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Exploring the Benefits of a Systems-based Approach to Plant Genetic Resources Conservation

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Plant genetic resources make essential contributions to increasing food security and nutrition, improving rural livelihoods, supporting the maintenance of ecosystem services (Frison *et al*., 2011; FAO/PAR, 2011) and to meeting the challenges of adapting to climate change (Hodgkin and Bordoni, 2012; Jarvis *et al*., 2015). Ensuring that plant genetic resources can make these contributions requires that they are conserved for present and future generations in the face of continuing genetic erosion in many production systems, as a result of the expansion of more uniform cultivars and the spread of intensive agricultural practices (IPES Food, 2016).

Over the past sixty years a variety of ways of ensuring the long-term conservation of plant genetic resources have been developed. These include: *ex situ* and *in situ* conservation programmes and a range of national and international policies and collaboration. These programmes have been supported by a growing body of knowledge of the many different aspects of conservation of different types of plant genetic resources, and an increasing capacity to undertake conservation activities. The reports by FAO of the State of the World's Plant Genetic Resources for Food and Agriculture (FAO, 1996; 2010) document the developments that have occurred in conservation and use of plant genetic resources while the different Global Plans of Action set out perceived needs and priorities for future conservation efforts (FAO, 2012). The global commitment to, and recognition of the importance of, plant genetic resources conservation is reflected in the entry into force in 2004 of the International Treaty on Plant Genetic Resources for Food and Agriculture, which currently has 140 contracting parties (http://www.planttreaty.org/list_of_countries).

Despite considerable efforts by international and national organizations, there are still considered to be substantial failings in our efforts to effectively conserve and make available plant genetic resources and the genetic diversity they contain. It has been reported that the genetic diversity present in many species and crops is not adequately conserved (Padulosi *et al*., 2002; Ford Lloyd *et al*., 2011), that the continuing contributions by farmers growing traditional varieties of crops are not recognized and understood (e.g. Chapter 12 in Jarvis *et al*., 2016; Zimmerer, 2003), that the links between *ex situ* and *in situ* conservation programmes are poor (Brush, 1995) and that, overall, the resources for conservation remain inadequate (Gepts, 2006).

The conservation of plant genetic resources involves a number of different activities undertaken by a wide variety of actors with often divergent interests, concerns and objectives (Baker *et al*., 2013). The many different elements and activities that contribute to the conservation and use of plant genetic resources can be thought of as constituting a more or less integrated and dynamic system (Hodgkin *et al*., 2013). Systems have been described as sets of interconnected elements and processes that result in a particular function or set of functions. Systems change over time in response to developments and changes in external forces, and themselves influence their external environment.

Exploring the systems features of plant genetic resources conservation involves investigating: (a) the connections between the elements, activities and processes (either distinct or overlapping) that support or influence conservation and use; (b) the different institutions and actors involved; and (c) the ways in which the operations of the system contribute to the maintenance and flows of materials and knowledge. A systems approach can help evaluate the extent to which a system is achieving its objectives. One systems approach, dynamic systems modelling, has been used to explore the food system and the ways in which diversity can contribute to desired food security and nutrition outcomes (Allen *et al*., 2014; Allen and Prosperi, 2016). Systems

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approaches have also been used to explore aspects of biodiversity conservation.

In this paper we use systems perspectives to explore the features of plant genetic resources conservation efforts with a primary focus on the national or country level. We consider the processes, linkages and relationships that operate in the conservation system and the different actors involved. Our objective is to explore alternative ways of investigating the strengths and weaknesses of current conservation efforts with a view to identifying possible improvements.

Elements of Systems Approaches

Systems approaches usually include a consideration of:

- The boundaries of the system – what is considered to be inside or outside the system of interest (which may vary depending on the perspectives of the observer);
- Inter-relationships or connections between the processes involved rather than just the different elements themselves; and
- The different actors, their interests and concerns – farmers still using traditional varieties may have very different roles and concerns from those who fund *ex situ* conservation activities;

They will often consider also:

- Hierarchies and the relationships between different subsystems – in the case of conservation systems, from local to international;
- The ways in which knowledge is used, shared and maintained; and
- The ways in which decisions are made and the relative power of different actors within the system.

The Plant Genetic Resources Conservation System

One way of identifying what might constitute a plant genetic resources conservation system and its boundaries is to identify the activities that contribute to conserving plant genetic resources and to making them available to current and future generations (Hodgkin *et al*., 2012) *viz*:

- Locating diversity, planning conservation and collecting;
- Management and maintenance of materials;
- Diversity analysis, characterisation and evaluation;
- Managing information and knowledge and making this available to users;
- Distribution and exchange of materials and the information associated with these;
- Selection, breeding, and variety development or improvement.

These processes are connected in a more or less linear manner. The final step, selection and variety development, leads to a range of new plant genetic resources in the production system which may themselves be the target of conservation activities thus forming a continuing cycle. The connections include internal smaller feedback loops or cycles so that, for example, diversity analysis provides information to support conservation planning and use of genetic resources.

Five identifiable areas of operation or domains can be identified in which these activities occur:

- *Ex situ* programmes, usually carried out as part of national or international programmes;
- Deliberate *in situ* and *on-farm* conservation actions for crop wild relatives and traditional varieties, undertaken or supported by national programmes, civil society groups and farmers themselves;
- Research and breeding efforts that support use of plant genetic resources;
- The agricultural production system itself and the plant genetic resources and genetic diversity found in it; and,
- The market operations involved in making products available and providing seed and planting materials.

While only the first two domains involve deliberate conservation activities carried out by identified organizations, all the domains contribute to the resources conserved for present and future generations.

As noted above, an important part of the analysis of the system is identification of the different actors involved in the various activities and in describing their interests and concerns (Table 1). The listing of actors in Table 1 is preliminary and subject to discussion but allows identification of some relevant questions and areas for further investigation. Thus, both conservation professionals and farmers undertake similar activities but with quite different objectives

Table 1. Direct contributions of selected actors to conservation related activities (X, XX – estimate of extent to which the actor undertakes specific activities)

Actor	Processes					
	Locating and planning	Maintenance of materials	Characterisation and evaluation	Information management	Distribution of materials	Selection and breeding
Farmers and rural communities	XX	XX	XX	XX	XX	XX
Farmer organizations and civil society groups	X	X	X	X	X	X
Extension officers				X	XX	
National agricultural research and development workers		X	XX	XX	X	
Biodiversity conservation organizations and environment agencies	XX	XX	X	XX		
PGR conservation professionals	XX	XX	XX	XX	XX	
Private and public sector breeders (including breeding research)		X	XX	XX	XX	XX
Seed distributors and sellers				X	XX	
National and international agribusiness			X	X	XX	XX
National policy makers				X		

and to different extents. Seed distributors and sellers are only likely to contribute to seed distribution and exchange although they may contribute to knowledge management and sharing information, and again have different objectives (maximizing sales and turnover) than those of conservation professionals (long-term maintenance of diversity) or farmers (production to meet livelihood needs). Policy makers are crucially important in setting the rules for different operations, especially seed distribution, but play no direct part in undertaking any of the specific activities apart from information management.

Actors influence both the links and the flows within the system in different ways. For example, national and private plant breeders and breeding organisations provide the main pathway for movement of *ex situ* conserved genetic diversity back to the production system. But, they also act as a substantial genetic bottleneck, supporting the return of very much less diversity than was obtained from a genebank's location and collecting activities. Analysis of flows between genebanks and breeding indicates that research, breeders' demands, crop identity and the biological nature of the materials are all important in determining the movement of materials into breeding programmes (Dulloo *et al.*, 2013). Exploring flows of resources between all the different processes and the roles of different actors is a further area where a systems approach would be rewarding.

Application to Key Issues

An important test of the value of systems approaches to plant genetic resources conservation is the extent to which it contributes to identifying ways in which some of the key problems identified above might be overcome. In this section we highlight how a systems approach can help identify insights to strengthen conservation activities. We use two examples: (1) limited conservation of key genetic resources and (2) the links between *in situ* and *ex situ* conservation.

(1) *Limited Conservation of Key Genetic Resources*

Neglected and underutilized crop species (NUS) have been reported to be under represented in conservation efforts with an average of possibly 8 accessions or less conserved *ex situ* for many of these species (Padulosi *et al.*, 2002). Exploring the processes and actors entailed in conserving genetic resources, it is apparent that it is farmers who are the main actors involved in locating and planting many NUS, maintaining materials, characterizing and evaluating them, managing information about them, distributing them, and selecting and breeding new varieties. Systems approaches can explore how the contributions of other actors might be enhanced (e.g. increasing *ex situ* conservation in genebanks, using agricultural extension services to share materials and information, expanding support for research and breeding programmes on NUS) or how to improve recognition of the contribution farmers make to conserving NUS (e.g. direct financial support, *on-farm* conservation programmes). Alternatively, such approaches might analyse the dynamics behind the replacement of NUS to identify intervention points to stem or reverse replacement. Consideration of a hierarchy of sub-systems might yield insights into missing processes or conflicting purposes at different levels from the individual farmer to global level.

(2) *The Links between In situ and Ex situ Conservation*

Ideally *ex situ* and *in situ* conservation efforts would be closely linked but, in practice, the links are weak. Systems approaches can be used to analyse boundaries to explore what is inside different actors' systems of interest that contribute or could contribute to conservation. For example, *in situ* conservation of CWR often depends on management of protected areas, but CWR are rarely within the boundaries of a protected area (PA) manager's system of interest. In the case of traditional varieties, the role of farming communities who *de facto* maintain crop genetic diversity *on-farm* is often ignored by many PGRFA conservation professionals. Systems approaches can contribute to bringing together the different stakeholders – conservation professionals, government workers in forestry and environment and biodiversity departments as well as men and women farmers from local communities – to explore their perspectives on the processes under consideration and to create new, meaningful linkages between the actors.

Conclusion

Although this paper provides only a brief overview, the preliminary results suggest that systems approaches may shed light on some key issues that confront those involved in the conservation and use of plant genetic resources. More work is required to explore the full complexity of the system as a whole and of its constituent parts. A next step could be to explore the conservation system for a range of individual crops and undertake a comprehensive stakeholder analysis to determine present and potential roles of all actors. This exploration would allow for a more complete and less general description of the processes involved, the relative contributions of the different areas of operation and the roles of the different actors. It would also make clear the benefits of a systems approach in increasing the efficiency of conservation and use of plant genetic resources for food and agriculture.

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