Genetic Resources for Food and Agriculture and Adaptation

**Part 1**

**Introduction**

A growing body of knowledge exists focused on the need to conserve genetic resources for food and agriculture (GRFA) in the face of stressors associated with global change. Today, global climate change is exacerbating existing threats to GRFA while at the same time inspiring new opportunities for the use of GRFA to progress adaptation efforts. In this paper we review different approaches linking GRFA and adaptation including a discussion of the relationship of GRFA with dimensions of vulnerability, adaptive capacity, and resilience. Then we provide a synopsis of current programs focused on utilizing GRFA for adaptation at different scales and levels of agricultural intensification. We highlight key gaps in our knowledge on the intersection between GRFA and adaptation including: data collection and monitoring, economic considerations, intersections of relevant technologies, governance issues, livelihoods, decision making, and ecological dimensions. This allows us to lay out a new way of conceptualizing GRFA and adaptation that highlights the factors influencing the use of GRFA by farmers and sheds light on ways in which actions and interventions from a broad number of stakeholders can either advance progress toward greater adaptation to climate change or they can hinder progress, and in some cases can even push toward maladaptation if appropriate safeguards are not put in place. This conceptualization offers new strategic opportunities for collaboration across scientific disciplines, critical analysis of current structural shortcomings, and recommendations for ensuring the progressive potential of GRFA for adaptation.

Agrobiodiversity (ABD) can be broadly defined as all domesticated biodiversity (i.e. crops and livestock) within agricultural systems as well as the non-domesticated biodiversity inside or outside agricultural systems that interplay in various ways with the health and functioning of those systems (i.e. crop wild relatives, pollinators, and soil invertebrates and microorganisms) (Pascual et al., 2011; Lenné and Wood, 2011). Encompassed within ABD are the plant genetic resources for food and agriculture (PGRFA) and animal genetic resources (AnGRFA) that form the foundation of food systems (together referred to as GRFA). GRFA provide options in the form of a range of different traits and attributes that can be utilized by crops and livestock to cope with stressors such as changing temperatures, changing availability of water, changing soil conditions, pests, parasites, and diseases (Jarvis and Hodgkin in Brush, 2000). Those useful traits and attributes are the result of a combination of active maintenance by farmers and evolutionary processes that have converged in specific locations over thousands of years. Throughout history and still today, farmers have selected particular plants and animals based on their traits and attributes as part of their risk management strategies for making a living in a variety of different environments and climates (Sthapit et al., 2010). Further, ABD also constitutes a central part of sustainable diets and nutrition, a means of economic diversification, as well as safeguarding cultural heritage (Bellon et al., 2011; Jarvis et al., 2011; Pautasso et al., 2012).

Agricultural systems are presently facing an unprecedented number of combined stressors that are spurring large reductions in GRFA. Comprehensive numbers of at risk species, extinctions, and genetic erosion are difficult to determine due to persisting gaps in available data for many areas. However, with regard to AnGRFA, The State of the World´s Animal Genetic Resources for Food and Agriculture (FAO, 2007) states that 62 livestock breeds went extinct between 2001 and 2007 and that 20% of globally known livestock breeds are at risk. Concerning PGRFA, FAO estimates that 75% of the world´s food comes from only 12 plant species and that approximately 75% of plant genetic diversity had been lost in the 20th century (FAO, 1996). The Second Report on the State of the World´s Plant Genetic Resources for Food and Agriculture (SoWPGR-2), published in 2010, lists land clearing, population pressures, overgrazing, environmental degradation, and changing agricultural practices as the primary causes of this genetic erosion (FAO, 2010). The proximate causes of agrobiodiversity loss being have been identified as the prioritization of a limited number of marketable cash crops and breeds that are often heavily reliant on synthetic agrochemical inputs, intensive breeding programs, unsustainable irrigation schemes, along with the conversion of forests and fields into mono-cropped operations and feed lots (Jackson, 2012). .

In a context of interwoven global stressors, concerns over the loss of GRFA and how it relates to increasing vulnerability of farmers and agricultural systems has spurred a large number of actions and programs within the conservation and policy arenas. These efforts include ex-situ or off farm conservation of GRFA, most often in the form of local, institutional, and international gene banks that livestock breeders and crop scientists can draw from in order to improve breeds and varieties better able to cope with a variety of agro-climatic conditions (Crop Genebank Knowledge Base, 2014). In addition to ex-situ efforts, opportunities and challenges posed by in-situ (on-farm) conservation of GRFA and, in the case of crop wild relatives (CWR) in protected areas, are also increasingly important areas of research (Jarvis et al., 2011). This in-situ research includes that focused on the conservation and use of neglected and underutilized species (NUS) (Padulosi et al., 2011).

In the policy arena, the importance of agricultural biodiversity has been recognized internationally through a number of COP decisions within the Convention on Biological Diversity (CBD) including recently within the CBD´s Aichi Biodiversity Targets for the period of 2011-2020 (CBD Strategic Goal C: Target 13: (CBD 2014)). Also, within the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the CBD (referred to as the Nagoya Protocol, 2010), and the Cartagena Protocol on Biosafety to the CBD (Cartagena Protocol, 2000). Further, in 2001, international collaborations were negotiated within the forum of FAO´s Commission on Genetic Resources for Food and Agriculture (CGRFA) resulting in the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), adopted during the thirty-first meeting of the FAO (FAO, 2014). The CGRFA also led the process for the development of the Global Plan of Action for AnGR (2007) which clarified the needs for conserving AnGR, prioritized measures for reversing erosion and underutilization of AnGR, and laid a plan for the implementation and financing of conservation efforts (FAO, 2007).

Over recent decades, increased understandings have emerged regarding the ways in which global climate change is further exacerbating the existing challenges for GRFA via a diverse range of stressors including rising temperatures, rising sea levels, changing rainfall patterns, extended droughts, increasing extreme events such as severe storms and flooding, unseasonal frosts, and widening ranges for disease vectors and invasive species among others (IPCC, 2014). These stressors portend numerous effects on GRFA, for example increasing temperatures can negatively impact cattle resulting in decreased meat and milk production (Nardone et al., 2010). Further, increasing temperatures and changes in precipitation patterns also have the potential to extend the ranges of harmful pests and pathogens that can negatively impact the health of livestock as well as the livelihoods of those that depend on them (Hoffmann, 2010). With regards to wild relatives, though uncertainty remains, it is estimated that around 16%-22% of these resources are under threat of extinction due to climate change (Lane and Jarvis 2008). Climate change is also expected to cause shifts in the geographic zones of suitability for many crop species, with some areas becoming more favorable for increased productivity in agriculture and others becoming less favorable (Lane and Jarvis, 2007; 2008). These shifts are expected to increase interdependence in global agricultural systems as far as management of AnGRFA and PGRFA are concerned (Fujisaka et al., 2011).

The combined effects of an increasingly interconnected economic system in which any stressor (e.g., commodity price shocks) transmits quickly across the globe, the standardization of intensive agricultural systems that pursue expanded levels of food and fibre production, along with changing climates lead to changing scenarios of vulnerability, adaptive capacity, and resilience for food systems and livelihoods across a broad range of enmeshed scales (Zimmerer, 2010). These scenarios will be further conditioned by factors such as geographic location, access to technologies, wealth and poverty, gender roles, land tenure, and other key variables (Drucker et al., 2008).

The link between losses of GRFA and vulnerability[[1]](#footnote-1) can be traced (though not always linearly) throughout many different levels of analysis including varieties and breeds, species, farms, households, countries, regions, and the global agricultural system (Zimmerer, 2010). For example, at the variety, breed, and species levels, genetic diversity represents flexibility in options for crops and livestock in dealing with risks such as pests, pathogens, and changing environmental conditions (Jump et al., 2007). At the agrarian household level we can investigate how GRFA is conserved and utilized by farmers in different ways for cultural and food security purposes, but also as a source of livelihoods options for dealing with economic market and environmental changes (Lipper and Cooper, 2009). As Pascual et al. (2011) note, agrobiodiversity (and the genetic resources it encompasses) can be viewed as providing a source of “natural insurance” for farmers against detrimental socio-economic and environmental fluctuations. The literature thus views the diversity of GRFA as being impacted by climate change but at the same time having the potential as a natural capital asset to help facilitate adaptation to those impacts (Jackson et al., 2007).

At the national level the relationship between vulnerability and GRFA is multifold, including prerogatives to establish food security for citizens through the provision of favorable agricultural finance and extension services structured and supported by appropriate laws, policies, and international collaborations, and how attention is paid to GRFA throughout these processes. These relationships are especially relevant when we consider that the global population is expected to grow by one billion people in the next twelve years, and that a large majority of that growth is foreseen to take place in developing countries, and especially the least developed countries where population numbers are expected to double from 898 billion in 2013 to 1.8 billion by 2050 (UN, 2012: xvi). FAO also projects that global caloric intake will increase in the future as consumption rates rise in a number of developing countries, thus further increasing demands on stressed production systems (FAO, 2003).

The remainder of the paper goes as follows: In the next section we give closer examination to the links between different types of conservation of GRFA and adaptation and then go on to present a selection of current programs that are utilizing GRFA for adaptation to climate change. Following that, in the penultimate section we present expert-identified gaps and challenges that remain for understanding and realizing the potential of using GRFA for adaptation. Finally, we close with proposing a new, more integrated conceptualization of the role of GRFA in adaptation and a strategy for optimizing that role across a diverse range of motivations and scales.

**Part 2**

**GRFA and Adaptation**

The IPCC differentiates between *incremental* adaptation, referring to adjustments that serve to maintain a system or processes, and *transformational* adaptation, referring to adjustments that fundamentally change systems or process in order to deal with actual or expected climate and its effects (IPCC, 2014). Today, most adaptation efforts worldwide are incremental adjustments, however a number of experts fear that these types of changes will not be adequate for addressing the scope of changes brought by global climate change and that systems will therefore need to undergo major transformations in order to succeed at adaptation (Kates et al., 2012).

The emphasis of the IPCC´s definition of adaptation as a “*process* of adjustment to actual or expected climate and its effect” is key as GRFA held in-situ (including CWR in their natural environments) is a foundational component of this adaptation process (IPCC, 2014). These resources not only provide the genetic material for use on-farm or within communities, but these resources are also the source of genetic material found in ex-situ collections such as genebanks. As Bellon and van Etten (in Jackson et al., 2014) argue in-situ conservation of GRFA is primarily concerned with conserving processes whereas ex-situ conservation is primarily concerned with the conservation of the results of processes. These processes encompass converging anthropogenic actions and evolutionary mechanisms that have developed in specific locations over time. Such processes can also be understood as *evosystem services* i.e., “the capacity for future evolutionary change and the continued discovery of useful products in the vast biodiversity storehouse that has resulted from evolution in the past” (Faith et al. 2010: 66). In an effort to better capture the importance of GRFA for maintaining these services and the essential role of in-situ, on-farm, conservation of these resources, scientists are currently developing ideas for a new agricultural paradigm of “evolutionary agriculture” that places central emphasis on supporting and safeguarding crop evolution and on-farm genetic resources for the benefit of farmers and biodiversity (personal communication from M. Bellon, 2014).

Ex-situ collections of GRFA, currently at the core of the ITPGRFA, serve as backup for many of the world´s most utilized crop varieties and are also seen as crucial for safeguarding genetic material that may no longer be extant or widely used in-situ (or may not be under future climate scenarios), although these collections are not currently comprehensive enough to provide adequate safeguards for many neglected or underutilized species, nor crop wild relatives (Khoury et al., 2010). Ex-situ collections have the potential to provide important inputs for small farmers who are in need of the particular traits held there, and further, these collections also serve as more efficient sources of genetic material for breeders to draw from when evaluating breeds and varieties for adaptive traits or when utilizing GRFA for creating new varieties through traditional breeding or through genetic modification (For an example see: Adapting Agriculture to Climate Change Project at [www.kew.org](http://www.kew.org) ).

Need transition paragraph or statement

***Current Farmer-focused Initiatives to Utilize GRFA for Adaptation to Climate Change around the World***

In East Asia (excluding China), South Asia, and Sub-Saharan Africa, approximately 95% of farms are small (less than five hectares) but collectively they represent the majority land use in those areas (Lowder et al., 2014). A number of these areas represent what are estimated to be some of the most at-risk locations in terms of current climate variability and anticipated climate change impacts under current projections for low-latitude regions (IPCC, 2014) and the most vulnerable in terms of food security and persistent poverty (Vermeulen et al., 2012). In an effort to utilize GRFA for helping address these challenges a variety of initiatives have been undertaken that focus on smallholder farmers, here we highlight a sample of these initiatives.

*Seeds for Needs:*

For example, the Seeds for Needs program facilitated by Bioversity International combines technological application of geospatial analysis (GIS) for predicting suitability of different seed varieties held in ex-situ collections with participatory field trials with over 10,000 small farmers in the Global South. In Ethiopia, specific landrace varieties were selected for trials due to their potential for addressing certain climate related stressors including drought and disease. This project focused on empowering female farmers, increasing awareness about risks of climate change, and supporting food security. The results included increased wheat varietal diversity, increased women´s empowerment, increased favorable perceptions of the marketability of landraces over that of improved modern varieties, and sustainability of introduced landrace varietals with a majority of farmers planning to continue planting the landraces in subsequent growing seasons (Gotor et al., 2014).

*Community Seed Banks:*

Other initiatives have also focused on utilizing the PGRFA resources available in ex-situ collections, especially community seed and gene banks for strengthening local seed supplies with climate impact resistant varieties. For example, in India, the nongovernmental organization Navdanya has promoted the establishment and maintenance of an extensive network of community seed banks that help conserve some 3,000 varieties of rice, 75 varieties of wheat, and numerous other cereals, vegetables, and other important food crops (Navdanya, 2009). These have helped respond to climate-related stressors, for example, the provision of flood-resistant varieties in Bihar in response to flooding, drought-resistant varieties in Bundelkhand in response to droughts, and of saline-resistant varieties in Orissa that have helped farmers adapt after extreme cyclone events (Navdanya, 2009). These types of community genebanks can be found in many areas throughout the world, for example, in addition to Ethiopia (and other Sub-Saharan African countries) and India, Brazil, Nepal, and Nicaragua also have over 100 community gene banks (for a more comprehensive review of community seed banks and their activities around the world and particularly in Nepal see Shrestha et al., 2013).

*Participatory Plant Breeding:*

Other initiatives have focused on working with small farmers to develop improved varieties of important food crops. There are two types of initiatives at the forefront of this area of interest, Participatory Plant Breeding (PPB) and Evolutionary Plant Breeding (EPB). The Platform for Agrobiodiversity Research (PAR) (2010) highlights a selection of PPB initiatives in India, Bangladesh, and Indonesia. In Uttar Pradesh, farmers have worked together on PPB to breed crops that are more resistant to the impacts of increasingly frequent and heavy floods, have worked to breed crops that require a shorter growing period in order to take better advantage of periods for planting prior to floods, and have bred crops for planting that are better able to tolerate soil conditions post-flooding (water logging) (Wahij, 2008). Similar programs have been undertaken in Bangladesh where shorter duration rice varieties have been bred through PPB in order to adapt to increasing floods (Kieft, 2001). In China, PPB action research coordinated by the Center for Chinese Agricultural Policy (CCAP) included both local landraces and varieties introduced from in-situ collections from the International Maize and Wheat Improvement Center (CIMMYT) (Yiching and Song, 2011). Results of that program showed increased income over non-project villages of up to 30%, productivity increases, increased appreciation of traditional knowledge, attraction of younger farmers, and increased decision making powers for women (Yiching and Song, 2011).

*Evolutionary Plant Breeding:*

EPB is often closely linked with PPB as well as with existing ex-situ collections of PGRFA. This type of breeding brings increased involvement of the scientific or professional plant breeding communities who work with farmers in their fields and in research plots to mix as many varieties of targeted crops as possible in the same fields where they can exchange genetic material freely (Rahmanian et al., 2014). Over time, through being exposed to local climate conditions and natural selection, these varieties become more adapted to changing conditions. In Iran, the Center for Sustainable Development (CENESTA) has spearheaded an EPB program with farmers that utilizes 1,600 varieties of barley supplied by the International Center for Agricultural Research in Dry Areas (ICARDA) (Rahmanian et al., 2014). It was found that the EPB varieties produced higher yields than their local and improved counterparts and that in some instances these EPB varieties did not need to be treated with pesticides and herbicides (Rahmanian, 2014). In addition to Iran, ICARDA has been involved in similar efforts with barley and wheat in Syria, Jordan, Eritrea, and Algeria (Ceccarelli et al., 2010). In Jordan, these efforts have proved useful in adapting to a variety of stressors, for example when the civil war in Syria closed off normal flows of crop breeding materials into the country (Rahmanian, 2014).

*Crowdsourcing:*

Citing issues with the success of attempts to upscale programs like PPB to a larger number of farmers, researchers are also looking into modern ways of reaching broader numbers of people in less time through utilizing crowdsourcing techniques for more rapid and far ranging seed variety dissemination and testing (van Etten, 2011). Crowdsourcing is the outsourcing of activities to ‘crowds’, large numbers of (generally unpaid) volunteers, who contribute with their skills and time to collective efforts (van Etten, 2011). These types of activities expand on a number of others that have sought to build on the bourgeoning uptake of mobile technologies across the global South in places like Sub-Saharan Africa where climate impacts are expected to be severe and use those technologies to help support adaptation. Such technologies have potential for engaging a much more broad pool of farmers in evaluating and distributing useful seeds than conventional programs are able to engage (vanEtten, 2011).

*Additional crop-focused activities:*

Though the spotlight for such programs has largely been focused on those in lower income or developing countries, PPB and EPB programs are also active in wealthier world regions such as Europe and North America. For example, a program based in Washington state and North Dakota in the United States is utilizing EPB methods for developing and utilizing greater diversity of organic buckwheat, quinoa, and spelt, though this initiative is not specifically targeted at climate change adaptation so much as development of economic niche markets (Murphy et al., 2008). These types of initiatives are not limited in influence to farmers of crops, livestock breeders are also interested in these enhanced varieties as superior fodder for their animals (source –ICARDA-Jordan video). Other smallholder focused programs aimed at adjusting crops and cropping systems in response to climate change include Participatory Varietal Selection (PVS) of potato and sweet potato varietals involving farmers in South America and Sub-Saharan Africa led by the International Potato Center (CIP) (For examples from Sub-Saharan Africa see: CIP, 2011).

*Animal Genetic Resources:*

Additional initiatives aimed at adaptation for smallholders of livestock are also being enacted in a number of world regions. For example, the International Livestock Research Institute (ILRI) and the CGIAR research Program on Climate Change Agriculture and Food Security (CCAFS) are working together with small farmers involved in the Climate Smart Villages project and other research locations on improving productivity in small livestock in the face of climate change (CCAFS, 2014). One example is of these institutions supporting champion farmers in Sub-Saharan Africa who have autonomously developed strategies for developing more locally resilient and economically viable goat breeds (through breeding local east African goat varieties from the local village with a male gala goat for increased milk production and faster maturity), and helping to extend those strategies to other farmers (Kilungu et al., 2014). ILRI has also developed a project entitled “Improving Utilization of Farm Animal Genetic Resources (Improving breeding strategies)” (see: [www.sustainable-livestock.ilri.org](http://www.sustainable-livestock.ilri.org)) in conjunction with projects on animal health and animal feeding. Such programs aimed at utilizing AnGRFA for adaptation face unique challenges in comparison to those involving PGRFA. Sparse comprehensive or detailed information is available concerning adaptive traits and genomic attributes of livestock breeds, especially any such data that is linked with climate models or predictions (Hoffmann, 2010). FAO is working with national governments around the world to try and address some of these gaps through the Global Plan of Action for Animal Genetic Resources (2007). In North America, organizations such as The Livestock Conservancy are working to recover lost or neglected livestock breeds and their unique characteristics through safeguarding traditional knowledge and breeding programs, however, perhaps due to less urgency in the form of impending negative climate impacts in that region these programs do not hold climate change adaptation as a major focus for their efforts (see: [www.livestockconservancy.org](http://www.livestockconservancy.org)).

***Technological Advances in Utilizing GRFA for Adaptation to Climate Change***

*Genetic Engineering*

By far the most controversial sub-topic within the subject of genetic diversity, agriculture, and adaptation is genetic modification (GM) of crops and livestock. This technology is said to hold potential for increasing resistance of crops and livestock to particularly concerning current and anticipated impacts of climate change including drought, increased pests and disease, rising temperatures, flooding, and salinity (Fedoroff et al., 2011). GM crops have been in production for over a decade and have had broad implications for commercial and smallholder production systems in many parts of the world and are widely utilized in the United States, Canada, Brazil, Argentina, India, China and Paraguay among others (James, 2011). There are glaring exceptions to this influence however, take for example the European Union where dissemination of GM varieties has been extremely limited and is subject to extraordinarily strict regulatory processes due to public pressure (James, 2011). For some, the potential gains offered by GM technologies are attractive when considering the predictions for growing global population, increased caloric intakes, and increasing urban populations dependent on commercial agriculture (Godfray et al., 2010). However, criticisms to GM include important issues of dependency of vulnerable populations on wealthy commercial breeders, cost barriers for accessing the technology, intellectual property rights, and food sovereignty, and decreased genetic diversity in agriculture overall, along with broader ethical concerns (Jacobsen et al., 2013). Opinions within communities of researchers working on PGRFA are divided just as popular opinion is. For example, since its inception in 2007 the Stress-Tolerant Rice for Africa and South Asia (STRASA) program that is funded by the Bill and Melinda Gates foundation and led by the International Rice Research Institute (IRRI) and AfricaRice, which includes a focus on flood resistant rice varieties, has been lauded by many within the PGRFA research sphere as a breakthrough that holds significant promise for increasing food security of small farmers (Ismail, 2013). By contrast, those that criticize this technology conclude that current funding being put toward GM technologies could be better utilized within other areas of research that are more diversity-centered and help to address underlying vulnerability issues (Jacobsen et al. 2013). Mercer et al. (2011) also voice concerns for what they foresee could be significant negative impacts on crop diversity and local livelihoods if transgenic technologies were to be mainstreamed in Mexico near the center of origin for Maize diversity. This strand of the literature criticizes the highly popular claims within certain media outlets and elsewhere that GM and transgenic varieties are a necessity for adapting to climate change, and suggests that they may be largely corporately supported rather than scientifically backed (Jacobsen et al. 2011). No GM livestock are currently available for commercial use, although technologies for engineering livestock do exist. There is, however, much debate regarding the feeding of GM crops to livestock as fodder (FAO, 2012). The Cartagena Protocol on Biosafety, an international agreement that aims to ensure safe handling, transport, and use of modified organisms was adopted in 2000 and currently has 168 party signatures, with the notable exception of the United States, one of the leading producers of GM crops (<http://bch.cbd.int/protocol/> ). The ITPGRFA and its associated Multilateral Treaty also has safeguards in place to try and limit the ability of corporate or other breeders from unequally benefitting from PGRFA collected from ex-situ collections involved in the treaty (FAO, 2001).

*Genomics*

A different branch of gene-focused technology that has revolutionized the way in which scientists understand GRFA is genomics. Genomics focuses on understanding the entire genome or DNA sequence of an organism and how its different genetic attributes and traits network together to produce different types of resistances and characteristics for that organism (FAO, 2007). In agriculture, this technology has been applied to both plants and animals. Increased capacities for sequencing of DNA and utilizing genomics for identifying adaptive traits brings these technologies to the fore of cutting edge science regarding GRFA and adaptation (Bevan and Uauy, 2013). Several prominent genome sequencing centers have emerged around the world including the Joint Genome Institute (JGI) in the US and the Beijing Genome Institute (BGI) in China, that provide a more efficient means of handling large amounts of data in a timely manner (Bevan and Uauy, 2013). These techniques make it easier for scientists to develop genetic markers that can be used to help identify desired adaptive traits within crops and livestock (Bevan and Uauy, 2013). There are numerous applications of these techniques currently being carried out. For example, with regard to AnGRFA, the AdaptMap Goats program is an international coordinated effort for genotyping and resequencing of goat breeds with a focus on the genetics of adaptation (AdaptMap Goats website, 2014).

Gaining more comprehensive understandings about the dynamics of adaptive genomic attributes across and among collections of organisms that coexisting in the same ecosystems and coupling that data with geographic information technologies has led to the emergent field of landscape genomics (Pariset et al., 2012). “Landscape genomics is the spatially explicit study of geographic patterns of genome-wide genetic variation” (Sork et al., 2013). Nextgen, an EU funded program focused on comparative analysis of intraspecific genomic data of cattle, sheep, and pigs is using landscape genomics for identifying genomic regions associated with disease resistance and adaptation (<http://nextgen.epfl.ch/>, 2013). The program has case studies in both Morocco and Uganda. The Yak Genome Database, an internet based resource, is a further example of increasing applications of genomic technologies (Hu et al., 2012). Landscape genomics is also being applied for studies of plant genetic resources including trees (Sork et al., 2013) and grasses (Acqua et al., 2014) that will help researchers to understand how best to utilized these tools for crops.

Despite the advances that have been made in utilizing GRFA for the purpose of supporting adaptation, our understandings of these processes remain incomplete. In the next sections we critically examine expert-identified challenges and gaps relating to GRFA and climate change adaptation that need to be addressed in order to progress our understandings and move forward with more integrated and comprehensive strategies for future actions.

**Part 3**

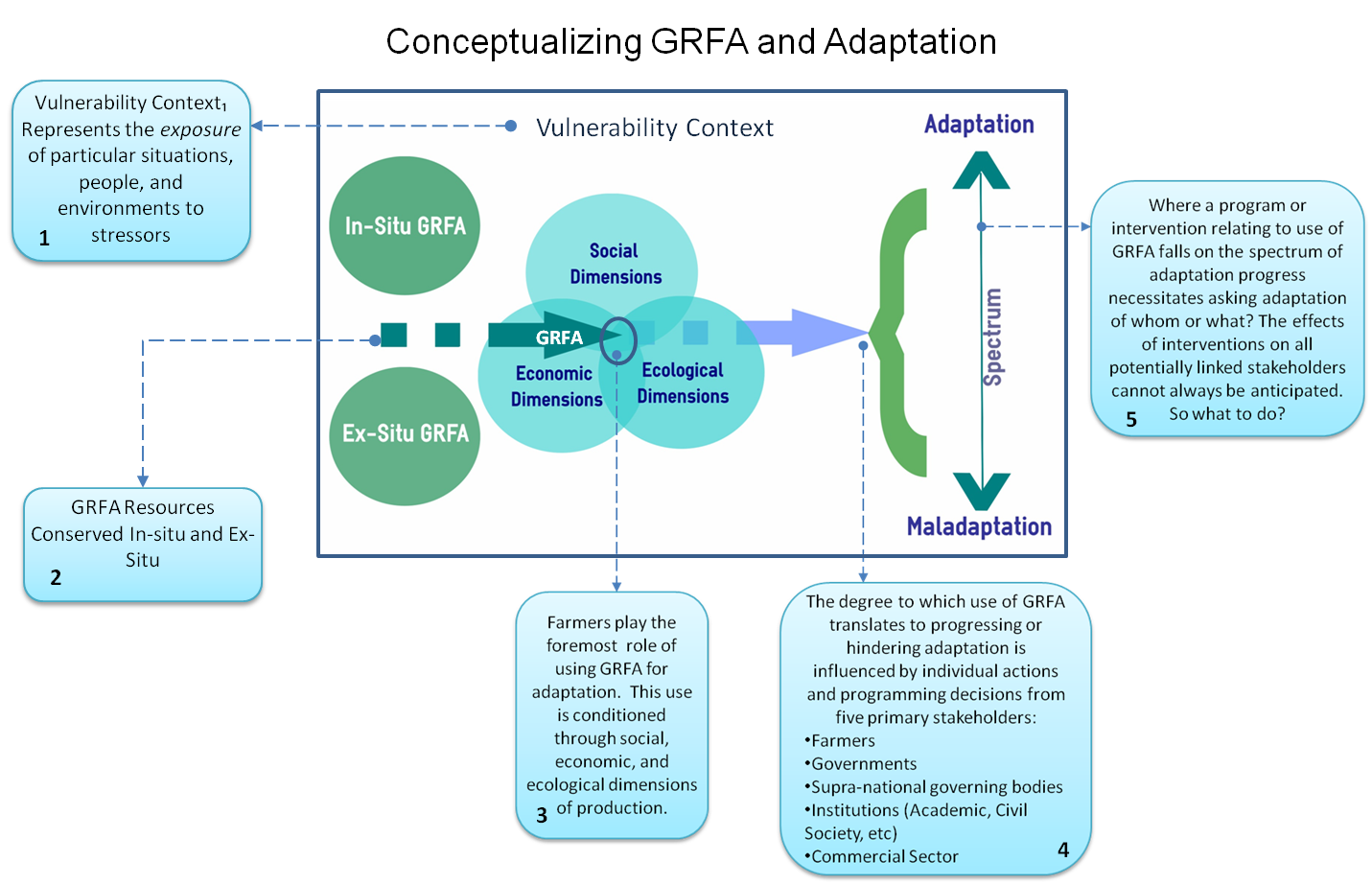
**Remaining Challenges – For consideration by co-authors (topics are flexible and we encourage authors to define their own contributions)**

1. – Connie McManus and Andrew Challinor:
   1. Data collection, monitoring, and integration considerations
      1. Despite advances in international policy regarding characterization of varieties and breeds, sharing of data, monitoring, and integration with current climate models, these tasks remain difficult to accomplish on the ground in many areas. Can you speak to what you view as the primary barriers to achieving these goals and whether or not you see a role for policy makers for overcoming these barriers? If you do not see policy makers as the most influential stakeholders for achieving these goals then whom (ex. National governments, local governments, traditional leaders, institutions?)? And further, do current policy frameworks easily facilitate engagement with these stakeholders?
2. – Adam Drucker and Dominic Moran
   1. Economic Considerations:
      1. A deeper understanding is needed of the costs and benefits for different stakeholders associated with utilizing GRFA in different ways (including PPB, EFB, PVS, and through more technical actions such as GM and genomics) in support of adaptation.
         1. According to IPCC WGIIAR5 Chapter 7.5 (2014), a meta-analysis of agricultural adaptation options showed that adaptive management options that focus on cultivar adaptation provide a 23% increase in yields over non-adapted options and 17% benefit when combining planting date and cultivar adjustments. However, we need more comprehensive data concerning the diversity of types of cultivar adjustment accompanied by the economic costs and benefits associated with those particular actions.
         2. We need a deeper understanding of the economic incentives of large scale commercial agribusiness for involvement in different types of breeding of GRFA in support of adaptation. We also need further investigation into how these commercial interests intersect with dimensions of local livelihoods, governance, and policy development.
3. Mary Thompson and Stella Nordhagen:
   1. Local Decision Making and Livelihoods
      1. Considerations of multidimensional livelihoods and how better understandings of their intersectional nature would contribute to adaptation efforts
      2. Decision making and the importance of seed systems in the context of global climate change
4. Irene Hoffmann, Roswitha Baumung and Ehsan Dulloo:
   1. National and International Policy Considerations
      1. Within policy, is placing the safeguarding of farmer rights preeminently within the jurisdiction of national governments the most effective or legitimate way to ensure the protection of those rights? How do the indications from IPCC and others regarding the need to devolve decision making processes regarding adaptation (WGIIAR5 14.2.3) fit with the country-level focus of most GRFA international policy instruments?
      2. With the current segregation of many policy mechanisms relating to PGRFA and ANGRFA, is this a hindrance to progress with overall utilization of GRFA for adaptation?
5. – Alessandra Stella, Paul Boettcher and Jacob van Etten:
   1. Considerations of deeper integration with relevant cutting edge technologies:
      1. The data and information that we do have needs to be more meaningfully taken up within available integrated genetic/genomic and geospatial technologies such as landscape genomics. These technologies are not cheap and the majority of the technical skill and funding for these types of technologies is based in Western countries.
6. -Unai Pascual and Louise Jackson:
   1. Considerations of GRFA in adaptation as it intersects with broader ecosystem services and “natural” environments
      1. Increasing the diversity of GRFA in a given agricultural system does not necessarily equal increased adaptive capacity of or decreased vulnerability of that system or the broader landscapes including natural environments and habitats that the system is situated with.
   2. How can we better capture these relationships? This should include discussions of land sparing and land sharing.

**Part 4**

**Moving forward**

All farmers are working within unique contexts of vulnerability, adaptive capacity, and resilience. These contexts are conditioned by factors such as location and type of production system as well as multiple additional economic, social, and ecological dimensions. The ways in which GRFA is perceived, accessed, and used in these contexts can be influenced by the actions and initiatives introduced by a range of different stakeholders with different motivations, varying levels of influence, and access to financial and political resources. The conceptual diagram below illustrates how GRFA can be traced through these contexts from conserved GRFA through multidimensional livelihoods of farmers, the area of influence of other stakeholders, and on toward either advancing or hindering the progress of adaptation.



1. (*Dynamic Setting*) -Vulnerability Context (As described in Carr, 2013 in relation to IPCC´s definition of exposure)
2. (*Material*) Conservation and Availability of GRFA
3. (*Use*) Use of GRFA by Farmers Conditioned by Social, Economic, and Ecological Dimensions of Production (Multidimensional influences on use)
4. (*Opportunities for Actions and Collaborations*) Programming and action decisions by five main stakeholders can influence where a particular intervention or strategy lands on the adaptation spectrum
5. (*Compass for Interventions and Collaborations*) The goal is to move the role of GRFA further along in progressing adaptation, not to leave it stagnant, hinder it, or even drive it toward causing maladptation. However, it is difficult for decision makers to anticipate all potential impacts from a given intervention, especially when we do not have hard information about potential impacts. (ex. GMO´s and dependency, PACS and sustainability issues, Participatory Plant Breeding and potential productivity issues). So how do we ensure progress?
   * Necessitate Multidimensional Program Capacity (Perhaps develop indicators of multidimensional program capacity as well as markers of sustainagility for helping to ensure progress in adaptation)
   * Utilize use of GRFA in spurring progressive transformational change among smallholders (Possibly as laid out in the proposal we worked on at BC3 this summer) in order to mitigate potential negative impacts
   * Utilize cutting-edge technologies to bring the best data to farmers and other stakeholders and put resources toward making that data useable for as broad a number of stakeholders as possible
   * Take a critical view of which stakeholders provide most effective and legitimate channels for safeguarding farmer rights (Indicates questions of governance)
   * Take a critical view of commercial sector motivations and how those can best be reconciled with potentially competing needs and motivations of other stakeholders, especially less powerful stakeholders

1. Here we draw on the IPCC’s definition of vulnerability as “the propensity or predisposition to be adversely affected” (IPCC, 2014). [↑](#footnote-ref-1)