non-marketable benefits of the livestock, and 2) the core concept of a single limiting input is inappropriate to subsistence production, as multiple limiting inputs (livestock, labour, land) are involved in the production process. As many of the livestock functions as possible (physical and socio-economic) should thus be aggregated into monetary values and related to the resources used, irrespective of whether these "products" are marketed, home-consumed or maintained for later use. A broad evaluation model involving three complementary flock-level productivity indices was developed and applied to evaluate subsistence goat production in the eastern Ethiopian highlands. The results show that indigenous goat flocks generated significantly higher net benefits under improved than under traditional management, which challenges the prevailing notion that indigenous livestock do not adequately respond to improvements in the level of management. Furthermore, it is shown that under the subsistence mode of production considered, the premise that crossbred goats are more productive and beneficial than the indigenous goats is wrong. The model thus not only underlines the value of indigenous AnGR to farmers but also provides a more realistic platform upon which to propose sound improvement interventions.

Tools

Two broad types of valuation approach for assessing the value of GR to farmers exist. Stated preference or "direct" methods (such as contingent valuation methods) use survey instruments to simulate a market-like situation. Respondents can then state their preferences in the light of hypothetically changed circumstances, with the data being used to value breeds and traits. By contrast, revealed preference or "indirect" methods seek to ascertain individuals' willingness to pay (WTP) for particular breeds and traits by observing their behaviour in related markets.

These methods have varying degrees of sophistication. Semi-structured interviews, direct observation, inventory, timelines, seasonal calendars, matrix (including wealth) ranking, preference ranking, as well as other approaches have been used both in focus group interviews and in household interviews (for example see: Drucker and Anderson, 2004; Pattison, 2000; and Zander et al., *forthcoming*).

While choice experiments have been used to determine the economic value of AnGR to farmers, as cited above, based on an initial identification of potential methodologies for valuing AnGR (ILRI/FAO, 1999), Drucker et al. (2001, p.9) categorised[8] a number of additional approaches as being appropriate for determining the actual economic importance of a breed (see Table III.1). These included aggregate demand and supply, cross-sectional farm and household, market share, and intellectual property rights (IPR) and contracts approaches. Described in detail in that publication, it is argued that these approaches are capable of, respectively: identifying the value of a breed to society by measuring consumer and producer surplus (first two approaches); providing an indication of the current market value of a given breed; and promoting market creation and support for the fair and equitable sharing of AnGR benefits.

Limitations

With the exception of the aggregate demand and supply approach by Karugia et al. (2001) and the conceptually inferior market share approach (fails to provide a measure of value that accounts for consumer/producer surplus) applied to Creole pigs in Mexico (Drucker and Anderson, 2004), almost no examples of application of these methodologies at the livestock breed level exist. With regard to the first two approaches this is largely the result of inadequate data availability other than for the main commercially popular breeds, combined with the difficulties of estimating shadow prices for home labour and forage use.

With regard to IPR/contracts, the authors are not aware of any applying to AnGR although livestock germplasm transfer for research purposes at institutions such as ILRI takes place under specific guidelines[9], in accordance with the CBD. The aim is to ensure that important genes or gene combinations are maintained in the public domain. Increasing interest in designing an international legal and regulatory framework for AnGR exchange and further developments in AnGR cryoconservation technology may, however, lead to IPR/contracts development over the coming years.

With regard to the stated preference choice experiment work, the limitations with regard to valuation work carried out on crops, described in Section II.6, are equally valid for AnGR valuation.

---

[8] Note that the categorization of the methodologies is not mutually exclusive. Some methodologies may be applicable under a number of different categories.

[9] ILRI undertakes collection of biological material with the "prior informed consent" (PIC) of the participating livestock-keeping communities involved, "under mutually agreed terms" (MAT), applying appropriate Germplasm Acquisition Agreements (GAA), with provisions for sharing of samples (for research) with collaborating Advanced Research Institutions under acceptable Germplasm Transfer Agreements (GTA).

III.2 What are the costs and benefits of conservation?

Findings

The costs of implementing an *in-situ* breed conservation programme may be relatively small, both when compared with the size of subsidies currently being provided to the commercial livestock sector and with regard to the benefits of conservation. However, few such conservation initiatives exist and even where the value of indigenous breeds has been recognised and support mechanisms implemented, significant shortcomings can be identified. Similar work regarding the costs and benefits of the *ex-situ* (cryo)conservation of livestock remains limited. However, under the assumption that technical feasibility brings cryoconservation of livestock species to within the same level of magnitude as that of plants, extensive conservation efforts would be justified on economic grounds.

Specific benefits of livestock diversity conservation accruing to livestock-keepers are related to the fact that livestock with different agronomic and product characteristics suit a range of local community needs, including the provision of non-output functions. Livestock provide manure to enhance crop yields, and transport for inputs and products, serving also for traction. Where rural financial and insurance markets are not well developed, they enable farm families to smooth variation in income and consumption levels over time. Livestock constitute savings and insurance, buffering against crop failure and cyclical patterns in crop-related income. They enable families to accumulate capital and diversify, serving a range of socio-cultural roles related to status and the obligations of their owners (Anderson, 2003). Nevertheless, very limited work on valuing these livestock-keeper level benefits has been carried out. Similarly the benefits to breeders of the existence of such diversity is also difficult to assess given the focus on improved (exotic) breeds and the failure of a number of crossbreeding programmes based on exotic x indigenous crosses. For society as a whole livestock diversity conservation may generate significant option and existence values but again these have not been valued systematically.

III.2.1 *In-situ* conservation

Cicia et al. (2003), in a developed country case study, show that a dichotomous choice stated preference approach can be used to estimate the benefits of establishing a conservation program for the threatened Italian "Pentro" horse. A bio-economic model is used to estimate the costs associated with conservation and a cost-benefit analysis is subsequently realised. Benefit estimates are based on society's willingness to pay for conservation and may therefore be associated with an existence value in this particular case. The results not only show a large positive net present value associated with the proposed conservation activity (benefit/cost ratio > 2.9) but also show that this approach is a useful decision-support tool for policy-makers allocating scarce funds to a growing number of animal breeds facing extinction.

Even where the value of indigenous breeds has been recognised and support mechanisms implemented, significant shortcomings can be identified. Signorello and Pappalardo

(2003), in an examination of farm animal biodiversity conservation measures and their potential costs in the European Union (EU), report that many breeds at risk of extinction according the FAO World Watch List are not covered by support payments as they do not appear in countries' Rural Development Plans. Furthermore, the results show where payments are made these do not take into account the different degrees of extinction risk that exist between breeds and payment levels are in any case inadequate, meaning that it can still remain unprofitable to rear indigenous breeds.

The lack of adequate incentives for indigenous breed conservation is despite the fact that conservation costs are shown to be relatively small by Drucker (*in press)* in a number of case studies. He draws on the safe minimum standards (SMS) literature and adapts Crowards (1998) minimax payoff matrix to consider breeds rather than species. The basic framework considers that the uncertain benefits of indigenous livestock breed conservation can be maintained, as long as a minimum viable population (the SMS – in this case the FAO measure of "not at risk", which is equivalent to approximately 1,000 animals) of the breed is also maintained. The costs of implementing a SMS are made up of the opportunity cost differential (if any exists) of maintaining the indigenous breed rather than an exotic or crossbreed. In addition, the administrative and technical support costs of the conservation programme also need to be accounted for. Empirical cost estimates are then obtained using data from three AnGR economics case studies (i.e. EU, Italy and Mexico). The results support the hypothesis that the costs of implementing a SMS are low (depending on the species/breed and location, these range from between approximately Euro 3,000 – 425,00 p.a.), both when compared with the size of subsidies currently being provided to the livestock sector (<1% of the total subsidy) and with regard to the benefits of conservation (benefit-cost ratio of > 2.9). Encouragingly, the costs are lowest in the developing country, given that an estimated 70% of the livestock breeds existing today are in developing countries where the risk of loss is highest (Rege and Gibson, 2003)

III.2.2 *Ex-situ* conservation

Similar work regarding the costs and benefits of the *ex-situ* (cryo)conservation of livestock remains limited. Nevertheless, Gollin and Evenson (2003) argue that assuming that technical feasibility brings cryoconservation of livestock species to within the same level of magnitude as that of plants, "there cannot be much doubt that the economics would justify extensive conservation efforts" (i.e. probable option values likely to be much higher than conservation costs).

Tools

Drucker et al. (2001, p.9) categorised a number of methodological tools as being appropriate for determining the appropriateness of *in-situ* conservation programme costs (see Table III.1). These included contingent valuation, production loss averted, opportunity cost and least-cost approaches. Described in detail in that publication, it is argued that these approaches are capable of, respectively: identifying society's willingness to pay for AnGR conservation; indicating the magnitude of potential production losses in the absence of maintaining AnGR diversity; identifying the cost of maintaining such diversity; and identifying cost-efficient programmes for the conservation of AnGR.

With the exception of Smith (1984a) and his production loss averted approach applied to pigs in the UK, only PGR applications could be cited at that time (see Chapter II, although Oldfield, 1989, contains some case studies about animal genetic resources..

That situation has changed over the intervening years as part of the follow-up to the ILRI/FAO (1999) workshop and subsequent initiatives of ILRI (Economics of AnGR Conservation and Sustainable Use Programme) and its partners. Recent *in-situ* studies have drawn on the construction of bio-economic models to model conservation costs and the use of contingent valuation techniques to model benefits (Cicia et al., 2003; Drucker and Anderson, 2004), as well as a range of other techniques borrowed from the economics literature, including that of the plant genetic resources valuation literature. On the benefit side, these have included estimates of market share and production loss averted, while least-cost/opportunity cost calculations have been used on the cost side (Drucker and Anderson, 2004; Pattison, 2002). With regard to the latter, such calculations have also been applied within the context of estimating the costs of establishing a safe minimum standard for livestock breed population numbers as part of a conservation programme (Drucker, *in press*), drawing on the work of Krutilla (1967), Ciriacy-Wantrup (1952), Ready and Bishop (1991) and Crowards (1998).

Limitations

Although the SMS approach is shown to have a role to play in *in-situ* AnGR conservation, more extensive quantification of the components required to determine SMS costs needs to be undertaken before it can be applied in practice. Such economic valuation needs to cover both the full range of breeds/species being considered, as well as ensure that as many as possible of the elements making up their total economic value are accounted for.

With regard to *ex-situ* AnGR conservation, cryopreservation technologies for livestock are only well-developed for a handful of species. Hence, valuation work in this field has been extremely limited to date, despite the fact that there is need for an integrated conservation approach, which combines a range of available *ex-situ* and *in-situ* options. *Ex-situ* AnGR valuation work may however advance more rapidly following the upcoming workshop entitled "Option and strategies for the conservation of animal genetic resources"[10])

[10] Montpellier, 7-10 November 2005. SGRP, FAO and AGROPOLIS

III.3 Which farmers should be targeted for participating in in-situ breed conservation programmes? Which farmers are most likely to maintain indigenous breeds?

Findings

Household characteristics play an important role in determining differences in farmer breed preferences. This additional information can be of use in designing cost-effective conservation programmes.

In the context of crops (Meng 1997), proposed that conservation programmes should target those households that are the most likely to continue to maintain local varieties. As these households will be the least costly to incorporate into a conservation programme, a "least cost" programme can be identified. The cost of an *in-situ* conservation programme can thus be expressed as the cost necessary to raise the comparative advantage of such breeds above that of competing breeds, animals or off-farm activities; and a relatively small investment may suffice to maintain their advantage in a particular farming system.

This conceptual approach to identifying low cost conservation strategies has recently been applied to estimate Creole pig conservation costs in Mexico (Drucker and Anderson, 2004) and Boran cattle in Ethiopia (Zander et al., *forthcoming*).

Scarpa et al. (2003b) show that for Creole pigs in Mexico, the respondent's age, years of schooling, size of the household and number of economically active members of the household were important factors in explaining breed trait preferences. Younger, less educated and lower income households placed relatively higher values on the attributes of indigenous piglets compared to exotics and their crosses (Drucker and Anderson, 2004). Pattison's (2002) findings further corroborate these results. In the context of a 10 year conservation programme that would bring the creole pig population to a sustainable size considered "not at risk" by the FAO classification system, he notes that small less well-off households would require lower levels or even (in 65% of cases) no compensation at all.

With particular regard to years of schooling, Scarpa et al. (2003b) found that it interacted significantly and positively with the need to purchase feed. This suggests that more educated people are less reluctant to buy weaned piglets which require purchased feed (an attribute more closely associated with exotics and their crosses) during rearing.

In the context of the number of economically active household members (a proxy for income, both on and off-farm), Scarpa et al. (2003b) show that small households with only one income-earner place relatively more value on piglets that do not require feed purchase, show high disease resistance and need only one bath a week (the latter a proxy for heat tolerance). All these factors are more closely associated with the indigenous breed.

Drucker et al., (1999) find no particular pattern regarding breeds, village size and the existence of a commercial pig farm within the village. It is concluded that other factors explain the above average presence of indigenous and crossbreed Creole pigs in particular villages.

In addition to the opportunity cost calculations related to indigenous breed substitution carried out in the above studies in Mexico, Zander et al. (*forthcoming*) carries out similar work for the Boran cattle of Ethiopia, characterising households by breed type ownership. Based on opportunity cost calculations, she identifies the annual payment needed to ensure that indigenous breeds are maintained. Such payments would, certus paribus, need to be made in perpetuity.

Tools and Limitations

A range of stated and revealed preference techniques can be used to relate household characteristics to breed preferences and opportunity costs of production. The premise of this set of studies is that continued conservation of genetic resource diversity on-farm makes most economic sense in those locations where both society and the farmers who maintain it benefit the most.

In targeting such households, Mendelsohn (2003) argues that conservationists must first make the case for why society should be willing to pay to protect apparently ‘‘unprofitable’’ AnGR resources and then must design conservation programs that will effectively protect what society treasures.

III.4 Policy (How do specific policies impact GR conservation and sustainable use? Which breeds should be a priority for conservation? How can conservation strategies be made cost-efficient?)

Findings

While the impact of policy factors on AnGR are readily discernable in broad terms, little is known about their relative importance. Furthermore, conservation policy needs to promote cost-efficient strategies and this can be achieved through the development of “Weitzman-type” decision-support tools. Such tools permit the allocation of a given budget among a set of breeds such that the expected amount of between-breed diversity conserved is maximised. Opportunity/Least cost approaches reveal that, in a number of cases, only minimal incentives and interventions would in fact be needed to ensure continued indigenous breed sustainable use, as the costs of implementing an *in-situ* breed conservation programme in certain areas are relatively low.

III.4.1 Livestock conservation policy

The current rapid rate of loss of GR diversity is the result of a number of underlying factors. While, in some cases changes in production systems and consumer preferences reflect the natural evolution of developing economies and markets, in other cases, production systems, breed choice and consumer preferences have been distorted by local, national and international policy. Such distortions may arise from macroeconomic interventions (e.g. exchange and interest rates); regulatory and pricing policy (e.g. taxation, price controls, market and trade regulations); investment policy (e.g. infrastructure development); and institutional policy (e.g. land ownership, GR property rights).

While the impact of such policy factors on AnGR are readily discernable in broad terms, little is known about their relative importance, as the implementation of policy and the realisation of policy research related to AnGR conservation and sustainable use is far less advanced in most countries than it is for PGR.

Simianer et al. (2003) and Reis-Marti (2003) provide one of the few examples of the conceptual development of a decision-support tool in this area. Recognising the large number of indigenous livestock breeds that are currently threatened and the fact that not all can be saved given limited conservation budgets, they elaborate a framework for the allocation of a given budget among a set of breeds such that the expected amount of between-breed diversity conserved is maximised. Drawing on Weitzman (1993) it is argued that the optimum criterion for a conservation scheme is to maximise the expected total utility of the set of breeds, which is a weighted sum of diversity, extinction probabilities and the value of the conserved breeds.

The methodology is illustrated with an example of 23 African zebu and zenga cattle breeds. The results indicate that conservation funds should be spent on only three to nine (depending on different model assumptions) of the 23 breeds and that these are not necessarily the most endangered ones. Note, however, that the measure of diversity used can be based on genetic distances (as in both this and the original Weitzman study) but alternative measures of diversity (e.g. based on the existence of unique attributes of certain breeds – e.g. trypanotolerance) could also be used. The implications for which breeds should be conserved may well differ depending on how the diversity index is constructed and the overall goal of the conservation programme (conservation of genetic diversity *per se*, maximising the number of unique traits conserved or maximising the livelihood contribution of the livestock diversity conserved).

In any case, where the models are sufficiently specified and essential data on key parameters are available, the framework can be used for rational decision-making on a global scale. Such models are, however, dependent on an understanding of individual breed conservation costs and hence need to be applied in conjunction with opportunity/least cost and safe minimum standard approaches. As discussed above, the findings from this type of studies have shown that only minimal incentives and interventions may in fact be needed to ensure continued indigenous breed sustainable use, as the costs of implementing an *in-situ* breed conservation programme in certain areas are relatively low. For example, Scarpa et al. (2003b) show that the net value that backyard producers place on the Mexican Creole pig is very similar to that of the other breeds. Nevertheless, where opportunity costs for indigenous breed production do exist vis-à-vis the main commercial breeds,[11] compensation payments must be adequate to make the rearing of such breeds profitable. Signorello and Pappalardo (2003) show that this is not in fact taking place in the EU and that such conservation support measures thus urgently need to be reviewed if they are to meet their goals.

III.4.2 Livestock breeding strategies[12]

In terms of breeding programme evaluation, breeding programmes have long used a selection index as a device for multiple trait selection in farm livestock, first introduced for animal breeding by Hazel (1943). For example, Mitchel et al. (1982) measured the value of genetic contributions to pig improvement in Great Britain by determining the heritability of important characteristics and isolating the genetic contributions to improved performance. Using linear regression techniques to compare control and improved groups over time[13], they found that the returns were substantial, with costs in the region of £2 million p.a. relative to benefits of £100 million p.a. The use of crossbreeding in commercial production was estimated to contribute approximately £16 million p.a. Farm level simulation models have been built for several species under high input management and have also focused on valuing heritable trait gain. For example, Ladd and Gibson (1978) use such a model to measure the economic values of three heritable characteristics in swine: backfat, feed efficiency and average daily weight gain.

Smith (1985), in the context of the importance of accounting for option values in genetic production function models, argues that genetic selection based on the current set of economic objectives is sub-optimal in an inter-temporal context (as some animal geneticists might suggest). Instead, given uncertainty about future needs, selection should be "directed to cater for foreseeable and even unpredictable futures" (Smith, 1985, p. 411). In particular, Smith (1984b) advocates the storage of stocks that contain currently undesirable traits that may only have temporary current value (e.g. market or grading requirements, carcass or product composition, special behavioural adaptations to current husbandry conditions, etc.).

Using hedonic approaches Jabbar et al. (1998) showed in Nigeria that although there were some differences in prices that were solely because of breed, most variation in prices was because of such variables as wither height and girth circumference that vary from animal to animal within breeds. Variation because of type of animal or month of transaction was also greater than that because of breed.

---

[11] Note that the existence of such an opportunity cost differential is not always the case - for example see Ayalew et al., 2003. Furthermore, alternatives to compensation approaches also exist. For example, where branding and niche market development have eliminated this opportunity cost, as is the case with Reggiano cattle and parmesan cheese.

[12] Based on Drucker et al., 2001.

[13] Note that breed conservation takes place in a dynamic context, including as a result of natural mutations and co-evolution. While selection/improvement can lead to gene loss, it can also be seen in terms of adding value to the genetic resources. Selection/improvement will only be in conflict with conservation where broader community breeding objectives are ignored in favor of objectives that may only have temporary current value.

Richards and Jeffery (1995) attempt to identify the value of relevant production and type traits for dairy bulls in Alberta, Canada. A hedonic valuation model is estimated that models semen price as a function of individual production and longevity characteristics for a sample of Holstein bulls.

Jabbar and Diedhiou (2003) show that a hedonic approach used to determine livestock keepers' breeding practices and breed preferences in southwest Nigeria, confirms a strong trend away from trypanotolerant breeds, especially Muturu. The results suggest that the best hopes for implementing a conservation/sustainable use strategy for breeds at risk such as Muturu is likely to be in other areas of West Africa where the Muturu is still found; for example in southeast Nigeria where trypanosomosis remains a constraint, where the Muturu is better suited to the farming systems and where a large market for this breed continues to exist.

Tools

While decision-support tools of the type described above can assist the identification of conservation priorities at the breed level (locally, nationally, regionally or globally), a number of methodologies also exist for identifying priorities in terms of goals at the breeding programme level. These include: breeding programme evaluation; genetic production function, hedonic and farm simulation model approaches (see Table III.1). Described in detail in Drucker et al. (2001), it is argued that these approaches are capable of, respectively: identifying the net economic benefits of stock improvement (first two); identifying trait values; and modelling the impact of improved animal characteristics on farm economies.

Although applications from the PGR field are cited (see Chapter II), a limited number of livestock breed/trait level applications also exist. This include Hazel, 1943; Ladd and Gibson, 1978; Mitchell et al., 1982; Smith, 1984 and 1985; Richards and Jeffery, 1995; Jabbar et al., 1998 ; and Jabbar and Diedhiou, 2003).

Limitations

With regard to livestock diversity, while the impact of policy factors is readily discernable in broad terms, little is known about their relative importance. There is therefore a need for such understanding as a first step toward the implementation of policies and market strategies that promote the effective utilization and conservation of the diverse populations of indigenous livestock breeds.

To this end, the development of a number of policy "decision-support tools" have been proposed as part of wider AnGR conservation and sustainable use projects in Africa and Asia currently being funded or considered for funding by BMZ (Germany) and the Global Environmental Facility (GEF). However, measures of breed genetic distances and conservation costs are lacking for many species/breeds and no such tools have yet been implemented in practice.

Policy issues related to GR property rights influencing access to and exchange of livestock germplasm are also important and are increasingly being discussed in international fora. However, Drucker and Gibson (2003) identify a range of issues that need to be researched before the relative costs and benefits of such an international regulatory instrument for AnGR can be determined. These include an improved understanding of the importance of continued access and trade in livestock germplasm for research and development purposes; and the nature of the costs and benefits arising from AnGR research.

Table III.1: AnGR Valuation Methodology Evaluation

Valuation Methodology	Purpose, Objective or Strength	Actor(s) for Whom Valuation Method is Most Relevant	Role in Conservation	*Type of Data Required*	Data Availability	Conceptual Weakness or difficulties
Methodologies for determining the appropriateness of AnGR conservation programme costs						
Contingent Valuation	Identify society's WTP for the conservation of AnGR, Farmer WTA compensation for raising indigenous AnGR instead of exotics or to determine farmer trait value preferences and net returns by breed	Policy-makers in charge of conservation	Define upper bound to economically justified conservation programme costs	Society preferences expressed in terms of WTP or WTA	Not normally available. Requires survey	Response difficulties when used for "non-charismatic" species and/or chronic genetic erosion
Production Loss Averted	Indicate magnitude of potential production losses in the absence of AnGR conservation	Farmers and policy-makers in charge of conservation	Justify conservation programme costs of at least this magnitude	Estimate of potential production losses (e.g. percentage of herd and market value of animals)	Animal market values available for commercial breeds. Potential herd loss must be estimated.	Not a consumer/producer surplus measure of value. Ignores substitution effects
Opportunity Cost	Identify cost of maintaining AnGR diversity	Farmers, and policy-makers in charge of conservation	Define opportunity cost of AnGR conservation programme	Household costs of production and net income	Not normally available. Requires survey	
Least Cost	Identify cost-efficient programme for the conservation of AnGR	Policy-makers in charge of conservation; farmers and breeders to some extent	Define minimum cost of conservation programme	Household costs of production and profitability	Not normally available. Requires survey	
Safe Minimum Standard	Assess trade-offs involved in maintaining a minimum viable population	Policy-makers in charge of conservation	Define opportunity cost of AnGR conservation programme	Conservation programme costs and benefit differential involved in raising different breeds	Not normally available. Requires survey and modelling.	Requires judgement as to whether breed substitution will in fact generate utility in excess of the unquantifiable benefits of indigenous breed conservation
Methodologies for determining the actual economic importance of the breed						
Aggregate Demand & Supply	Identify value of breed to society	Policy-makers in charge of conservation and livestock policy, as well as breeders	Value potential losses associated with AnGR loss.	Intertemporal or farm-level data	Available for commercial breeds. Not normally available for others – requires survey	Requires shadow pricing of home labour and forage
Cross-sectional Farm and Household	Identify value of breed to society	Policy-makers in charge of conservation and livestock policy; as well as breeders and framers	Value of potential losses associated with AnGR loss	Consumer and producer price differences by location	Not normally available. Requires survey	Requires shadow pricing of home labour and forage
Market Share	Indication of current market value of a given breed	Policy-makers in charge of conservation and livestock policy; as well as breeders and framers	Justify economic importance of given breed	Market value of animal products by breed	Generally available but not always by breed	Not a consumer/producer surplus measure of value. Ignores substitution effects
Intellectual Property Rights & Contracts	Market creation and support for "fair and equitable" sharing of AnGR benefits	Policy-makers in charge of conservation; as well as breeders and framers	Generate funds and incentives for AnGR conservation	Royalty payments or terms of contract	Usually available when such arrangements exist although can be commercial secret.	Limited duration of contracts
Methodologies for priority setting in AnGR breeding programmes						
Evaluation of Breeding Programme	Identify net economic benefits of stock improvements	Farmers and breeders	Maximise economic benefits of conserved AnGR	Yield effects and input costs	Available for commercial breeds. Not normally available for others – requires survey/research	Difficulty in separating the contribution of genetic resources from other costs of programme
Genetic Production Function	Identify net economic benefits of stock improvements	Farmers and breeders	Maximise expected economic benefits of conserved AnGR	Yield effects and input costs	Available for commercial breeds. Not normally available for others – requires survey/research	
Hedonic	Identify trait values	Farmers and breeders, as well as policy-makers in charge of conservation	Value potential losses associated with AnGR loss. Understand breed preferences.	Characteristics of animals and market prices	Available for commercial breeds. Not normally available for others – requires survey/research	Not a consumer/producer surplus measure of value. . Ignores substitution effects
Farm Simulation Model	Model improved animal characteristics on farm economics	Farmers and breeders	Maximise economic benefits of conserved AnGR	Inputs and outputs. Technical coefficients of all main activities	Available for commercial breeds. Not normally available for others – requires survey	Correct definition of farm objective function. Aggregation for estimating consumer surplus can also be problematic

Source: Drucker et al. 2001

References

Anderson, S. 2003. Animal genetic resources and sustainable livelihoods. Ecological Economics 45 (3): 331-339.

Ayalew, W., J. M. King, E. Bruns, and B. Rischkowsky. 2003. Economic evaluation of smallholder subsistence livestock production: lessons from an Ethiopian goat development program. Ecological Economics 45 (3): 473-485.

Barrett, J.C. 1991. The economic role of cattle in communal farming systems in Zimbabwe. In: workshop on 'The socio-economic impact of improved tick and tick-borne disease control in Zimbabwe.' Veterinary Research Laboratory, Harare. 9 May 1991.

Brown, K., Pearce, D., Perrings, C. and Swanson, T. 1993. Economics and the conservation of global diversity. Working Paper Number 2. Global Environmental Facility. Washington D.C.

Cicia, G., E. D'Ercole, and D. Marino. 2003. Costs and benefits of preserving farm animal genetic resources from extinction: CVM and bio-economic model for valuing a conservation program for the Italian Pentro horse. Ecological Economics 45 (3): 445-459.

Ciriacy-Wantrup, S. 1952. Resource conservation: economics and policies. University of California Press, Berkeley.

Crowards, T. .1998. 'Safe minimum standards: costs and opportunities', Ecological Economics 25, 303-314.

Cunningham, E.P. and Syrstad, O.1987. Crossbreeding bos indicus and bos taurus for milk production in the tropics. FAO Animal Production and Health Paper 68. FAO, Rome.

Danckwerts, J P (n.d., about 1974) A socio-economic study of veld management in the tribal areas of Victoria Province Department of Agriculture, University of Rhodesia: Salisbury.

Drucker, A. G., V. Gómez, N. Ferraes-Ehuan, O. Rubio, and S. Anderson. 1999. Comparative economic analysis of criollo, crossbreed and exotic pigs in backyard production of Yucatan, Mexico. FMVZ-UADY Mimeo.

Drucker, A. G., V. Gómez, and S. Anderson. 2001. The economic valuation of farm animal genetic resources: a survey of available methods. Ecological Economics 36 (1): 1-18.

Drucker, A. G. and Gibson, J.P. 2003. A Legal and Regulatory Framework for AnGR? Issues for Consideration. Paper presented at: Workshop on Farm AnGR Legal and Regulatory Framework, Maputo, Mozambique, 19-23 May 2003. FAO/UNDP/GTZ/CTA/SADC.

Drucker, A. G. (*in press*). An application of the use of safe minimum standards in the conservation of livestock biodiversity. Environment and Development Economics

Drucker A.G. and Anderson S. (2004). Economic analysis of animal genetic resources and the use of rural appraisal methods: Lessons from South-East Mexico. International Journal of Sustainable Agriculture. Vol 2 (2) pp. 77-97.

FAO (Food and Agriculture Organisation of the United Nations). 2000. World Watch List for Domestic Animal Diversity, 3rd Ed., FAO, Rome.

FAO. 1999. The global strategy for the management of farm animal genetic resources. Rome.

GFA. 1987 Study on the economic and social determinants of livestock production in the communal areas - Zimbabwe. Final Report Gesellschaft für Agrarprojekte consultancy report to the Department of Veterinary Services, Harare.

Gollin, D and Evenson, R. 2003. Valuing Animal Genetic Resources: Lessons from Plant Genetic Resources. Ecological Economics 45 (3), 353 -363.

GTZ. 2001. 'Community-Based Management of Animal Genetic Resources-A Tool for Rural Development and Food Security'. Workshop Proceedings, Mbabane, Swaziland, May 7-11.

Hall, S.J.G. and J. Ruane. 1993. Livestock breeds and their conservation – global review. Conservation Biology 7(4), 815-825.

Hammond, K. and Leitch, H. 1996a. The FAO global program for the management of farm animal genetic resources. In: Miller, R., Pursel, V. and Norman, H. (Eds). Biotechnology's Role in the Genetic Improvement of Farm Animals. American Society of Animal Science. pg 24-42.

Hammond, K. and Leitch, H. 1996b. The FAO global program for the management of farm animal genetic resources. In: Beltsville Symposia in Agricultural Research. XX. Biotechnology's Role in the Genetic Improvement of Farm Animals. (Eds. Miller, R., Pursel, V. and Norman, H.) American Society of Animal Science, Illinois. p. 24 - 42.

Hazel, L. 1943. Genetic basis for selection indexes. Genetics, 28, pp. 476-490.

ILRI. 1999. Economic valuation of animal genetic resources. Proceedings of an FAO/ILRI workshop held at FAO Headquarters, Rome, Italy, 15 - 17 March 1999. ILRI, Nairobi, Kenya. 80 pp.

ITDG (Intermediate Technology Development Group). 1996. Livestock keepers safeguarding domestic animal diversity through their animal husbandry. Dynamic Diversity Series. Ed. Patrick Mulvaney, ITDG, Rugby, England.

Jabbar, M., B. Swallow, G. d'Iteran, A. Busari. 1998. Farmer preferences and market values of cattle breeds of west and central Africa. Journal of Sustainable Agriculture 12: 21-47.

Jabbar, M. A., and M. L. Diedhiou. 2003. Does breed matter to cattle farmers and buyers? Evidence from West Africa. Ecological Economics 45 (3): 461-472.

Karugia, J., Mwai, O., Kaitho, R., Drucker, A., Wollny C. and Rege, J.E.O. (2001), 'Economic Analysis of Crossbreeding Programmes in Sub-Saharan Africa: A Conceptual Framework and Kenyan Case Study. Animal Genetic Resources Research 2. ILRI. Nairobi, Kenya. 55pp.

Krutilla, John. 1967. Conservation Reconsidered. American Economic Review 57, 777-786.

Ladd, G., and C. Gibson. 1978. Microeconomics of technical change: what's a better animal worth? American Journal of Agricultural Economics 60 (2): 236-240.

Livestock in Development (1999) Livestock in poverty-focused development. Livestock in Development. Crewkerne, UK.

Mendelsohn, R. (2003) The challenge of conserving indigenous domesticated animals. Ecological Economics 45, 501-510.

Meng, E. C. H. 1997. Land allocation decisions and *in situ* conservation of crop genetic resources: The case of wheat landraces in Turkey. Ph.D. dissertation Davis, California, USA: University of California.

Mitchell, G., C. Smith, M. Makower, and P. J. W. N. Bird. 1982. An economic appraisal of pig improvement in Great Britain. 1. Genetic and production aspects. Animal Production 35 (2): 215-224.

Oldfield, M. 1989. The value of conserving genetic resources. Sinauer Associates, Sunderland. Massachusetts.

Pattison, J. 2002. Characterising backyard pig keeping households of rural Mexico and their willingness to accept compensation for maintaining the indigenous Creole breed: A Study of Incentive Measures and Conservation Options. Unpublished M.Sc. thesis. University of London.

Pretty, J. 1995. Regenerating agriculture: policies and practice for sustainability and self-reliance. Earthscan.

Ready, R. and Bishop, R. 1991. 'Endangered species and the safe minimum standard', American Journal of Agricultural Economics 73, 309-312.

REDES-AT-GRAIN. 1994. Alarma Animal.. Biodiversidad No.2 December 1994.

Rege, J.E.O., 1999. The state of African cattle resources I. Classification framework and identification of threatened and extinct breeds. Animal Genetic Resources Information 25: 1-25.

Rege J.E.O. 2003. *In-situ* conservation of farm animal genetic resources. In: CIP-UPWARD. Conservation and sustainable use of agrobiodiversity: A source book. Los Banos, Laguna, The Philippines. pp. 434-438.

Rege, J. E. O., and J. P. Gibson. 2003. Animal genetic resources and economic development: issues in relation to economic valuation. Ecological Economics 45 (3): 319-330.

Reist-Marti, S., Simianer, H., Gibson, G., Hanotte, O. and Rege, J.E.O. 2000. 'Weitzman's approach and breed diversity conservation: An application to African cattle breeds.' Conservation Biology 17 (5), 1299 - 1311

Richards, T and Jeffrey, S. 1995. Hedonic pricing of dairy bulls – an alternative index of genetic merit, Department of Rural Economy. Project Report 95-04. Faculty of Agriculture, Forestry, and Home Economics. University of Alberta Edmonton, Canada.

Scarpa, R., A. G. Drucker, S. Anderson, N. Ferraes-Ehuan, V. Gómez, C. R. Risopatrón, and O. Rubio-Leonel. 2003b. Valuing genetic resources in peasant economies: the case of 'hairless' Creole pigs in Yucatan. Ecological Economics 45 (3): 427-443.

Scarpa, R., E. S. K. Ruto, P. Kristjanson, M. Radeny, A. G. Drucker, and J. E. O. Rege. 2003a. Valuing indigenous cattle breeds in Kenya: an empirical comparison of stated and revealed preference value estimates. Ecological Economics 45 (3): 409-426.

Scoones, I C 1990 Livestock populations and the household economy: a case study from southern Zimbabwe PhD thesis, University of London.

Signorello, G., and G. Pappalardo. 2003. Domestic animal biodiversity conservation: a case study of rural development plans in the European Union. Ecological Economics 45 (3): 487-499.

Simianer, H., S. B. Marti, J. Gibson, O. Hanotte, and J. E. O. Rege. 2003. An approach to the optimal allocation of conservation funds to minimise loss of genetic diversity between livestock breeds. Ecological Economics 45 (3): 377-392.

Smith, C. 1984a. Estimated costs of genetic conservation of farm animals. pp 21-30 in Animal Genetic Resources Conservation and Management, Data Banks and Training. FAO Animal Production and Health Paper n° 44/1, Rome.

Smith, C. 1984b. Genetic aspects of conservation in farm livestock. Livestock Production Science, 11, pp. 37-48.

Smith, C. 1985. . Scope for selecting many breeding stocks of possible economic value in the future. Animal Production: 403-412.

Steinfeld, H 1988 Livestock development in mixed farming systems Wissenschaftsverlag Vauk: Kiel.

Swanson, T.M., 1994. The International Regulation of Extinction. New York University Press, New York.

Swanson, T.M., 1995a. Why does biodiversity decline? The analysis of forces for global change. In: Swanson, T.M. (Ed.), The Economics and Ecology of Biodiversity Decline: The Forces Driving Global Change. Cambridge University Press, Cambridge, UK.

Swanson, T.M., 1995b. Uniformity in development and the decline of biological diversity. In: Swanson, T.M. (Ed.), The Economics and Ecology of Biodiversity Decline: The Forces Driving Global Change. Cambridge University Press, Cambridge, UK.

Tano, K., M. Kamuanga, M. D. Faminow, and B. Swallow. 2003. Using conjoint analysis to estimate farmer's preferences for cattle traits in West Africa. Ecological Economics 45 (3): 393-407.

Tisdell, C. 2003. Socioeconomic causes of loss of animal diversity genetic: analysis and assessment. Ecological Economics 45 (3), 365 -376.

Vaccaro, L.P. de. 1973. Some aspects of the performance of European pure bred and crossbred dairy cattle in the tropics: Part I: Reproductive efficiency in females. Animal breeding Abstracts. 41, pp. 571-589

Vaccaro, L.P. de. 1974. Some aspects of the performance of European pure bred and crossbred dairy cattle in the tropics: Part II: Mortality and culling rates. Animal breeding Abstracts. 42, pp. 93-103.

Weitzman, M. 1993. What to preserve? An application of diversity theory to crane conservation. Quarterly Journal of Economics February pp. 157-183.

Wickham, B and Banos, G. 1998. Impact of international evaluations on dairy cattle breeding programmes. Proceedings of 6th World Congress on Genetics Applied to Livestock Production, Armidale, 23, pp. 315-322.

Wollny, C. 2003. The need to conserve farm animal genetic resources through communitybased management in Africa: Should policy-makers be concerned?. Ecological Economics 45 (3), 341 – 351.

Zander, K., Drucker, A. Holm-Muller, K. and Mburu, J. (*forthcoming*). Costs and constraints of conserving animal genetic resources: The case of Borana cattle in Ethiopia.

Chapter IV.
Conclusions

Adam G. Drucker, Melinda Smale and Patricia Zambrano

IV.1. Findings

A number of gaps are evident in the applied economics literature about valuing crop biodiversity. The role of crop genetic resources in mitigating either production and consumption vulnerability has not been adequately tested, particularly in marginal environments and semi-subsistence production systems, as distinct from input-intensive, high potential environments where modern varieties dominate. There is a need for a more comprehensive framework to analyze the role of product and seed markets, in particular. Hypotheses have centred on the determinants of crop biodiversity levels on farms, while the estimation of benefits has focused almost exclusively on the aggregated social or investment returns from utilizing crop genetic resources in commercial agriculture. In order to address the issues that are most prominent for national policy-makers, emphasis in on-farm research should be shifted toward testing hypotheses about the impacts on poor farmers in developing economies of using diverse genetic resources.

FAO staff who reviewed this study identified three areas for further research. First, current and option values might be worth considering in the context of the informal sector. Although there is literature concerning the current use values and option values of crop genetic resources in formal sector breeding and the commercial seed industry, the informal sector remains the most important source of planting material for many farmers in developing economies, and particularly among poorer farmers in marginal environments. Patterns of farmer-to-farmer exchange, natural and human selection affect the genetic content of seeds in the informal sector. One might hypothesize, for example, that the marginal value of maintaining a variety is higher in informal sector "breeding" compared to the formal sector, because there are fewer possibilities of substitution and search costs would be lower.

Second, despite the fairly wide range of "snapshots" of why farmers value diversity and the factors that influence diversity levels on farms, the static frameworks used are limited in their depiction of the dynamic processes of economic change and genetic erosion. Yet, these processes are at the crux of research and policy interest. Research should lend greater insights into why and how private values change, and how these changes related to measures of farmer welfare and consumer welfare.

Third, a critical component of agricultural biodiversity is knowledge, including both indigenous/local and scientific knowledge. This aspect of crop and livestock biodiversity has not been raised, most likely because there is little applied work on the topic. Economics concepts could be applied to investigate the value of information about genetic resources and their diversity.

Recent advances in economic valuation for livestock genetic resources have eased some methodological/ analytical constraints, and the issue of data availability now seems more critical. Data related to farmers' preferences for different genetic resource attributes and the value placed on these across species, varieties/breeds and production systems are needed.

The valuation approaches discussed in Chapters II and III frequently rely on intensive, primary data collection, particularly given the problems of market imperfections commonly encountered in developing economy situations. Where such imperfections are significant, the impact of violations of the underlying assumptions of the valuation methodologies must be carefully considered and appropriate measures taken (if application is still feasible). Violations of assumptions will frequently mean that much of the required data will have to be collected through specially designed surveys.[14] Where market prices do not exist or are distorted, adequate shadow prices will need to be determined for relevant inputs and outputs.

Institutional approaches are lacking in the literature so far. If included at all, they are treated as constraints or parameters that are exogenous to the optimising behaviour of individuals. There are limitations to what can be accomplished solely through valuation exercises, since management of genetic resources involves important institutional and organizational decisions. Formal sample surveys will often need to be applied in conjunction with rural appraisal methods (Drucker and Anderson, *2004*) and stakeholder analyses. These methods entail not only the collection of information but also its eventual use by local people in planning further activities, in interactive and open-ended processes. Often, the emphasis in rural appraisal is as much on the process of involving the community in planning and decision-making as it is on the information, which is critical for community-based, *in-situ* conservation of either crop or livestock genetic resources.

In some respects, the economics literature regarding the value of PGR for agriculture has a longer history and is therefore more extensive than that of AnGR, especially in developing economies. The field of economics of AnGR conservation and sustainable use has developed rapidly during recent years. In addition, there is evidence that the applied literature in the two areas has had mutual influence. The AnGR literature has adapted methodological approaches from the PGR field and used similar tools (e.g. stated and revealed preference survey techniques), while recent advances in the AnGR literature have been applied in at least one PGR study. Nonetheless, methods are not entirely interchangeable because livestock provides a number of services that are not provided by crops.

[14] Given that the FAO (1998) proposes conducting AnGR resource assessments as part of the development of farm AnGR management plans, such data may increasingly become available. This of course assumes that economic valuation issues are properly incorporated into such assessments from the beginning. Nevertheless, as many countries are still in the process of developing State of the World AnGR reports and these do not necessarily incorporate such issues/data, specifically designed surveys will need to be carried out, at least in the short to medium-term.

IV.2. Prospects for integrating economics research on crop and livestock biodiversity

The motivation for this paper was the notion that scientific research about agrobiodiversity could be advanced by a holistic approach to valuing its components. As a first step, a review of findings, methodologies and their limitations might reveal common approaches and contrasts, enabling researchers to exploit synergies and work toward an integrated research agenda. The hypothesis is that the costs, benefits, and policy recommendations differ when interactions among biodiversity components are taken into account. As a second step, this hypothesis could be tested by undertaking a pilot project with a joint research design.

Several observations support this hypothesis in the case of crops and livestock, taken as an initial example. First, many small-scale farmers, especially in subsistence-oriented agriculture, integrate the production of crops and livestock (Box IV.1). Policy and development interventions at the local level often deal with the same people. Second, livestock and crops compete for some of the same lands, crop products serve as inputs for livestock production, and manure and animal power serve as an input to crop production. Thus, policies and development interventions that affect crop GR often affect livestock GR, and vice versa. Finally, some of the most significant forces driving change in crop and livestock biological diversity are the same—intensification of production, mechanization, certain forms of commercialization and product uniformity (Tisdell 2003; Pingali and Smale 2000).

With respect to an integrated approach, much remains to be done. For example, a quick perusal of existing studies raises several key points. First, PGR studies have tended to take livestock numbers and breeds as given or exogenous factors that are indicators of the wealth of a farm household or community, or indicators of access to animal traction, rather than modelling them as explicit choices to be determined simultaneously with the choice of crops/varieties (Table IV.2).

In a rare exception to this "rule", Birol's choice experiment, (which was influenced directly by the work undertaken in livestock research (Scarpa et al. 2003a; 2003b]), the integration of crop and livestock production was treated as a choice variable - an attribute of Hungarian home gardens. Her findings underscore the economic value farmers place on this attribute. A related study conducted with participatory methods in the same locations confirms that maize landraces are considered to be better quality feed (Bela, Balázs and Pataki 2005). Similarly, in Nagarajan's (2004) study of millet crops in Andhra Pradesh and Karnataka states, India, farmers scored varieties based on their provision of feed and fodder, with some implications for growing multiple millet crops to meet the needs of different types of livestock. Differences in the suitability of different varieties for feed or fodder use have been documented in a number of studies of maize landraces in Mexico, although the variable was not significant in the econometric analysis included here (Smale, Bellon and Aguirre Gómez 2001).

Box IV.1: Mixed Crop Livestock Production Systems

A search of public databases (World Bank World Development Indicators and FAOStat) revealed no global data available for the number of farmers in the developing world that depend on both crops and livestock for their livelihoods. Some data were identified that document the extension of different types of farming systems around the world. An indirect way to assess the extent to which farmers in the developing world rely on both crops and livestock is to examine the extent of the area in mixed farming systems. To visualise this, Gaskell mapped six mixed farming systems (Figure IV.1) from the complete set of farming systems mapped by Thornton et al.(2002).

Mixed farming systems are defined as areas where "more than 10 percent of the dry matter fed to animals comes from by-products and stubble or more than 10% of the total value of production comes from non-livestock farming activities" (Thornton et al., 2002: 17). Thornton et al (2002) determined that the three different global maps for cropland underestimated levels and extensions. To overcome this limitation, they combined the USGS Land Use/Land cover system from Anderson et al (1976) with maps of population density and length growth periods (LGP). The three mixed farming systems they define are in turn subdivided according to whether they are rainfed or irrigated.

From the map, it is evident that most of the mixed farming systems in the developing world are rainfed, and most are likely to be characterised by smallholder production. The authors give several examples of the types of producers falling into each category and illustrate with regional examples. Although the underlying data have limitations, as does any other satellite-based information, the map demonstrates clearly that mixed farming systems are common among farmers in developing economies, and particularly those found in rainfed regions.

Dixon et al (2001) take a much broader approach, basing their classification of farming systems according to the availability of natural resources and dominant pattern of farm and household activities. They differentiate eight farming systems in six main regions of the world. The final set are72 farming systems with an average agricultural population of 40 million people. Dixon et al (2001) map each of them but provide specific data for only 20 (see Table V.1). The total cultivated area for these 20 mixed farming systems is 806 million ha, with a cattle population of 533 million, and a human population of 1.6 billion.

In contrast to these studies, AnGR valuation studies have also tended to model "feed" as a generic input, with little subsequent exploration of the types of crop varieties involved (e.g. Scarpa et al. 2003b). The value of manure and animal power inputs into crop production have been frequently ignored, despite the fact that they can form a significant proportion of total livestock output. The value of animal traction and manure (as fertiliser and a source of fuel) has been shown to be significant in a number of studies (Barrett 1992; GFA, 1987; Danckwerts 1974; Scoone 1990; Steinfeld 1988). For example, estimates of the combined value of these outputs vary between 21% and 72% of the total value of livestock output among communal herds in different parts of Zimbabwe.

Several conclusions from the literature reviewed here are germane to the prospects for integrated research. A high degree of location/production system-specificity is apparent in the findings of either the crops or livestock studies. While generic decision-support tools could be elaborated, specific outcomes will depend on local circumstances. To date, too much research has focused on one specific crop, while treating other crops and other economic activities (including livestock production) as exogenous or given. A similar argument can be made for AnGR research. Whole household-farm analytical frameworks could be applied in order to consider agrobiodiversity components in an integrated manner. These must be linked, however, to frameworks for community decision-making and spatial maps of crop and livestock populations. Finally, policies designed to support the conservation of diverse and adaptive landraces/breeds may be different from those required to support the conservation of rare landraces/breeds. Hence, policies and programmes aimed at improving individual components of agrobiodiversity may reduce the chances that other components are sustained.

Figure IV.1. The estimated extent of area in the world where farmers depend on both crops and livestock

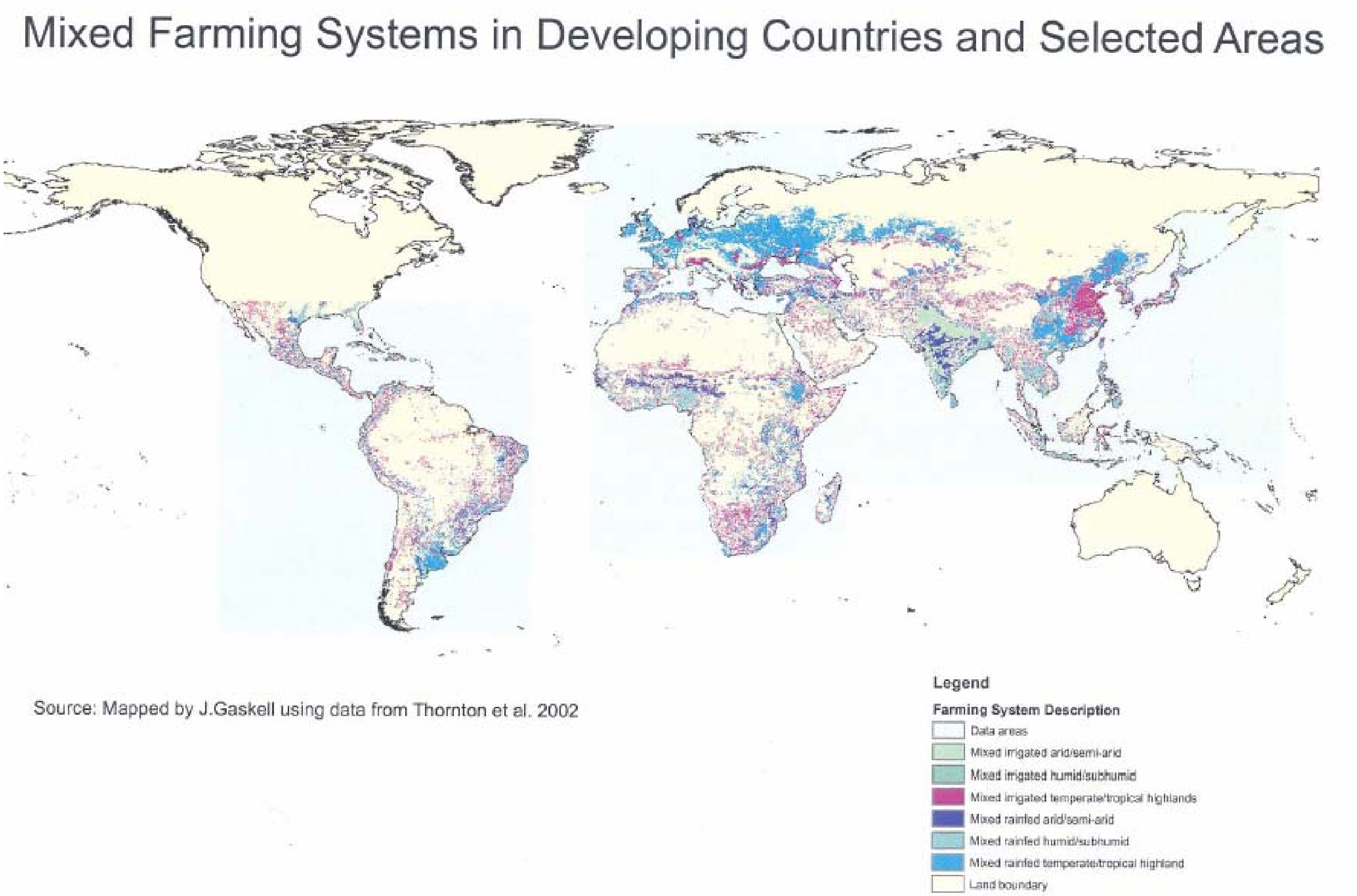

Table IV.1. Production system

Source : Dixon et al (2001)

No.	Page	Region	Farming system	Total population	Agricultural population	Total area	Agroecological zone	Cultivated area	Irrigated area	Cattle population
.				*m*	*m*	*m ha*		*m ha*	*m ha*	*m*
1	48	Sub-Sahara Africa	Maize mixed system	95	60	246	dry subhumid	32	0.4	36
2	55		Tree crop	50	25	73	humid	10	0.1	2
3	58		Irrigated	14	7	35	various	3	2	3
4	62		Cereal -root mixed system	85	59	312	dry subhumid	31	0.4	43
5	66		Millet-sorghum mixed system	54	33	198	dry subhumid	22	0.6	25
6	98	Middle East	irrigated, large scale	80	16	19	arid semiarid	8	8	2
7	102		Highland mixed system	65	27	74	semiarid subhumid	22	5	2
8	105		rainfed mixed system	40	16	17	dry-moist subhumid	14	0.6	8
9	108		dryland mixed system	50	13	42	semiarid subhumid	17	3	6
10	145	East. Europe Central Asia	mixed system	99	16	85	subhumid	35	4	14
11	148		highland mixed system	68	15	100	semiarid subhumid	38	4	24
12	152		rainfed mixed system	98	14	425	semiarid	106	2	14
13	186	South Asia	rice farming system	293	130	36	humid	22	10	51
14	192		rice-wheat farming system	68	15	100	semiarid subhumid	38	4	24
15	197		highland mixed system	98	14	425	semiarid	106	2	14
16	201		rainfed mixed system	371	226	147	dry subhumid	87	14	126
17	232	East Asia and Pacific	lowland rice farming system	825	474	197	moist subhumid	71	33	52
18	238		rice-wheat farming system	68	15	100	semiarid subhumid	38	4	24
19	242		upland intensive mixed system	530	314	310	various	75	18	52
20	249		temperate mixed system	247	162	99	dry subhumid	31	12	11
All 20				3,298	1,651	3,040		806	127.1	533

Table IV.2. PGR economic literature treatment of AnGR

Country	Crop	Author	AnGR variable: Measurement	Concept	Role in analysis	Finding
Ethiopia	Coffee	Wale (2004)	value of livestock per consumption requirement	risk/vulnerability	explain crop diversity	farmers with lower value of livestock assets per consumption requirement have more of an incentive to diversify their demand for coffee attributes
Ethiopia	Cereals	Benin et al. (2004)	tropical livestock units (TLU) and oxen ownership	wealth, access to traction	explain crop diversity	for TLU: negative effect for teff, positive for barley and wheat, and positive for all cereals (evenness); For oxen: positive effect for teff, negative for barley and wheat, positive for all cereals (richness and evenness)
Ethiopia	Cereals	Gebremedhin et al. (2005)	oxen ownership		explain crop diversity	negative for finger millet; positive for barley, negative effect on inter-crop diversity of cereals at village level
Ethiopia	Cereals	Lipper et al. (2005)	livestock assets	wealth	explain crop diversity	not significant
Hungary	Home gardens	Birol .(2004)	whether or not home garden has integrated crop and livestock production	component of agricultural biodiversity	stated preference and revealed preference for home garden with this attribute	farmers value this component, especially in some regions

Table IV.2. PGR economic literature treatment of AnGR(cont...)

Country	Crop	Author	AnGR variable: Measurement	Concept	Role in analysis	Finding
India	Millet crops (sorghum, finger millet; pearl millet, foxtail millet and small millet	Nagarajan (2004)	value of livestock	wealth	explain crop diversity	negative for sorghum and minor millets at village level
Mexico	Maize landraces	Smale et al (2001)	measuring provision of feed and fodder by variety			not statistically significant
Nepal	Rice	Gauchan (2004)	livestock value	wealth	explain crop diversity	livestock assets are not significantly related to rice diversity, but are statistically significant predictors that households will grow landraces
Peru	Potato	Winters et al. (2005)	milk production	competing source of income	explain crop diversity	negatively related to potato variety diversity
Uganda	Banana	Edmeades et al. (2005)	value of livestock	wealth	explain crop diversity	positive for variety and use group richness

References

AAFC (Agriculture and Agri-Food Canada). (1999). PFRA, biodiversity and livestock grazing. www.agr.ca/pfra/land/grazing.htm

Barrett, J.C. (1991). The economic role of cattle in communal farming systems in Zimbabwe. In: workshop on 'The socio-economic impact of improved tick and tick-borne disease control in Zimbabwe.' Veterinary Research Laboratory, Harare. 9 May 1991.

Bela, G., Balázs, B., and Pataki, G.(2005) Institutions, stakeholders, and the management of crop genetic sources on Hungarian family farms. In: Smale, M. (ed.) *Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change.* CABI Publishing (forthcoming), Wallingford, UK, pp.

Benin, S., M. Smale, J. Pender, B. Gebremedhin and S. Ehui. (2004). The economic determinants of cereal crop diversity on farms in the Ethiopian Highlands. *Agricultural Economics* 31: 197-208.

Birol, E. (2004) Valuing agricultural biodiversity on home gardens in Hungary: An application of stated and revealed preference methods, PhD Thesis University College London, University of London, UK.

Cicia, G., D'Ercole E., and Marino D. (2003) Costs and benefits of preserving farm animal genetic resources from extinction: CVM and bio-economic model for valuing a conservation program for the Italian *Pentro* horse. Ecological Economics 45, 445-459

Drucker, A. and Anderson, S. (2004). 'Economic analysis of animal genetic resources and the use of rural appraisal methods: lessons from Southeast Mexico'. International Journal of Sustainable Agriculture Vol 2(2) pp. 77-97.

Dixon, J., Gulliver, A., and Gibbon, D. Hall, M. (ed.) (2001). *Farming systems and poverty,* FAO and World Bank, Rome and Washington D.C.

Danckwerts, J P (n.d., about 1974) A socio-economic study of veld management in the tribal areas of Victoria Province Department of Agriculture, University of Rhodesia: Salisbury

Edmeades, S., Karamura, D., and Smale, M.(2005) Demand for cultivar attributes and the biodiversity of bananas in Uganda. In: Smale, M. (ed.) *Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change.* CABI Publishing, Wallingford, UK, pp

FAO (Food and Agriculture Organization of the United Nations). FAOSTAT. databases, available at http://apps.fao.org/faostat/.

FAO. (1997). Livestock and the environment: Finding a balance.

Gauchan, D. (2004) Conserving Crop Genetic Resources On-Farm: The Case of Rice in Nepal. PhD dissertation, University of Birmingham.

Gebremedhin, B., Smale, M., and Pender, J.(2005) Determinants of cereal diversity in villages of Northern Ethiopia. In: Smale, M. (ed.) *Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change.* CABI Publishing, Wallingford, UK, pp.

GFA. (1987) Study on the economic and social determinants of livestock production in the communal areas - Zimbabwe. Final Report Gesellschaft für Agrarprojekte consultancy report to the Department of Veterinary Services, Harare.

Gollin, D. and Evenson R. E. (2003) Valuing animal genetic resources: lessons from plant genetic resources. *Ecological Economics* 45 , 353-363.

Le Houerou, H.N. (1989). The Shrublands of Africa. In: “The biology and utilization of shrubs”. Academic Press: 119-143.

Lipper, L., Cavatassi, R., and Winters, P.(2005) Seeds supply and on farm demand for diversity: a case study of Eastern Ethiopia. In: Smale, M. (ed.) *Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change.* CABI Publishing , Wallingford, UK, pp.

Milchunas, D.G. and Lauenroth, W.K. (1993). Quantitative Effects of Grazing on Vegetation and Soils over a Global Range on Environments Ecological Monograph 63 (4) 327-66.

Nagarajan, L. (2004) Managing Millet Diversity: Farmer's Choices, Seed Systems and Genetic Resource Policy in India. PhD Dissertation, University of Minnesota.

Pingali, P. and M. Smale. (2000). “The Modernization of Agriculture and Crop Genetic Diversity.” In S. Levin et al. (eds.), *The Encyclopedia of Biodiversity*. San Diego, Academic Press.

Scarpa, R., Drucker A. G., Anderson S., Ferraes-Ehuan N., Gómez V., Risopatrón C. R., and Rubio-Leonel O. (2003a) Valuing genetic resources in peasant economies: the case of 'hairless' creole pigs in Yucatan. *Ecological Economics* 45 , 427-443.

Scarpa, R., Ruto E. S. K., Kristjanson P., Radeny M., Drucker A. G., and Rege J. E. O. (2003b) Valuing indigenous cattle breeds in Kenya: an empirical comparison of stated and revealed preference value estimates. *Ecological Economics* 45 , 409-426.

Scoones, I C 1(1990) Livestock populations and the household economy: a case study from southern Zimbabwe PhD thesis, University of London.

Steinfeld, H (1988) Livestock development in mixed farming systems Wissenschaftsverlag Vauk: Kiel

Smale, M., Bellon M. R., and Aguirre Gómez J. A. (2001) Maize diversity, variety attributes, and farmers' choices in Southeastern Guanajuato, Mexico. *Economic Development and Cultural Change* 50 , 201-225.

Thomas, D.S.G. and Middleton, N.J. (1994). Desertification: Exploding the Myth. Wiley and Son, West Sussex. U.K.

Thornton, P. K., Kruska, R. L., Henninger, N., Kristjanson, P. M., Reid, R. S., Atieno, F., Odero, A. N., and Ndegwa, T. (2002). *Mapping Poverty and Livestock in the Developing World,* International Livestock Research Institute, Nairobi, Kenya.

Tisdell, C. (2003) Socioeconomic causes of loss of animal genetic diversity: analysis and assessment. *Ecological Economics* 45 , 365-376.

Wale, E. (2004) The economics of on-farm conservation of crop diversity in Ethiopia: incentives, attribute preferences, and opportunity costs of maintaining local varieties of crops. Ph.D. thesis University of Bonn, Centre for Development Research (ZEF), Germany.

Winters, P., Hintze, L. H., and Ortiz, O.(2005) Rural development and the diversity of potatoes on farms in Cajamarca, Peru. In: Smale, M. (ed.) *Valuing Crop Biodiversity: On-Farm Genetic Resources and Economic Change.* CABI Publishing (forthcoming), Wallingford, UK, pp.

World Bank. World Development Indicators (2004). CD Rom Washington DC.