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Ecological Economics 45 (2003) 353–363
ECOLOGICAL ECONOMICS
www.elsevier.com/locate/ecolecon

ANALYSIS

Valuing animal genetic resources: lessons from plant genetic resources

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Received 28 January 2002; received in revised form 1 August 2002; accepted 12 August 2002

Abstract

A growing body of theoretical and empirical studies has examined issues relating to the valuation, utilization, and management of plant genetic resources (PGRs). This paper attempts to summarize relevant lessons from this literature for animal genetic resources. Conceptually and methodologically, there are strong similarities between plant and animal genetic resources. However, the literature on PGRs makes it clear that most of the important policy questions require empirical information—about costs of collection and storage; about the ‘‘uniqueness’’ of desirable traits; about the technologies for in situ and ex situ conservation, etc. In these respects, there are big differences between plant and animal genetic resources. Improving the empirical understanding of animal genetic resource conservation should be a focus of future research.

Keywords: Genetic resources; Animal agriculture; Gene banks; Economic value

1. Introduction

Plant breeders have long recognized the value of plant genetic resources (PGRs) in the form of ‘‘original’’ or farmer-selected cultivar types (landraces), mutants, sports, and related wild species. Ex situ collections of these original materials have been established for all important crops. The state of both ex situ and in situ collections is summarized in Table 1. These collections have been developed over long periods of time. The proportion of original materials that have now been conserved in collections is quite high for most crops. The ‘‘gene banks’’ in which these materials reside are supported as an integral part of plant breeding programs based in national agricultural research systems (NARS) and international agricultural research centers (IARCs).

A comparable system for animal genetic resources (AnGRs), where resources embodied in animal breeds are collected and preserved in institutionally supported collections, has not been developed. Many breeds are maintained in in situ collections (herds) that depend on support by

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0921-8009/03/$ - see front matter
doi:10.1016/S0921-8009(03)00090-9

Table 1
Genetic diversity collection and utilization by commodity

	Area (Mha)	Landraces (× 1000)	% in collections	Wild species	% in collections	In situ collections	Ex situ						Utilization distribution
							Major collections (× 1000)	Accessions (× 1000)	% CGIAR	% Dup.	% LR	% WS	
Commodity													
Bread wheat			95	24	60	Few	24	784	16	50	17	2	
Durum wheat		150	95	24	60	Few	7	20	14	32	53		High
Triticale			40				5	40	38	66			
Rice	149	140	90	20	10	Few	20	420	26	75	25	1	High
Maize	130	65	90		15	Few	22	277	5	80	16	0	High in LDCA
Sorghum	43	45	80	20	0	Few	19	169	21	42	18	0	Low
Millets	38	30	80		10	None	18	90	21		33	2	Low
Barley		30					16	484	5	23	9	1	
Oats							20	222	0		1	4	
Rye							8	287	0		8	0	
Food legumes													
Beans			50		70	Few	15	268	15	76	21	1	Low-medium
Soybeans	66	30	60			None	23	174	0	?	2	1	Low-medium
Chick peas					75		13	67	41	75	29	1	
Lentils					95		5	26	30	95	30	3	
Fava beans					25		10	29	33	35	42	0	
Peas					0		18	72	0		4	0	
Groundnuts		15			28		16	82	18	28	15	1	
Cowpeas					30		12	86	19	30	19	2	
Pigeon peas					22		4	25	52	22	50	2	
Lupin							10	28	0		12	16	
Root crops													
Potato	19	30	95		30	Few	16	31	20	100	13	5	High
Sweet potato	10	5	50			Few	7	32	21	93	16	6	Medium
Cassava	16		35		29		5	28	30	90	23	2	Low-medium
Yam		3					2	12	25	20	24	0	
Sugar cane		20	70										

private individuals and groups, rather than a more formal institutional mechanism. Animal genetic resources are thus more vulnerable to losses from changes in support than are PGRs. Ex situ collections include zoos and other live animal parks away from the native habitat of the animals in question. Other forms of ex situ collections have taken on increasing importance as technology has improved, including cryopreservation of sperm, ova, and embryos. Until recently, ex situ collections of animal genetic resources have necessarily been small in both size and scope, having relatively limited numbers of animals from different breeds and species. In recent years, new techniques of cryopreservation, and declining costs, have begun to encourage ex situ conservation approaches for animal genetic resources.

In this paper, we review the small but well developed literature on the economics of PGRs, with the goal of asking what lessons can be learned for animal genetic resources. We first review valuation categories and sources of value. We then review specific lessons that emerge from studies on the management and valuation of PGRs. We conclude by drawing some inferences for policy and research.

2. Valuing animal genetic resources: sources of value and comparisons with plant genetic resources

An abundant recent literature has delineated the theoretical and conceptual basis for valuing genetic resources. For purposes of brevity, this paper will simply note that surveys can be found in Brown (1990), Pearce and Moran (1994) and Food and Agriculture Organization (1998), Evenson et al. (1998), and Gollin and Smale (1999), among others. This paper will also restrict its attention to utilitarian values of genetic resources—in other words, those associated with human well-being. In doing so, we acknowledge omitting a view that is embraced by many environmentalists (see for example Shiva, 1991), who believe that genetic diversity has value in itself. We do not dispute the importance of non-utilitarian sources of value. Clearly there are uncomfortable ethical problems that come from valuing animal genetic resources entirely through the lens of human sensibilities.

Within the utilitarian framework, there are many different sources of value for genetic resources. These can be classified into direct use values, indirect use values, and non-use (or "existence") values, as shown in Table 2. Direct use values are most clearly related to breeding use. However, there are other direct uses associated with the preservation of rare genetic materials, typically in situ. For example, a rare plant or animal variety might be valued for particular niche production of food types—an exotic type of wool or cheese, for example. Indirect use values are related to future uses of the genetic materials: these are the values that derive from future use for human purposes (one widely cited indirect use value is the "option value" of maintaining genetic materials in order to retain the option of using them at some future date). Finally, non-use values are derived from the pure satisfaction that people derive from the continued existence of rare breeds, regardless of any material benefits that they gain from these breeds.

In this paper, we will focus primarily on direct use values of animal genetic resources—most clearly related to the use of these resources in breeding. This is not to deny the importance of other sources of value; but in many cases, we have difficulty in measuring or assessing indirect use values or non-use values.

The direct use values of animal genetic resources are related to the uses of AnGRs in pre-breeding and breeding. These values are affected by related activities, such as inventorying, collection, evaluation, and exchange. Pre-breeding activities are important in animal genetic resources. By this, we mean the systematic crossing and evaluation of original genetic resources to develop advanced lines for breeding. Since these breeding lines can be widely used outside the program that originates them, private sector research programs will tend to invest too little in pre-breeding work. This has clearly been true for PGRs. Even when private firms have been heavily involved in delivering finished varieties, they often build their proprietary materials from breeding lines developed in national or international programs. For animal

Table 2
PGR activities and values

Activities	Direct use value		Indirect use value		Non-user existence value
	Breeding	Recreation	Option	Diversity	
Genetic resource in nature		x	x		x
Inventorying	x	x	x		x
Collection					
Ex situ	x		x		
In situ	x	x	x		x
On-farm	x	x	x		x
Evaluation					
Agronomic	x		x	x	
Genetic	x	x	x	x	
Exchange					
Information system	x		x		
Restriction	x		x		
Pre-breeding					
Landrace combination	x			x	
Advanced lines	x			x	
Breeding					
IARCs	x			x	
NARs	x			x	
Private	x			x	

genetic resources, it would be reasonable to imagine that the same situation would pertain: there is little incentive for any private firm to engage in extensive pre-breeding, unless there is a way for them to recover the costs of this activity subsequently.

The non-use values of animal genetic resources may not be as large as the use values. But they may be more important for animal genetic resources than for PGRs. Conserving a rare breed of sheep is perhaps a more compelling "story" for the public than conserving a rare variety of sorghum. As a result, ordinary people may get more satisfaction from knowing that rare breeds are being maintained than for knowing that a crop landrace is being preserved in an ex situ collection.

The distinction between use and non-use values is important for other reasons. Use values are associated with production and are thus a type of "public producer good", whereas non-use values cannot be associated with production and are thus a type of "public consumer good". Consumer goods are fundamentally different from producer goods. Their consumption depends on income and prices. It appears, from most data on membership in environmental advocacy groups and expressions of support for biodiversity, that the non-use consumption of genetic resources has a high income elasticity. These goods are consumed predominantly by rich people in rich countries. Producer goods, on the other hand, are very different. The demand for producer goods is derived from the demand for the goods that they produce. In the case of PGRs, these goods are basic food grains (and feed grains, to some extent), legumes, and root crops. These goods are consumed by the poor and are vital to their welfare. Thus, they are demanded most heavily by the poor in poor countries. The distinction between use (producer goods) and non-use (consumer goods) is also important in a political and development sense. If the tastes of the rich for non-use genetic resource conservation are imposed on the poor (through pressure to regulate and tax), they can do great harm to the poor—rather like insisting that farmers consume less food so that they can consume more grand opera[2].

3. Uses of plant genetic resources

Table 1 above provides an overview of basic data on PGR diversity and collection status. Table 3 provides a broader perspective on the role of international breeding programs in crop varietal production in 11 crops over the 1965–2000 period. This table, based on a recently completed study of crop genetic improvement (Evenson and Gollin, 2003), shows rates of varietal improvement by crop, region, and period. It also shows international centers' contributions to pre-breeding in the form of (a) crosses made in an international program and released in a national program (IX); (b) crosses made by a national program with at least one parent crossed in an international center (IP); and crosses made in a national program with at least one ancestor other than a parent crossed in an international center.

These data are impressive in showing the ''leverage'' of international programs in plant breeding. A synthesis study of these data showed that from 1970 to 1998, national program investments in plant breeding doubled. This would have produced a 70% increase in varietal production in the absence of pre-breeding by international centers. With the availability of breeding lines and other advanced materials from the international centers, the effectiveness of national program investments was increased, so that varietal production more than doubled.

We do not have comparable data for animal breeding programs. It appears, however, that they are very different, in part because of ''replicability'' issues. New crop varieties, once they have attained population stability, can be quickly multiplied and hence replicated in large areas. Prior to artificial insemination, the replicability of superior animals was limited to a relatively small number of individuals. With artificial insemination, the animal genetic resources of a superior male animal could be widely replicated, but replication among female animals was limited. That has changed with recent embryo transfer technology (and potentially with cloning), so that animal genetic resources may no longer face severe replicability constraints[3].

It should also be noted that the animal ''breed'' is not entirely comparable to the plant ''landrace,'' even though farmers produced both in the absence of scientific breeding programs. Most landraces are differentiated by single traits—often controlled by single genes. Their value in many uses is based on this single trait. With appropriate techniques, plant breeders are likely to turn to collections of germplasm in search of materials with particular traits. This does not appear to take place to the same degree in animal breeding, where diversity within breeds is important. Thus, many changes in animal breeding (e.g. leaner animals) are achieved within each of the major breeds.

4. The economics of collecting and managing plant genetic resources: theory and empirical findings

The theory of valuing and managing PGRs is reasonably well understood and has been surveyed before[4]. These genetic resources are an impure public good, and markets typically do not give the right incentives for conservation to the farmers, herders, hunters, and gatherers whose actions may have a large impact on the conservation of species, landraces, breeds, and varieties. There is thus prima facie support for public actions that promote conservation.

[2] We do not suggest that farmers themselves—or the poor—do not attach existence values to genetic diversity or to the conservation of rare germplasm. We simply suggest that in poor countries, and among those people for whom subsistence concerns weigh most heavily, the use values of germplasm dominate the existence values.

[3] Interestingly, it appears that in poultry (and to some extent in pig) breeding, the replicability constraint was reduced by the grandparent–parent–chick hatching system through which a few relatively small poultry breeding programs now dominate the world's production of broilers and layers.

[4] See, among others, Gollin and Smale (1999) and Evenson et al. (1998).

Table 3
Average annual varietal releases by crop and region 1965–1998

Crop	Average annual releases							1965–1998 IARC content[b]			
	1965–1970	1971–1975	1976–1980	1981–1985	1986–1990	1991–1995	1996–1998[a]	IX	IP	IA	IN
Wheat	40.8	54.2	58.0	75.6	81.2	79.3	(79.3)	0.49	0.29	0.08	0.14
Rice	19.2	35.2	43.8	50.8	57.8	54.8	58.5	0.20	0.25	0.07	0.48
Maize	13.4	16.6	21.6	43.4	52.7	108.3	71.3	0.28	0.15	0.04	0.53
Sorghum	6.9	7.2	9.6	10.6	12.2	17.6	14.3	0.16	0.07	0.06	0.71
Millets	0.8	0.4	1.8	5.0	4.8	6.0	9.7	0.15	0.41	0.09	0.35
Barley	0.0	0.0	0.0	2.8	8.2	5.6	7.3	0.49	0.20	0.01	0.30
Lentils	0.0	0.0	0.0	1.8	1.8	3.9	(3.9)	0.54	0.05	0.01	0.40
Beans	4.0	7.0	12.0	18.5	18.0	43.0	(43.0)	0.72	0.05	0.01	0.19
Cassava	0.0	1.0	2.0	15.8	9.8	13.6	(13.6)	0.53	0.15	0.01	0.31
Potatoes	2.0	10.4	13.0	15.9	18.9	19.6	(19.6)	0.17	0.06	0.02	0.75
All crops											
Latin America	37.8	55.9	65.9	92.5	116.2	177.3	139.2	0.39	0.14	0.04	0.43
Asia	27.2	59.6	66.8	86.3	76.7	81.2	79.9	0.18	0.29	0.10	0.43
Middle East North Africa	4.4	8.0	10.2	12.2	28.4	30.5	82.2	0.62	0.22	0.04	0.12
Sub-Saharan Africa	17.7	18.0	23.0	43.2	46.2	50.1	55.2	0.45	0.21	0.07	0.27
All regions	87.1	132.0	161.8	240.2	265.8	351.7	320.5	0.36	0.17	0.05	0.42

[a] Number in parentheses are simple repetition of 1991–1995 rates because of insufficient data.
[b] IX, variety based on IARC cross; IP, variety based on NARS cross with at least one IARC parent; IA, variety based on NARS cross with at least one non-Parent IARC ancestor; IN, variety based on NARS cross with no IARC ancestors.

The use value is based on the actual and potential flow of materials from a collection into a breeding program and eventually into farmers' fields. No careful empirical study has actually succeeded in putting a value on a collection of genetic resources, but the theory is clear[5]. Collections should be expanded so long as the expected marginal value of an additional accession exceeds the costs (with both benefits and costs appropriately discounted over time).

Simpson et al. (1996) show that the marginal value of large collections gets very small, because if a trait is common, a marginal accession will seldom be useful, and if it is rare, it will be difficult to collect. An exception arises when there are systematic differences between materials that are collected "early" and those that are collected "late" (Evenson and Lemarié, 1998). For example, if collections are assembled non-randomly, and if traits are distributed non-randomly, it might be the case that entire pockets of varieties—such as rice varieties from the highlands of Assam—may be under-represented in the collection, and may also contain traits that prove valuable. The marginal value of these accessions may be high.

A number of studies have focused on management issues as well as valuation. One question is whether it makes sense to characterize and evaluate a collection before any specific "problem" emerges. For example, should a gene bank manager test all of the material in a gene bank for disease and pest resistance, or should he or she wait until a specific pest outbreak? Koo and Wright (2000) suggest that under some occasions, it makes sense to screen an entire collection in advance; under other conditions, it does not.

Assuming that the collection has not been screened in advance, searching is a dynamic process. If scientists truly do not know the distribution of useful traits in the collection, the search process yields valuable information about the distribution of traits. This in turn guides searchers in identifying appropriate search strategies (Rausser and Small, 2000). In general, the size of a search depends on the importance of the problem and the expected distribution of useful traits (Gollin et al., 2000). Under some conditions, very large searches are justified. Gollin et al. (2000) show that it may make sense to search essentially the entire population of wheat varieties for some configurations of search costs, search benefits, and distributions of desirable traits.

Some other policy questions have not yet been addressed for PGRs, but the answers are fairly clear. For example, some debate has addressed the issue of whether in situ or ex situ conservation should be pursued. To the extent that the two approaches are substitutes, whichever is cheaper is preferred. To the extent that they play different roles, it may make sense to pursue both strategies.

Some empirical questions are also still open. Yes, marginal value is necessarily small in a big collection. But what is "small"? And when is a collection "big"? The marginal value of an accession should be compared with the costs. But what are the costs over time? For most crops, we do not know the answer even within an order of magnitude.

5. Key lessons from the economics of plant genetic resources for animal genetic resources

What are some key lessons from the literature on PGRs, and what are the implications for animal genetic resources. A number of points can be identified.

5.1. *Costs of conservation have important implications for management and value*

An important lesson of the literature on valuation and management of PGRs is that the costs of conservation matter a great deal (see Wright,

[5] A number of studies, however, have attempted to measure the hypothetical value of uncollected resources—for example, species in a hectare of rainforest. Mendelsohn and Balick (1995) offer an illustrative approach to this problem.

1997). Costs differ, of course, between in situ and ex situ collections. There are also significant differences across plant species. For small grains that are self-pollinated, relatively small numbers of seeds can be kept in gene banks. Similarly, relatively small numbers of plants need to be maintained in in situ collections. By contrast, maize is a coarse grain that frequently cross-pollinates. Large quantities of seeds are needed to conserve germplasm ex situ. For still other plants, such as potatoes or bananas, ex situ collections may consist of vegetative materials or tissue culture, rather than seeds. Costs can differ a great deal depending on the type of material being stored and the quantities in storage.

Relatively little literature has actually documented the costs of storing PGRs in ex situ collections (Pardey et al., 1998). It is clear, however, that optimal storage and collection strategies depend a great deal on these costs. For animal genetic resources, the costs of storage are likely to play an even more important role in affecting strategies for collection, storage, and search. Frozen embryos, eggs, and semen may be more costly to collect and store than other materials. If so, this will have important implications for the types of materials to be conserved, the quantities in which they are conserved, and the methods of conservation.

5.2. Low utilization of rare materials does not imply low value

For PGRs, gene banks are used relatively little for regular breeding purposes. In most cases, breeders prefer to work with advanced breeding lines, including released varieties, rather than wild species or landraces, which may have numerous undesirable traits. As long as the available pool of improved varieties offers sufficient genetic variation, breeders have no incentive to look elsewhere for germplasm. The only times when it makes sense for breeders to turn to unimproved germplasm is when the pool of elite materials lacks a particular trait and the breeders believe there is some possibility that they can find that trait in the larger pool of unimproved lines.

The low utilization of materials from gene banks does not imply, however, that they have low value. Gollin et al. (2000) suggest that breeders will seldom take advantage of a “large” collection of wheat genetic resources. But if the payoffs are high enough, the rare circumstances when breeders do find valuable material in the gene bank are enough to pay for the costs of the collection many times over. Thus, the value of a gene bank need not lie in its everyday use. Instead, it may be occasional searches for rare material that make gene banks valuable.

In animal genetic resources, this pattern is likely to be echoed. Most breeders are disinclined to work with unimproved animals or wild species. Within breeds, there is often enough genetic variation for scientists to select for desirable traits and to screen out undesirable ones. There is little benefit to using genes from landraces or traditional breeds, except in the unusual cases where there are identifiable traits that have been bred away from improved animals.

But the fact that cattle breeders seldom look for desirable genetic attributes in rare breeds does not mean that those breeds lack value. We should expect the value of rare breeds and wild species to come primarily from unusual instances in which common breeds turn out to lack a valuable trait. Even the prospect of this situation confers substantial value on rare breeds.

5.3. The practical difficulty of maintaining ex situ collections may be high, and it may be higher for animals than for plants

For most plant species, in situ collections of germplasm are relatively little used, and it appears that ex situ collections will offer the primary mode of conservation. In situ collections are feasible only in places where farmers have some reasons to maintain their traditional varieties, and it is both technically feasible and (in some sense) desirable to collect essentially all varieties for gene banks.

By contrast, in many animal species and breeds, in situ collections are quite important, in part because cryopreservation is not fully reliable. These in situ collections are costly, however, and they are vulnerable to negative shocks to herds or flocks and to habitats[6].

Collections of animals in situ may be quite expensive to manage. In the case of a rare breed of livestock, the minimum herd size needed to maintain sufficient diversity may be quite large, and the herd must be matched closely with an appropriate habitat. Basic management approaches may differ from those for plant germplasm collections. For example, it is standard practice in plant gene banks to store duplicate collections with other gene banks. But while this is easy and relatively cheap for plants, duplication of in situ collections of animals can be complicated.

Thus, an important area for research on the economics of animal genetic resources will be to help gene bank managers determine when in situ collections are sensible and when they are not. The payoffs to developing truly effective (and cost-effective) ex situ conservation techniques may be large.

The preservation of habitat, by contrast, can be quite costly, and it should be noted that in situ preservation is mostly habitat preservation. Here, the issue of producer versus consumer goods is relevant. Many activist groups in this field are not only calling for preservation that is much more costly than the true costs of conserving germplasm, but they are often asking the poor, indirectly, to bear the costs of conservation when the rich are the ultimate beneficiaries.

5.4. Emerging biotechnologies will alter the types of materials to be conserved and the frequency with which they are used

As biotechnology has grown in significance, attention has focused on the implications for the conservation of genetic resources. On the one hand, biotechnology would appear to make genetic resources more valuable, because the technology increases the range of transformations possible, reduces the costs (and increases the speed) of varietal improvement, and generally expands the possibilities for manipulating genetic material. On the other hand, biotechnology might reduce the need for conserving genetic resources, because the ability to move genes easily across species barriers might reduce the quantities and range of source materials. This is ultimately an empirical question, and we cannot hope to answer it until the technology becomes more clearly established.

The evidence from PGRs may not be entirely relevant, but the situation thus far in most crops has been that biotechnology has been used first and most effectively for transferring single-trait characteristics into a “basic plant type”. Today, the desired “genes” may cross species boundaries, but they are effectively being used in the same process of varietal improvement that has dominated conventional breeding (and wide crossing) strategies for the past three or four decades.

In the case of PGRs, the new methods seem to require more genetic resources, perhaps drawn from more species. But as a generalization, the value of PGR collections appears to have been increased by the development of biotechnology methods. In addition, biotechnology methods enable more complex evolution of genetic resources for possible use.

New fields of research are now opening up as crop genomes are mapped and genomic and proteinomic work are initiated. These new fields appear also to raise the value of genetic resources generally.

How much of this will apply to livestock biotechnology? In the short run, reproductive technologies that speed the pace of replication seem destined to play an important role. Vaccine development may also quicken and become more targeted. But the use of single-gene traits in animal breeding may be less important than in plant breeding. If so, then the value of rare breeds and other animal genetic resources may not be increased as much by biotechnology as we would

[6] For example, in times of war or domestic disturbance, ex situ collections of livestock are vulnerable to being eaten, in a way that is unlikely for plant genetic resources. The value of an ex situ collection of livestock for consumption purposes is far higher than the value of an ex situ collection of grain.

expect for PGRs. Of course, scientific advances generally overtake this kind of speculation, so any predictions should be offered with humility.

6. Conclusions

One lesson to be drawn from the literature on PGRs is that conservation is, in general, quite inexpensive—certainly in comparison to the potential benefits that could theoretically emerge from genetic resources. Although animal genetic resources are perhaps more costly to collect and store, and although they appear to be used less directly in breeding, the economics are still striking. There are perhaps 4000 or so rare breeds of livestock. The costs of maintaining breeding herds for these rare breeds could be quite low. The indirect use value—an option value—of preserving these breeds is probably high enough to justify the costs.

More generally, consider a crude cost calculation for the conservation of all plant and higher animal species that can be conserved using cryopreservation techniques. For plant species, using ex situ gene bank technology (which is not applicable for all plant species), the costs of maintaining ex situ preservation of all 250 000 higher plant species is probably little higher than the costs for the one million or so distinct crop landraces (with duplication to six million accessions). Similarly, for all higher animal species, cryopreservation costs may be quite modest, to the extent that the technologies for preservation can be made feasible. If the costs per livestock species conserved are within an order of magnitude of the costs of conserving each plant species, there cannot be much doubt that the economics justify extensive conservation efforts.

From a methodological standpoint, many of the techniques developed for assessing the value of PGRs seem to be appropriate for animal genetic resources, as well. Hedonic studies, simulation techniques, and production function estimates all seem to be pertinent to the case of animal genetic resources. The challenges in this area of research are primarily empirical rather than theoretical: developing the needed data should be a focus of research effort.

Acknowledgements

This paper benefited from the helpful and constructive comments of Adam Drucker and Riccardo Scarpa. Our thinking about plant genetic resources has been shaped by a number of colleagues and critics, including Victoria Cabanilla, T.T. Chang, Tom Hargrove, Bent Skovmand, Melinda Smale, and Brian Wright. D. Gollin gratefully acknowledges receiving support through the Gaylord Donnelley Fellowship administered by the Yale Institute for Biospheric Studies.

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