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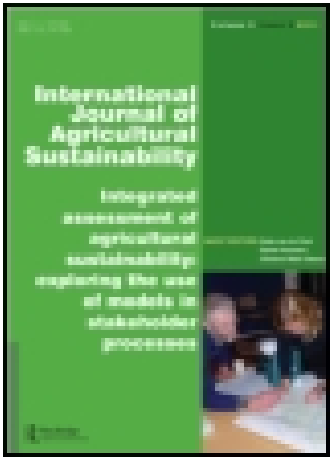

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Mauricio R. Bellon[a], Elisabetta Gotor[a] & Francesco Caracciolo[b]

[a] Bioversity International, Via dei Tre Denari 472/a, 00057 Maccarese (RM), Italy

[b] Department of Agricultural Economics and Policy, University of Naples Federico II, Via Universita 96, 80055 Portici (Na), Italy

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Conserving landraces and improving livelihoods: how to assess the success of on-farm conservation projects?

Mauricio R. Bellon[a*], Elisabetta Gotor[a] and Francesco Caracciolo[b]

[a]*Bioversity International, Via dei Tre Denari 472/a, 00057 Maccarese (RM), Italy;* [b]*Department of Agricultural Economics and Policy, University of Naples Federico II, Via Universita 96, 80055 Portici (Na), Italy*

Smallholder farmers who grow diverse landraces in centres of crop diversity contribute to sustaining the capacity of agricultural and food systems to adapt to change by maintaining crop evolution in their fields today, thus enabling humanity to continue to have the broad genetic variation needed to adapt crops to changes tomorrow. Given this fact, the last 20 years have witnessed an ever-growing interest in on-farm conservation of crop infra-specific diversity. While numerous projects to support it have been, and continue to be, implemented worldwide, there has been very little systematic assessment of the extent to which these projects have been effective at contributing to the maintenance of crop diversity on-farm and the creation of associated benefits for the farmers involved. The factors and relationships implicated in attaining conservation and livelihood results are complex, so that a conceptual scheme that brings them together in a simplified but coherent fashion can be extremely useful for the scientists, donors, policy-makers and practitioners concerned. This paper presents a conceptual framework for analysing on-farm projects, the trade-offs involved and assesses their success in a more systematic way.

Keywords: crop infra-specific diversity; evolutionary services; plant genetic resources; genetic erosion

Introduction

Crop biological diversity has been and continues to be the basis of our food supply and good nutrition, providing humans with various and nutritious foods, and other products and services. In particular, the phenotypic and genetic variation present within a crop species – that is, crop infra-specific diversity (hereafter referred to as crop diversity) – allows farmers and scientists to adapt a crop to heterogeneous and changing environments. This adaptive capacity is illustrated by the diffusion of a great number of crops from their centres of origin to completely new and different environments. The conservation of infra-specific diversity of crops has been a worldwide concern for many decades due to the worry that a great amount of this diversity would disappear with agricultural and economic development, that is, genetic erosion (Brush, 2004; Gepts, 2006; van de Wouw, Kik, van Hintum, van Treuren, & Visser, 2010). This concern has led to the collection and conservation of seeds and planting material in gene banks, that is, *ex situ* conservation (Gepts, 2006). While genetic erosion certainly has occurred worldwide (Food and Agriculture Organization of the United Nations [FAO], 2010), a large amount of crop diversity is still retained

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*Corresponding author. Email: m.bellon@cgiar.org in developing countries by smallholder farmers (van de Wouw et al., 2010). This is particularly true for crops in their centres of domestication and diversity where farmers continue to grow landraces[1] (Brush, 2004; Jarvis et al., 2008; Zimmerer, 2010). The recognition of this 'de facto' conservation of crop diversity has led to a growing interest in on-farm conservation of landraces in centres of crop diversity as a complement to *ex situ* conservation (Bellon, Pham, & Jackson, 1997; Bretting & Duvick, 1997; Brush, 2004; Gepts, 2006).

On-farm conservation of landraces refers to the maintenance of crop evolution in farmers' fields, farms and landscapes (Brush, 2004) and aims at retaining potentially useful but undetermined genetic variation, and to generating novel variation needed to maintain the capacity of crops to adapt to change (Bellon, 2009). It produces both private and public benefits (Smale, 2006; Smale & Bellon, 1999). The former refers to the benefits that farmers capture directly from the process and are available to them only – such as income and food security –while the latter refers to benefits that farmers and others, including society at large, can capture from the process – such as the genetic diversity available to adapt crops to changing circumstances. On-farm conservation depends on the active participation of farmers and the existence of incentives for them to maintain crop diversity on-farm (Bellon et al., 1997; Brush, 2004; Zimmerer, 2010). Keeping the capacity of crops to adapt to changing environmental and socioeconomic conditions is essential for maintaining the resilience of agricultural and food systems, particularly in the face of climate change (Bellon & van Etten, 2014; Folke, 2006).

While de facto conservation of diverse landraces on farm continues for many crops in their centres of diversity, maintaining crop diversity on-farm can entail important costs to farmers, who increasingly face strong incentives to abandon this diversity. For this reason interventions to support farmers in maintaining this diversity are needed. In the last 20 years many projects to support on-farm conservation have been implemented worldwide by many different types of institutions (national and international non-governmental organizations, farmers' organizations, universities and international research organizations) and supported mainly by foundations and international organizations (Gotor, Caracciolo, Blundo Canto, & Al Nusairi, 2013). The global reach and significance of these efforts are exemplified by a recent global survey of managers, policy-makers and practitioners involved in *in situ* and on-farm conservation carried out by FAO that included 1168 respondents, 90% of whom supported the establishment of a global network for *in situ* conservation and on-farm management of plant genetic resources for food and agriculture (Borgen Nilsen et al., 2013). On-farm conservation projects have piloted numerous interventions to support on-farm conservation. A recent and extensive review (Jarvis, Hodgkin, Sthapit, Fadda, & Lopez-Noriega, 2011) identified 59 different types of interventions for supporting on-farm conservation worldwide, but there has been little empirical evidence collected that they actually made a difference beyond what de facto conservation already achieves. There is a lack of systematic assessment of the extent to which projects have actually produced on-farm conservation results in terms of maintaining crop diversity on-farm (including farmers' knowledge and practices that underpin this diversity) as well as creating associated benefits for the farmers involved.

The factors and interrelationships involved in on-farm conservation are complex, so that a conceptual scheme that brings them together in a simplified but coherent fashion can be extremely useful for scientists, donors, policy-makers and practitioners involved in on-farm projects, to assess the success of their projects in a more systematic way. This paper presents a framework for analysing and assessing whether interventions by projects aimed at supporting on-farm conservation deliver relevant conservation and livelihood results (i.e. their effectiveness).

The rest of the paper is organized as follows. First, we present a review of the private benefits that underpin on-farm conservation and of the public benefits that it generates. This is followed by a discussion and conceptualization of the dilemma that the interaction between these two types of benefits presents to society under conditions of economic and cultural change. Then we discuss what on-farm conservation projects are and how they contribute to address this dilemma. Based on this, we present a framework to assess whether this type of projects deliver what they are supposed to and discuss some of the challenges faced in their assessment. Finally, we present some concluding remarks.

The private benefits that underpin on-farm conservation

For any crop, infra-specific diversity is unequally distributed around the world and is usually concentrated in its centres of diversity, which often coincide with the crop's centre of domestication (Gepts, 2006) (Figure 1). In these locations, there is a presence of a large genetic diversity expressed in a multiplicity of phenotypes with different traits associated with a long history of co-evolution between humans and crops, as is reflected in agricultural systems characterized by: (i) the cultivation of a diverse set of landraces with an associated knowledge base; (ii) the existence of multiple uses and preparations, usually linked with particular cultural preferences; (iii) specific management practices such as intercropping or rotations, as well as seed selection and sharing; (iv) matching specific landraces to particular environmental niches for optimizing production and managing risk and (v) social norms and organization that underpin all of these aspects (Bellon, 1996; Brush, 2004; Perales, Brush, & Qualset, 2003; Zimmerer, 2010).

The reasons smallholder farmers maintain or abandon diverse landraces

Smallholder farmers in these centres maintain diverse landraces of a crop because they play multiple roles in their lives and livelihoods, addressing different needs and constraints, and providing

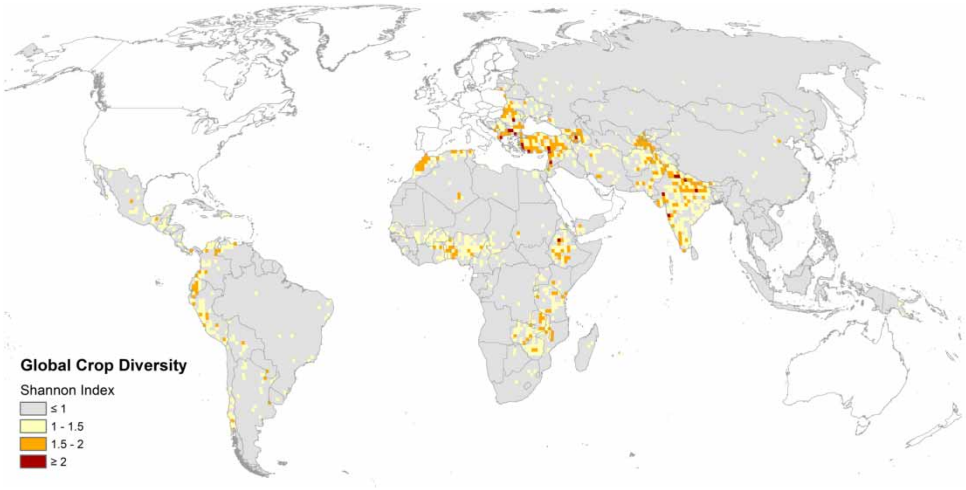

Figure 1. Map of hotspots of crop diversity for the 35 food crops included in the Annex 1 of the International Treaty on Plant Genetic Resources for Food and Agriculture (ftp://ftp.fao.org/docrep/fao/011/i0510e/i0510e.pdf). The map is based on the geographic distribution of geo-referenced accessions in gene banks. About 477,000 records, accessed through the Gateway to Genetic Resources Genesys (http://www.genesys-pgr.org/), were used to calculate the Shannon Index (a commonly used diversity index) with a spatial resolution of 1 degree by 1 degree (about 110 km by 110 km) latitude–longitude grid. While this distribution is based on gene bank collections and is biased due to sampling effort and not necessarily reflects all diversity that may exist or what is still in farmers' fields, it illustrates where known hotspots of crop diversity are located. Only accessions collected in mid- and low-income countries according to the World Bank classification (http://data.worldbank.org/about/country-classifications/country-and-lending-groups) were included, since it is likely that these are the areas where much of this diversity may still actually exist in the fields, rather than only in gene banks.

a range of benefits. Benefits include: (a) optimizing crop production under agro-ecological heterogeneous conditions, particularly in marginal areas (Bellon & Taylor, 1993; Ceccarelli, 1996; Di Falco & Chavas, 2009; Worthington, Soleri, Aragon-Cuevas, & Gepts, 2012); (b) managing risk (Cavatassi, Lipper, & Narloch, 2011; Di Falco & Chavas, 2009; Di Falco & Perrings, 2005); (c) producing a variety of products with different uses (Brush, 1992; Keleman, Hellin, & Flores, 2013; King, 2007); (d) profiting from commercial opportunities in niche markets (Devaux et al., 2009; Keleman et al., 2013; King, 2007); (e) providing themselves with appreciated varieties due to consumption qualities or cultural significance (Arslan & Taylor, 2009; Brush, 1992; Isakson, 2011; Perales, Benz, & Brush, 2005; Rana, Garforth, Sthapit, & Jarvis, 2007) and (f) managing labour during the agricultural season (Bellon, 1991).

Farming households are not static, but are constantly faced with new challenges and opportunities, particularly those brought about by economic development and cultural change, which in many cases reduce the value of maintaining crop diversity on-farm because the functions and associated benefits of crop diversity may become irrelevant, may be replaced by cheaper alternatives or may entail increasing opportunity costs (Bellon, 2004; Isakson, 2011; Zimmerer, 2010). Specific reasons to abandon crop diversity include:

1. Availability of scientifically bred varieties with higher yields and better disease resistance, together with that of external inputs such as fertilizers – that reduce agro-ecological heterogeneity – and of pesticides, may foster specialization and the replacement of a broad array of local varieties for just a few (Evenson & Gollin, 2003; Heal et al., 2004; van de Wouw et al., 2010).
2. Development and increasing reach of modern value chains may make traditional value chains linked to niche markets to become uncompetitive, leading to less commercial opportunities for marketing diverse varieties or products derived from them (Tisdell & Seidl, 2004; van de Wouw et al., 2010).
3. Availability of new products may compete with products derived from traditional crops or local varieties in terms of price and convenience (Andersen, 2012), which together with changes in taste, or an increased perception that traditional crops and varieties are associated with poverty or low social status, may reduce their appeal (Keller, Mndiga, & Maass, 2005).
4. Increased migration and off-farm labour opportunities can decrease the feasibility of maintaining crop diversity on farm which tend to be labour intensive, by decreasing labour supply and increasing its opportunity cost (Isakson, 2011; Rana et al., 2007; Zimmerer, 1991).
5. Migration and off-farm labour opportunities also can provide alternative sources of income to manage risk, reducing the need to maintain crop diversity (Barrett, Reardon, & Webb, 2001; Di Falco, Adinolfi, Bozzola, & Capitanio, 2014).
6. Increased availability of formal seed systems may lead farmers to abandon traditional seed management practices such as seed saving, selection and sharing in favour of purchasing seed, stopping processes of crop evolution (Vigouroux, Barnaud, Scarcelli, & Thuillet, 2011a).

The role of markets and economic development

Many of the factors that reduce the benefits and increase the costs of maintaining crop diversity on farm, as the examples above illustrate, are associated with increased participation by smallholder farmers in different types of markets (inputs, outputs and labour) as both producers and consumers. Economic development in rural areas is linked to the development of markets and participation of famers in them (Barrett, 2008). While there is not an inherent trade-off between crop diversity and market participation, and under many circumstances the latter presents opportunities to maintain the former, particularly at the scale that smallholders farm (Asfaw, Lipper, Dalton, & Audi, 2012; Isakson, 2011; Keleman et al., 2013), there may be a threshold after which the generation of additional benefits derived from participating in markets – referred hereafter as market-based livelihood benefits – may require and foster specialization and thus entail a trade-off for farming households between the generation of those benefits and the maintenance of crop diversity on farm.

Research over the last 20 years has shown that for smallholder farmers the balance between the benefits and the costs of maintaining crop diversity is a complex process that depends on the specific crop, the agro-ecological conditions in which farmers operate, the levels of market development present, as well as cultural factors (Bellon, 2004; Brush, 2004). For example, there are many species of regional and local importance where no breeding has taken place, and hence local landraces are still the mainstay for farmers who grow them (Gruere, Guiliani, & Smale, 2009; Padulosi, Heywood, Hunger, & Jarvis, 2011). Even for major crops, scientifically bred varieties are often inadequate for farmers' circumstances; seed may be unavailable or they complement rather than replace landraces so both are grown together. Smallholder farmers commonly operate in poorly functioning markets with high transaction costs[2] that raise the price paid by buyers and lowers the price received by sellers, limiting market participation and fostering self-consumption (Barrett, 2008; De Janvry, Sadoulet, & de Anda, 1995; Key, Sadoulet, & de Janvry, 2000). Under these conditions farmers' production and consumption decisions are linked, thus consumption preferences continue to influence their decisions (Taylor & Adelman, 2003) and profit maximization is not the only production objective (Arslan & Taylor, 2009). This can lead to high shadow prices[3] for landraces, well above their market price, showing that market prices only capture a fraction of the private value that farmers attach to them (Arslan & Taylor, 2009; Smale & Bellon, 1999). This in turn means that cultural preferences play a role in their decision-making. Even in well-functioning markets, landraces can be competitive, perform well under improved management and can provide important commercial opportunities (e.g. maize, Keleman et al., 2013; Perales, Brush, & Qualset, 1998), particularly as new uses are discovered and products developed as knowledge progresses and new markets are created (Keleman & Hellin, 2009).

The public benefits that on-farm conservation provides

On-farm conservation delivers an evolutionary service

Smallholder farmers and the landraces they grow constitute co-evolving socio-biological systems that maintain genetic diversity under evolution. For a given crop, farmers influence through their knowledge, preferences and practices, the alleles and genotypes that pass from one generation to the next and their spatial distribution –contributing to shape the traits under selection – the demography of crop populations under their management, and their exposure to varying biotic and abiotic factors (Brush, 2004; Bellon, 2009; Gepts, 2006; Labeyrie et al., 2014; Vigouroux et al., 2011a). Traditional practices of saving and sharing seed by and among farmers underpin these systems. These practices are embedded in network structures that connect farmers and landraces within and across environments – through seed flows and gene flow – and are essential to understand the spatial structure of crop genetic diversity and its dynamics (Gepts, 2006; Labeyrie et al., 2014; Nagarajan & Smale, 2007; Pautasso et al., 2013; Samberg, Fishman, & Allendorf, 2013; Vom Brocke, Christinck, Weltzien, Presterl, & Geiger, 2003; Westengen et al., 2014). Since the presence of genetic diversity in populations is fundamental for adaptive evolution in response to changing environmental conditions (Sgro, Lowe, & Hoffmann, 2011), conserving these socio-biological systems is important because they contribute to retaining potentially useful but undetermined genetic variation, and to generating novel variation needed to maintain the capacity of crops to adapt to change (Bellon, 2009). These systems thus provide an evolutionary service[4] to society. Since social, economic and cultural conditions as well as agro-ecological environments change, keeping crop evolution on farm contributes to the generation of a diversity of 'winning' (adaptive) combinations of genes and traits that are constantly being updated in response to multiple and varying situations. This in turn ensures that farmers and society are able to cope with and adapt better to change (Bellon, 2009). Crop evolution may be critical for adaptation to climate change among smallholder farmers who depend on landraces (Bellon & van Etten, 2014; Mercer & Perales, 2010). There is already evidence of adaptive phenotypic and genetic changes among pearl millet landraces under farmer management in dry areas of Niger in response to climate change in a relatively short time span (Vigouroux et al., 2011b). On-farm conservation is then about conserving socio-biological systems that maintain crop evolution on farm and provide a public benefit to society.

The supply of public benefits by on-farm conservation: the relationship between phenotypic and genetic diversity

While conceptually the idea of on-farm conservation as an evolutionary service that generates a public benefit to society is useful, in practice we still have limited understanding of the shape of the functional relationship that links the diversity of landraces at the phenotypic level – what farmers manage and influence – and the genetic diversity and evolutionary potential that results from the process, that is, its public benefit; and how this relationship changes across scales from a community to a landscape to the full range of adaptation of a crop. This is important because this functional relationship is the supply curve of the public benefit that smallholders who maintain crop evolution in their farms provide to society. The metrics linking crop diversity at the phenotypic and genotypic levels can be quite complex, with measures varying depending on the traits measured and the scale at which measurement is performed (van Heerwaarden, Hellin, Visser, & van Eeuwijk, 2009; Van Zonneveld et al., 2014). For example, at a broad scale that encompasses the range of distribution of rice landraces across countries in south and southeast Asia, Ford-Lloyd, Brar, Khush, Jackson, and Virk (2008) have shown that rice genetic diversity increases with the number of landraces examined, and thus they consider that the number of landraces is an effective and simple proxy indicator of genetic diversity. The functional form between a crop's phenotypic diversity and the associated genetic diversity will depend on the reproductive system of the crop, population sizes (effective population size), drift, gene flow and the variance, magnitude and speed of selection pressures (both human and biophysical), as well as the scale of analysis. There is still limited understanding of this relationship, particularly in the context of on-farm conservation projects. This is an area in need of further research.

The social dilemma of on-farm conservation

The socio-biological systems that maintain landraces in centres of crop diversity produce both private and public benefits, but in ways that can result in a 'social dilemma', where incentives can be against crop diversity and its sustainable use and in favour of economic activities that erode them. Public benefits tend to be diffuse, longer term and may be poorly understood; thus they are often ignored in individual decision-making, which focuses on private benefits that tend to be concrete and short term. This, together with the fact that resources are limited, often leads to a divergence of interests between individuals and society and thus to trade-offs between the generation of public and private benefits.

The dilemma can be represented in a set of simplified trajectories that synthesize the results presented in the previous sections (Figure 2) mapping how changes in incentives that farmers have to maintain crop diversity (upper graph, Figure 2(a)) translate into changes in the genetic diversity available to society to adapt crops to change (lower graph, Figure 2(b)). The two graphs in the figure share and are linked by a common *x*-axis: the diversity of varieties of a particular crop – crop phenotypic diversity – that a community of farming households maintain on farm. The upper graph (Figure 2(a)) shows the relationship between crop phenotypic diversity and

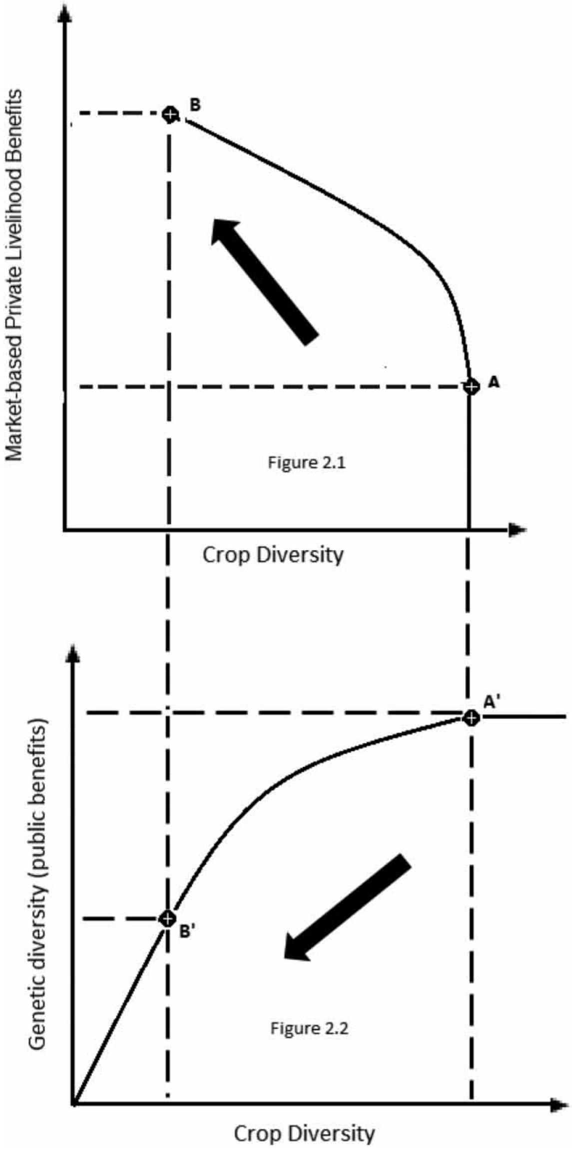

Figure 2. Linking the expected trend of the relationship between crop diversity and the associated private and public benefits at the community level.

the private market-based livelihood benefits[5] farmers derive from growing the crop. The trajectory starts at the far right side of the *x*-axis with farming households maintaining high diversity on farm and deriving a certain amount of market-based benefits from it. With a growing engagement in markets, market-based livelihood benefits start to increase but without entailing a trade-off with crop diversity; for example, market participation may provide more opportunities for the sale of diverse varieties in niche markets. Eventually, a threshold is reached where the incentives for specialization may outweigh those that favour diversity (point A in Figure 2(a)) leading to a trajectory in which increasingly market-based livelihood benefits (e.g. income) linked to specialization into a few varieties replace both market- and non-market-based benefits derived from crop diversity. At first, the drop in crop diversity may be small relative to the gains in market-based livelihoods reflecting limited opportunities for specialization due to poorly functioning markets with high transaction costs, or few available market-based alternatives to the benefits provided by crop diversity (e.g. fertilizers to compensate for soil heterogeneity, or insurance and non-agricultural sources of income to manage risk). Eventually the trajectory may accelerate as more market-supplied alternatives for replacing the functions of crop diversity become available and cheaper, the opportunity costs of maintaining diversity increase and/or market niches disappear as bulk markets become dominant, up to the point where there is complete specialization in one variety or farmers reach a new equilibrium with a smaller number of crop varieties (point B in Figure 2(a)).

The lower graph links crop phenotypic diversity to the genetic diversity it contains and is under evolution (Figure 2(b)). As noted above, the functional relationship between these two factors is still poorly understood. It is possible however to hypothesize for illustrative purposes a simple cumulative relationship in which each additional landrace (phenotype) adds new alleles and/or genotypes to the total genetic diversity, but after a certain point at a decreasing rate as increasingly the genetic make-up of new additions may be already present in the stock. With this simple functional relationship between crop phenotypic diversity and genetic diversity, the graph maps the impact of the trajectory depicted in the upper graph of increased specialization by farming households and the supply of genetic diversity available as a public benefit. The trajectory identified between points A and B in Figure 2(a), describing a trajectory of increasing private market-based livelihood benefits to farmers but with a decreasing crop diversity, corresponds to a decreasing trajectory for genetic diversity and thus public benefits for society (move from A’ to B’ in Figure 2(b)). So while farmers pursue their legitimate private interest (e.g. higher incomes), crop diversity that may be central to ensuring their own and others’ adaptation to changing conditions or to the needs of future generations (the public benefit) may be lost (thus the dilemma). Farmers as individuals may tend to under-invest in the conservation of landraces and associated genetic diversity relative to what society at large would consider optimal (Heal et al., 2004; Smale & Bellon, 1999). Since many of the factors contributing to the erosion of crop diversity may enhance farmers’ well-being, it would not be fair to ask farmers to forego these opportunities for the sake of maintaining crop diversity for future use. Outside interventions that align individuals’ and society’s interests may be needed to maintain the viability of on-farm conservation.

Addressing the dilemma: a framework for assessing on-farm conservation projects

Interventions may be needed to maintain the public benefits derived from crop diversity once de facto conservation ceases to be viable (after point A in Figure 2(a)), if these benefits are deemed as socially desirable. Interventions should be aimed at shifting the trajectory of change between private market-based livelihood benefits and crop diversity in order to reduce the loss of genetic diversity, and thus of public benefits to society, while improving the livelihoods of farming households. This is the rationale for implementing on-farm conservation projects. These types of projects usually execute a series of interventions that provide farmers with options such as technologies, development of capacities and skills or forms of organization aimed at changing the way they access, manage, use, perceive, consume and/or market crop diversity. Interventions could include: (a) organization of seed fairs to know and obtain local varieties among farmers that are not usually in contact; (b) participatory evaluation of local varieties; (c) development and dissemination of agronomic practices, harvesting or processing technologies that target specific constraints of local crops; (d) training on new recipes and food preparations for local crops and varieties; (e) organizing fairs of traditional foods; (f) organizing fairs for marketing local crops and (g) forming farmer associations to market them. Interventions can influence the demand for crop diversity by aiming at increasing its value for farmers, decreasing the opportunity costs of maintaining it or improving its supply by reducing the costs of accessing seeds and planting material as well as related information on diverse landraces (Bellon, 2004).

The impact of a successful on-farm conservation project can be depicted in the context of the trajectories presented in Figure 2. This is done in Figure 3 by showing that a successful on-farm conservation project should shift the trajectory of the private livelihood benefits to the northeast of the upper graph (Figure 3(a) from point B to C). Point C in the new trajectory is associated with similar market-based private livelihood benefits as point B, but with higher levels of genetic diversity (shift from A' to C' in the lower graph, Figure 3(b)). Although some genetic diversity has been lost (C' $<$ A'), a much higher level remains compared to what would have been possible in the original trajectory (C' $>$ B').

The effectiveness of an on-farm conservation project: hypotheses to be tested

In the context of this simple schema, an on-farm conservation project provides options to farmers aimed at enhancing the value of crop diversity under economic and cultural change. In a successful project, farmers select and apply some of these options, which in turn should translate into private livelihood benefits for them and their households in terms of enhanced income, increased food consumption and improved security, productivity, stability and/or reduced vulnerability. The new ways in which crop diversity is used and managed due to the application of the options provided by interventions should lead to its maintenance in the community, and continue to yield public benefits to society (e.g. genetic diversity and thus evolutionary services). This simple chain of events presents a generic narrative that articulates how interventions are linked to changes leading to desired results. This narrative provides an approach for empirically assessing their success by identifying four different but related hypotheses to be tested in the case of on-farm conservation projects. These hypotheses are:

1. Participation in project interventions should lead farmers to apply options provided by the interventions, generating a new trajectory (shift from B to C in Figure 3);
2. The application of these options should lead farmers to maintain higher levels of crop diversity than would have been possible without interventions due to the additional benefits that interventions enabled (move from a to c instead of a to b in the x-axis);
3. Farmers with higher levels of crop diversity should obtain additional benefits from this diversity (change in the slope of the new trajectory A-C compared to trajectory A-B);
4. The higher levels of crop diversity linked with the application of these options should be associated with higher levels of genetic diversity and thus evolutionary services than would have occurred otherwise (move from A' to C' instead of A' to B').

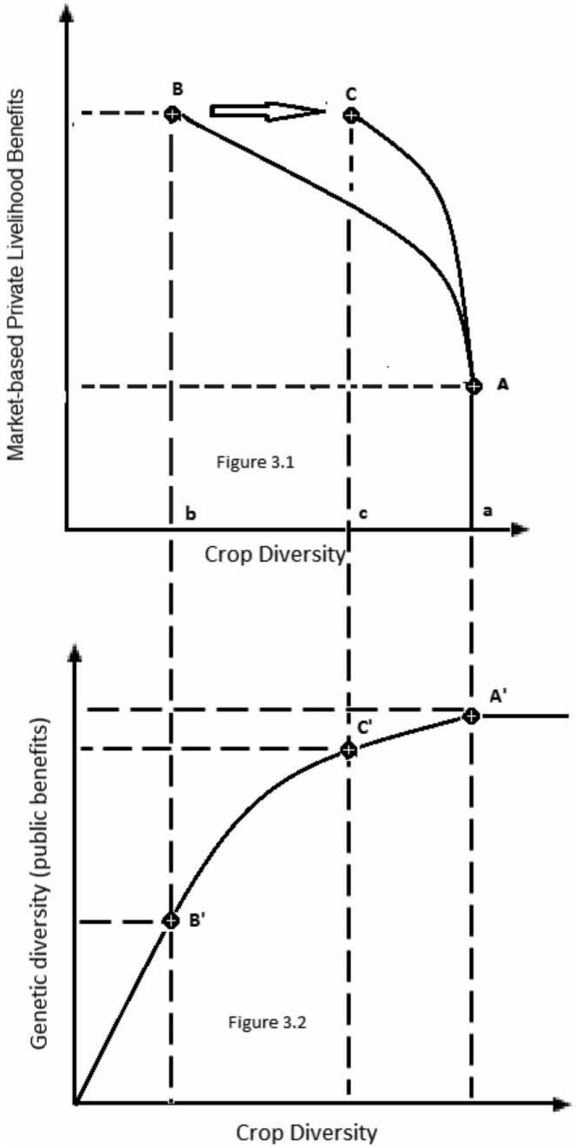

Figure 3. The effect of on-farm conservation project interventions on the trend of the relationship between crop diversity and the associated private and public benefits at the community level.

Depending on the initial position of the farming community in the process and on the slope of the curve relating crop diversity to genetic diversity, the shift to higher private livelihood benefits can be linked to a modest decrease in public benefits. If the private net benefits derived from these options minus their costs of implementation are judged by farmers as desirable enough, this should lead them to continue to apply them beyond the lifetime of the project, ensuring project sustainability. In some cases enhancing the benefits farmers derive from crop diversity may not be feasible, or the benefits may not be large enough for them to continue to maintain crop diversity on farm. If the public value of this diversity is deemed to be high, then interventions that provide payments for agro-biodiversity conservation may be necessary (Narloch, Drucker, & Pascual, 2011).

It is important to acknowledge that there may be other possible trajectories for the relationship between crop diversity maintained on farm and agricultural development that may lead to different scenarios in this framework, particularly under conditions of climate change. For example, crop diversity maintained on farm and agricultural development may complement each other in particular circumstances (thus not involving trade-offs) or their relationship may change at different stages of development. There could be cases where the slope of the curve may shift from negative to positive or vice versa at some threshold level of crop diversity depending on the location, climatic, time and many more factors. The existence and determination of thresholds where such shifts may take place is an area of empirical research that deserves to be further studied. For the sake of simplicity we did not explore other scenarios, and focused on what we consider the conventional view that underpins the concept of genetic erosion, but the need to explore other relationships – particularly if empirical evidence indicates so – is an area for future development, and the framework is flexible enough to accommodate and reflect on those different scenarios.

Testing the theory of change: some considerations

The hypotheses presented above can be tested empirically. This requires clear and measurable indicators of the application of the options provided by project interventions, of crop diversity (both phenotypic and genetic), relevant livelihood benefits and a proper set of comparisons. The first three hypotheses deal with social sciences issues, and testing them statistically present empirical challenges that are common, but also well-understood, in the evaluation of agricultural interventions. These include the presence of endogeneity, selection bias and confounding effects which could complicate the identification of the real causal impact of a project. Many technical options exist however to address these problems (Barrett & Carter, 2010; Caliendo & Hujer, 2006; Gotor et al., 2013). The fourth hypothesis deals with issues pertaining to crop population genetics and biogeography (Bellon et al., 1997; Brown, 1999; Van Zonneveld et al., 2014), and remains an area in need of further research. We have applied this framework to test the first three hypotheses in the context of five on-farm conservation projects of six native grain and tuber crops in the High Andes of South America.[6] Although an in-depth presentation of the methods and results is beyond the scope of this paper, results showed that projects implemented multiple interventions. In all projects, participation in these interventions was associated with the application by households of a higher number of options provided by interventions, which in turn was associated with increased crop diversity, and higher crop diversity was associated with increased household benefits in three of the projects. The description of the empirical model and the discussion on the results will be the subject of a separate publication.

Concluding remarks

The processes and results associated with on-farm conservation of landraces in centres of crop diversity are complex; causality is neither clear nor obvious. The framework presented here, while based on a simplification of the issues and relationships involved, provides a conceptual tool to assess the effectiveness of on-farm conservation projects at delivering conservation and livelihood benefits, and thus their success. It is valuable because it provides a scheme that allows us to reflect systematically on these issues, organize our knowledge and identify knowledge gaps and lack of understanding. It formulates a general approach aimed at testing for evidence of a process of change by examining a series of linked hypotheses that should take place if a project is successful.

The focus here has been at the community level, but there are linkages across scales (below and above the community level) that may be crucial to better understand the processes and effects of on-farm conservation projects. From a public perspective, the value of on-farm conservation is related to the maintenance and generation of a broad base of genetic variation in constant evolutionary flux. The value of the evolutionary services delivered by on-farm conservation, while grounded at the community level, is connected to broader social and ecological landscapes where diverse landraces are maintained by different farming communities and interlinked to various degrees through seed systems (Labeyrie et al., 2014; Samberg et al., 2013; Westengen et al., 2014). These landraces are distributed across different types of environments, thus facing diverse selection pressures from environmental factors as well as from human management and preferences. A landscape perspective on on-farm conservation merits further consideration by researchers, whose work could benefit, for example, from the approaches and methods of landscape genetics (Manel et al., 2010; Schoville et al., 2012). While this perspective is increasingly being used to understand the interactions between farmers' management of crop phenotypic diversity and patterns of genetic diversity across landscapes (Labeyrie et al., 2014; Samberg et al., 2013; Westengen et al., 2014), its implications for on-farm conservation projects have not been explored yet.

The framework highlights that on-farm conservation projects, by implementing interventions linking the conservation of crop diversity with improved smallholder farmers' well-being, not only should create incentives for farmers to continue to maintain this diversity and generate evolutionary services, but also should contribute to making the conservation process fairer by aligning their short-term private interests with society's long-term public ones. This in turn would counter the common criticism that on-farm conservation keeps farmers poor and burdens them with maintaining public benefits at the expense of their private interests. The challenge of any on-farm conservation project then is to identify, design and implement interventions that make the on-farm conservation of crop diversity for tomorrow's needs compatible with improved livelihoods and well-being among the farmers who conserve it today.

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Notes

1. Landraces are defined as dynamic populations of a cultivated plant with a historical origin, distinct identity, often genetically diverse and locally adapted, and associated with a set of farmers' practices of seed selection and field management as well as with a farmers' knowledge base (Camacho-Villa, Maxted, Scholten, & Ford-Lloyd, 2005).
2. Costs associated with market transactions that include: search and information costs, bargaining and decision costs, policing and enforcement costs, that is, resource losses due to lack of information (Dahlman, 1979).

3. Shadow price refers to the value of goods or services not traded in markets, which may diverge from market prices because of high transaction costs of buying and selling or imperfect substitutability between market-purchased and home-produced crops, for example, commercially available maize may not have the consumption characteristics valued by farmers or their cultural significance (Arslan & Taylor, 2009).
4. Evolutionary services have been defined as 'all of the uses or services to humans that are produced from the evolutionary process' (Faith et al., 2010, p. 4), thereby contributing to keeping options open to benefit from biodiversity in unanticipated ways (Faith et al., 2010).
5. It should be stressed that farming households also derive non-market benefits from crop diversity as explained earlier, and the total benefits that households obtained from diversity are the sum of market and non-market benefits. In the graph, the *y*-axis is only accounting for the market-based benefits, but not for the non-market ones.
6. Project reports are available at http://www.ccrp.org/projects/farm-conservation

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