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Innovations in Climate Risk Management: Protecting and Building Rural Livelihoods in a Variable and Changing Climate[1]

James W Hansen[1,*], Walter Baethgen[1], Dan Osgood[1], Pietro Ceccato[1], Robinson Kinuthia Ngugi[2]

[1]International Research Institute for Climate and Society, The Earth Institute, Columbia University, 61 Route 9W, Monell Building, Palisades, NY 10964-8000, USA

[2]University of Nairobi, Department of Land Resources Management & Agricultural Technology, Range Management Section, P.O. Box, 29053-00625, Nairobi, Kenya

Corresponding author, **jhansen@iri.columbia.edu**

Abstract

We argue that more effective management of climate risk must be part of the response of the international agriculture community to the double crisis of persistent poverty and a changing climate. The most promising opportunities to adapt to climate change involve action on shorter time scales that also contributes to immediate development challenges. Climate risk management (CRM) combines systematic use of climate information, and technology that reduces vulnerability and policy that transfers risk. The cost of climate risk comes both through damaging extreme events and through forfeited opportunity in climatically-favorable years. Effective CRM therefore involves managing the full range of variability, balancing hazard management with efforts to capitalize on opportunity. We discuss several innovations for managing climate risk in agriculture, which have not yet been fully mainstreamed in international agricultural research-for-development. First, effective rural climate information services enable farmers to adopt technology, intensify production, and invest in more profitable livelihoods when conditions are favorable; and to protect families and farms against the long-term consequences of adverse extremes. Second, information and decision support systems synthesize historic, monitored and forecast climate information into forms that are directly relevant to institutional decisions (planning, trade, food crisis response) that impact farmer livelihoods. Third, innovations in index-based insurance and credit overcome some of the limitations of traditional insurance, and are being applied to pre-financing food crisis response, and to removing credit constraints to adopting improved technology. We present a typology of CRM interventions around the concept of dynamic poverty traps.

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1. Responding to a Double Crisis

The international agriculture community finds itself at the intersection of two crises. First, hunger and extreme poverty persist in our world at an unacceptable scale. The Green Revolution, which saved more lives and did more to reduce hunger and poverty than any other human intervention in history, largely bypassed large, marginal rainfed agricultural regions, particularly in the semi-arid tropics, where rural poverty and hunger continue to frustrate the ongoing efforts of the CGIAR and an aggressive global campaign around the Millennium Development Goals (MDGs). Around the same time that the MDGs focused global effort toward eradicating extreme poverty, the threat of climate change finally captured the world's attention, bringing us to another crisis. In some ways, the "climate crisis" parallels the fear of Malthusian disaster that, in the 1960s, catalyzed the Green Revolution and the formation of the CGIAR. The crisis at that time was not the occurrence of famine – famine has always been with us. Rather it was an alignment of public awareness, political will and advances in technology that became a catalyst for change, largely because of the handful of visionaries who saw the opportunity to apply knowledge in new ways and at an unprecedented scale, and mobilized others to action. For the international agriculture community, the current crisis is not just the very real threat that climate change could undo past development efforts. It is a crisis of opportunity to respond to age-old problems – problems that are rendered more intractable by a variable climate, and that a changing climate threatens to intensify – in new ways and with new resources that come with public concern and political will at a global scale.

The IRI and an increasing number of development organizations see better management of climate risk today as an essential and feasible step toward reducing long-term vulnerability to a variable and changing climate. Climate risk management (CRM) includes: (a) systematic use of climate information to reduce the uncertainty that impacts planning and decision making, (b) climate-informed technologies that reduce vulnerability to climate variability (e.g., crop diversification, water harvesting, irrigation, improved water use efficiency, breeding for heat or drought tolerance), and (c) climate-informed policy and market-based interventions that transfer some part of risk away from vulnerable rural populations (e.g., innovate use of insurance and credit, social safety nets, proactive disaster management). It deals with climate variability at multiple time scales. However, the most promising and perhaps most neglected opportunities to impact poverty and food security involve seasonal to decadal time scales, falling between the extremes of daily weather and the 50-100 year time scales typical of climate change scenarios.

Effective climate risk management addresses the full range of variability, balancing protection against climate-related hazards with effort to capitalize on opportunity. It must involve a culture of climate awareness as well as systematic use of climate information among a range of stakeholders. In most contexts, it will require overcoming long-entrenched barriers between the agricultural development, food security early warning and response, and climate communities. Much of the CGIAR's work in marginal rainfed regions fits well within this view of CRM. Yet, several emerging opportunities to manage climate risk – new ways to use new types of climate information, climate-informed livelihood strategies, innovations in financial risk transfer products – are consistent with CGIAR goals and potentially synergistic with CGIAR technology, but have yet to be fully exploited within the CGIAR's programs. Subsequent sections discuss three such avenues for managing climate risk for agriculture and food security.

1.1. Climate Risk Management for Climate Adaptation

"Climate change," associated with long-term natural and anthropogenic changes in the chemical composition and heat balance of the global atmosphere, is one end of the continuum of time scales at which the atmosphere varies, illustrated in Fig. 1 for an index of the West African Sahel. The linear trend, representing the climate change time scale, reveals a 23% per century decline in expected annual rainfall (Fig. 1a). Interactions between the atmosphere and its underlying ocean surface, such as those associated with the El Niño/Southern Oscillation (ENSO) in the tropical Pacific, influence the decadal (Fig. 1b) and year-to-year time scale (Fig. 1c) which are often referred to as "climate variability." "Weather" is characterized by local-scale variations at daily or sub-daily time scales (masked by the averaging in Fig. 1). Even in this region marked by the strongest decadal variability observed anywhere, the year-to-year time scale accounts for the largest portion of overall variability,[2] and is important enough that any attempt to adapt to longer-term changes must deal with current variability.

Although the long-term threat from climate change is real and serious, the most promising opportunities to contribute to agricultural development and poverty alleviation in the face of long-term climate change arguably involve actions, including more effective management of climate risk, on shorter time scales. First, with a few

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[2] Averaging to produce the index dampens the interannual component of variability. The interannual component accounts for upward of 70% of the variance at several individual long-term stations in the region.

exceptions (e.g., coastal zones susceptible to sea level rise, irrigated agriculture fed by glaciers), the projected impacts of climate change on agriculture tend to be amplifications (sometimes reductions) of the substantial challenges that climate variability already imposes. Efforts to adapt to the impact of climate change can therefore hope to succeed only if they prove effective at managing the challenges that climate risk currently imposes on agriculture. Managing current climate risk offers a win-win opportunity for developing countries to contribute to legitimate current development priorities while reducing vulnerability to a changing climate. Second, in the face of pressing legitimate development priorities and a 2015 deadline for the MDG targets, the long (50-100 year) time horizons of climate change scenarios that have shaped the dialog about adaptation are a disincentive for action. Planning horizons tend to be short for communities already living on the edge of survival, and for governments of poor countries dealing with pressing development problems. The substantial uncertainty of climate change projections (particularly for precipitation), at the local scale needed for adaptation decisions, is a further obstacle to investing in adaptation. Finally, poverty is perhaps the greatest source of vulnerability to climate at all time scales (Antle et al., 2004; Mendelsohn et al., 2001). Therefore improving rural livelihoods now through aggressive pro-poor development may be the most promising avenue for adapting to future climate change. John Lynam (Lynam, 2006) expressed it well:

> *"The irony about climate change and African agriculture is that the most effective means to mitigate the possible negative consequences of future climate scenarios is to increase the rate of agricultural growth and development of these sectors. This is not to say that in many areas of Africa, climate change may even further retard development possibilities, but without development, there is very little means by which African agricultural sectors can cope with the negative effects of climate change."*

1.2. Managing the Full Range of Variability

Effective CRM for agriculture and food security deals with the full range of impacts across the full range of climate variability. Rural livelihoods are impacted by both *ex post* impacts – the losses that follow a climate shock such as a drought or flood – and *ex ante* impacts, which refer to the opportunity costs associated with conservative strategies that risk-averse decision makers employ in advance to protect themselves from the possibility of climate shocks. This distinction can be illustrated by a probability density function of some climate-sensitive agricultural outcome (e.g., production, farm income) (Fig. 2).

The most visible impacts are crisis events in the left tail of the distribution, associated with climatic extremes. Poor countries and the relatively poor within countries are disproportionately impacted by climate-related disasters (Carter et al., 2007; Easterly, 2001; Gaiha and Thapa, 2006). Adverse climatic conditions that are less severe cause hardship, but are within the coping capacity of the affected populations. The ex-post impact of a severe, uninsured climate shock can have long-term livelihood consequences through direct damage to crop and livestock productivity, infrastructure, the few productive assets of the poor and sometimes health and life, and also through the strategies that vulnerable households employ to cope with the resulting crisis, such as liquidating productive assets, defaulting on loans, migration, withdrawing children from school to work on farm or tend livestock, severely reducing nutrient intake and over-exploiting natural resources, to weather the resulting crisis. Permanent abandonment of farms and migration to urban centers or refugee camps is an extreme example. Such coping responses sacrifice capacity to build a better life in the future, often leading vulnerable households into long-term poverty and even destitution (Carter and Barrett, 2006; Dercon, 2004; Dercon, 2005; McPeak and Barrett, 2001).

The uncertainty associated with climate variability, combined with risk aversion on the part of decision makers, causes substantial loss of opportunity in climatically-favorable and even average years (the center and right portion of the distribution in Fig. 2). Without knowing when the next climate shock will come, poor farmers employ a range of precautionary ex-ante strategies to protect against the possibility of catastrophic loss, but at the expense of reduced average productivity and profitability, and inefficient and even exploitive resource use. Farmers' ex-ante responses to risk include: selection of less risky but less profitable crops (Dercon, 1996) or cultivars (Morduch, 1990), under-use of fertilizers (Binswanger and Sillers, 1983; Bliss and Stern, 1982), engaging less household labor in farming enterprises (Rose, 2001; Rosenzweig and Stark, 1989), and shifting from productive to non-productive but more liquid assets as precautionary savings (Fafchamps, 2003; Paxon, 1992; Zimmerman and Carter, 2003). For the risk-averse smallholder farmer, climate-related risk appears to be a significant disincentive to the investment in productive assets (Barrett et al., 2007a) and adoption of improved technology needed to move toward prosperity (Kebede, 1992; Marra et al., 2003). The resulting opportunity cost is a serious impediment to agricultural development efforts and hence to rural livelihoods and agrarian economies.

Disentangling the ex-post and ex-ante livelihood impacts of uninsured climate risk is analytically difficult, yet limited evidence suggests that the opportunity costs of farmers' ex-ante response to climate risk is substantial –

perhaps greater than the ex-post cost of shocks (Elbers et al., 2007) – and is much greater for those who are relatively poor and hence least able to tolerate risk (Rosenzweig and Binswanger, 1993; Zimmerman and Carter, 2003). Although the greatest setbacks to rural livelihoods are often linked to the most damaging climatic extremes, farmers experience opportunity costs in favorable and near-normal seasons far more frequently.

The ex-post and ex-ante impacts of climate risk combine with other factors to trap rural populations in chronic poverty. One class of dynamic poverty traps occurs when there is a critical threshold of household assets, below which individuals are unable to accumulate the necessary resources to escape poverty (Barrett, 2005; Carter and Barrett, 2006). The tendency for risk tolerance to decrease with decreasing resource endowment (Dercon, 1996; Pope and Just, 1991) contributes to the higher opportunity cost of climate risk for the relatively poor, and hence the locally-increasing marginal productivity that contributes to the existence of the multiple equilibria associated with a poverty trap (Barrett, 2005; Carter and Barrett, 2006). Ex-post coping response to severe or repeated climate shocks can push households to divest productive assets to a point below the poverty trap threshold (Dercon, 2004; Hoddinott, 2006). Climate risk also impacts institutions in a manner that further constrains economic opportunities and hence reinforce poverty traps at the household level (Barrett and Swallow, 2006; Carter and Barrett, 2006). Examples include the increasing cost of food crisis relief competing with agricultural development for shrinking donor resources (Barrett and Carter, 2001), and the widespread reluctance of lenders to serve smallholder rainfed farmers. We return to CRM in the context of poverty traps at the end of the paper.

2. Climate Information Services for Farmers

The ex-ante impacts of climate variability (Section 1.2) represent the cost of uncertainty. To the degree that climatic uncertainty adversely impacts farmer livelihoods, climate information that reduces the uncertainty that farmers face has potential to improve livelihoods, enabling farmers to adopt improved technology, intensify production, replenish soil nutrients and invest in more profitable enterprises when conditions are favorable or near average; and to more effectively protect their families and farms against the long-term consequences of adverse extremes. While historic data, monitoring and prediction at all lead times reduce uncertainty, we highlight prediction at the seasonal lead time.[3] First, because seasonal forecasts match the period between the many climate-sensitive decisions that must be made prior to planting, and harvest when outcomes of those decisions are realized, they expand the realm of adaptive management to include, e.g., allocation of farm land and household labor, choice of crops and production inputs, financing and procurement arrangements, and market contracts. Second, historic climate records, real-time monitoring and short- and medium-range weather prediction are often either accessible through existing services (e.g., weather forecasts, agrometeorological bulletins) or established within farmers' indigenous knowledge and observation. Finally, seasonal forecasts have been the object of substantial research that has yielded useful insights for rural climate information services more generally.

2.1. The Present Gap

Although seasonal climate forecasts have been disseminated routinely for at least ten years in much of Africa and Latin America and more than two decades in some parts of the world, they have not yet been integrated effectively into agricultural development, and hence remain a new and largely unexploited innovation. A brief historical perspective is needed to understand why. This year marks the tenth anniversary of regional climate outlook forums (COFs) in southern and eastern Africa, and southeastern South America. With backing from the WMO, NOAA, several donors, and international climate centers such as the IRI, the COFs bring national meteorological services (NMS) and a set of users from a region together to develop, distribute and discuss potential application of a consensus forecast of rainfall and sometimes other variables for the coming season. The COFs have shaped, and typify, the way operational seasonal forecasts are provided in many developing countries. A typical forecast (Fig. 3) expresses rainfall, aggregated over large spatial regions and averaged in time over a 3-month season, as probability shifts of the climatological tercile categories – described in qualitative terms as "above-normal," "normal" and "below-normal." In principle, NMSs are charged with downscaling and interpreting COF consensus forecasts, and engaging stakeholders within their countries. In practice, forecasts often reach national stakeholders in essentially the form, format and scale that come out of the COFs, although probabilistic information is often collapsed into a deterministic forecast of the most probable tercile category.

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[3] Cane (2001) and Goddard et al. (2001) provide useful overviews of the basis and practice of seasonal climate prediction.

The COFs made important early contributions to public awareness, dialog between NMS and other stakeholders, technical capacity of NMS and regional climate centers, and sustaining forecast production and dissemination. However, the model of COFs as “a hub for activation and coordination of regional climate forecasting and applications activities into informal networks” (Basher et al., 2001, p. 13) has generally not served agricultural development well. Credibility (i.e., perceived technical quality and authority of information), salience (i.e., perceived relevance to user’s decisions) and legitimacy (i.e., perception that the information service seeks the user’s best interest) have been proposed as prerequisites for successful adoption of climate information (Cash and Buizer, 2005; Meinke et al., 2006). Credibility – providing authoritative consensus forecasts through NMS in the face of multiple and sometimes conflicting information sources – was a key part of the rationale for the COFs (Dilley, 2001; Orlove and Tosteson, 1999; Patt et al., 2007). Putting the climate community at the center of designing information products, and inviting, informing and educating “users” gave users from agriculture little influence over the design of the products (at a cost to salience) and little ownership of the process (at a cost to legitimacy), as Cash et al. (2006) argued for the case of southern Africa. The gap between existing climate services and the needs of development is not limited to the COFs. A multi-stakeholder assessment of the use of climate information in Africa concluded that the gap pervades across sectors and from local to policy levels, and attributed it in part to “market atrophy” resulting from the interplay between ineffective demand by development stakeholders and inadequate supply of relevant climate information services (Hansen et al., 2006a).[4]

Surveys and pilot studies of the use and value of seasonal forecasts for smallholder agriculture in developing countries generally reveal a high level of awareness and interest in using forecast information, and have identified a range of promising management responses (e.g., Ngugi, 2002; Tarhule and Lamb, 2003; Ziervogel, 2004). They have also identified a few common obstacles to use and benefit. The most commonly reported obstacles are associated with communication – inequitable access; and mismatch between farmers’ needs and the scale, content, format, or accuracy of current operational forecasts (Archer, 2003; Ingram et al., 2002; O'Brien et al., 2000; Pagano et al., 2002; Phillips, 2003; Ziervogel, 2004). Other reported obstacles include the cost, risk and learning time associated with adopting and adapting the new technology (Patt and Gwata, 2002; Ziervogel, 2004); and credit and

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[4] Hellmuth et al. (2007) presents case studies of exceptions to this generalization in Africa, including rural climate information services in Mali.

other resource constraints that limit flexibility to respond to information (Ingram et al., 2002; Ngugi, 2002; Phillips, 2003; Phillips et al., 2001; Vogel, 2000). These constraints are, to a large degree, symptomatic of inadequate policies and institutional process, and therefore potentially amenable to intervention. While these pilot studies have yielded a wealth of insight into how constraints might be overcome, until recently few attempted to do so, or to engage those institutions that have potential to address the constraints. Furthermore, while many studies have characterized the predictability of climate variations at a seasonal lead time in all of the COF target regions, much less has been done to either evaluate the accuracy of the COF forecasts over time, or to disentangle the relative importance of forecast accuracy and communication constraints in limiting effective uptake. However, adoption rates and reported benefits have been fairly high in pilot projects in Zimbabwe, southern India and Burkina Faso, where extended interaction between smallholder farmers and researchers overcame some of the communication barriers (Huda et al., 2004; Meinke et al., 2006; Patt et al., 2005; Roncoli et al., Submitted).

2.2. Toward More Effective Rural Climate Information Services

Effective climate information services for farming communities will involve improving information products, information services, delivery of those products and services, and addressing institutional issues surrounding ownership and coordination. We illustrate some of the opportunities from the experience of the IRI and University of Nairobi in a pilot project in semi-arid Eastern Province (Machakos and Makindu), Kenya that aimed to develop and evaluate climate information products, training materials and communication protocols that improve adoption and benefit, and that have potential for scaling up through existing institutions.

2.2.1. Products

Experience in a range of contexts (Childs et al., 1991; Ingram et al., 2002; Jochec et al., 2001; Madden and Hayes, 2000; Nelson and Finan, 2000; O'Brien et al., 2000; Phillips and McIntyre, 2000; Ziervogel, 2001) reveals that farmers can best use climate forecast information when it: (a) is interpreted at a local scale; (b) includes information about timing (e.g., rainy season onset, risk of dry spells) beyond seasonal climatic means; (c) expresses accuracy in transparent, probabilistic terms; and (d) can be interpreted in terms of agricultural impacts and management implications. The coarse spatial and temporal scales of operational seasonal forecasts were once assumed to represent fundamental constraints of climate science. Evidence now shows that it is feasible to provide skillful forecasts at individual stations with only modest loss of regional-scale skill (Gong et al., 2003), and to forecast seasonal rainfall frequency (Moron et al., 2006) and the risk of damaging mid-season dry spells (Sun et al., 2007).

We provided participating farmers in Kenya with forecasts of October-December rainfall total and the number of rain days, downscaled to a local weather station, presented in the form of a probability-of-exceedance graph, alongside their climatological distributions. Time series of historic climate observations and model predictions completed what we considered the minimum set of forecast information (Fig. 4). With these graphs, we sought to present the forecast within the context of historic climate variability, and to represent forecast uncertainty, in probabilistic terms, as transparently as possible. Several considerations guided the choice of formats (Hansen et al., 2004a). (a) Transparent presentation builds confidence by transferring trust from the provider to the data. (b) To benefit fully and avoid increasing risk from over-responding, farmers need to understand and act on uncertain forecast information in a manner that is consistent with how they respond to climate variability in the absence of the new information. (c) Historic time series are an effective bridge between the way farmers think about variability in terms of memory of past years, and more formal probability formats. (d) Time series of observations and model predictions provide a link to interpreting and validating formal probability formats. Due to incompatible scales and unavailability of hindcast time series from the official forecast adapted from the GHACOF, we derived downscaled forecasts from GCM rainfall fields over eastern Africa (Hansen and Indeje, 2004).

Seasonal forecasts should ideally be packaged with other forms of climate and even market information both because of their utility for risk management, and because they provide the context for interpreting forecast information. As a relatively new input to agriculture, seasonal forecasts have potential to add value to existing agrometeorology information services where they exist, or stimulate demand for other types of information where they are currently not provided to rural communities.

2.2.2. Services

We propose that climate information is best packaged within a suite of services that include education, technical guidance and perhaps advocacy. Our work in Kenya dealt with the one aspect of education within two-day farmer training workshops (July 2004) at each location. The workshops provided participants with training in seasonal prediction and the new graphical formats, and a forum for discussing management implications with their peers.

They allowed us to test farmers' understanding and reactions to the package of tailored information and training in a group setting.

Activities designed to relate time series graphs to farmers' experience included discussions of memory of rainfall in recent seasons, plotting reported rainfall depths on a blank graph, and validating the resulting bar graph against their collective memory. We then led participants through the process of sorting the rainfall series onto a probability-of-exceedance graph, and then discussed interpretation, using analogies of locations that are somewhat wetter (dryer) to aid understanding of shifts to the right (left). Once the participants demonstrated collective understanding of the probability-of-exceedance format, we compared the climatological distribution, based on an extended time series, with the distribution in El Niño years to convey the notation that a forecast is a shift from the climatological distribution. Analogies of hot smoke rising and the way repositioning a stone changes currents in a stream were helpful in explaining how warming in the eastern Pacific could influence rainfall in Kenya.

Group interaction in breakout discussions about management responses to hypothetical forecasts, designed primarily to test understanding of graphic forecast formats, clearly stimulated co-learning about how to apply the information. Although the actual October-December forecast fell close to the climatological mean, questionnaires revealed that farmers changed planted areas, tillage practices, and use of certified seed and manure applications in the direction of intensification, in response to the forecast. Most were satisfied with the forecast and their management responses, valued the training, and recommended that it be continued on a regular basis.

2.2.3. Delivery

Farmers are most likely to act on climate information when it comes through sources of information and advice that they already know and trust. Radio and ICT-based communication offer immense potential to support the delivery of climate information services, and might be the only short-term option where there are no functional agricultural extension services or alternatives (e.g., development NGOs, agribusiness); but cannot replace the trust, visual communication of location-specific information, feedback and mutual learning that face-to-face interaction provides.

A motivation for our approach was to design and assess climate information products and services with potential to be produced on a routine basis through Kenya's NMS, and that could be further developed and delivered through the country's agricultural research and extension system, on a sustained basis and at scale. It is technically feasible to produce downscaled forecasts in the new formats for those locations where long-term daily rainfall data exist and can be digitized. We also have some confidence that the workshop process for introducing farmers to probabilistic forecast information can be adapted for use by agricultural extension personnel (including their non-governmental counterparts) who receive training.

As with other pilot research projects, a small set of participating farmers received information services – a training workshop followed by a shorter seasonal forecast dissemination meeting – directly from project-based researchers and facilitators on a temporary basis. Our efforts stimulated latent demand and raised expectations for continued services that we could not fulfill in the absence of sustained project funds or successful transfer – a danger that Meinke et al. (2006) discuss in the context of a pilot CRM project in southern India.

3. Information and Decision Support Systems for CRM

Although farmers are the ultimate managers of their own livelihoods, the agricultural sector includes a range of institutions, e.g., ministries of agriculture, food security relief organizations, agribusiness, and rural financial services, whose climate-sensitive decisions can greatly impact the farmers' welfare. Relative to smallholder farmers, institutional users of climate information tend to need information at aggregate scales, have greater ability to process quantitative information but greater need to automate integration of different types of information, and are more likely to be restricted by established procedures and required to give account for the basis for decisions. In most cases, effective use requires that raw climate information (climatology, observations and predictions) be translated into quantitative information (e.g., soil water status, pest or disease risk, vegetation conditions, crop yields), with uncertainties quantified, that is more directly related to decisions, uncertainties expressed in probabilistic terms if it is to be useful for decision making in agriculture. Computer-based information and decision support systems (IDSS) that integrate multiple sources of information, often at different time scales, in new ways, spatially in a GIS environment, are an effective step toward improving the use of climate information among institutional partners. Collaborative development of an IDSS allows an institution to tailor climate information products to their decisions.

3.1. Monitoring the Agricultural Environment

The FAO and IRI collaborated to improve an early warning system (EWS) that integrates climate and desert locust information to detect at an early stage any outbreaks that might threaten crop production. The desert locust (*Schistocerca gregaria,* Forskål) lives in remote desert zones extending from North Africa to Southwest Asia which are far from populated centres and therefore difficult to access. During quiet periods (known as recessions) it is usually restricted to the semi-arid and arid regions of Africa, the Near East and South-West Asia. When conditions are favourable for reproduction (i.e. moist sandy/clay soils for ovipontes and green vegetation for hopper development), desert locusts increase in number and change their behaviour from solitarious to gregarious. Gregarious adults form swarms that can be carried by the wind over great distances and threaten crops and pastures in about 50 countries. The Desert Locust plague of 1986-89 and subsequent upsurges in 1992-94, 1996-98 and 2003-2004 demonstrated how quickly this pest multiplies and spreads, threatening economies and the environment in locust-prone countries. Early detection based on ground surveys of potential breeding sites is constrained by remoteness and by limitations of funding, personnel and transportation. The EWS uses satellite monitoring of rainfall and vegetation to support more efficient surveillance over large areas (Ceccato et al., 2006). The daily rainfall images and 16-day interval vegetation images at high spatial resolution (250 m) are used operationally by the FAO and Ministries of Agriculture in 23 affected countries. The EWS is designed for use within a GIS-based IDSS already in place at FAO (Ceccato et al., 2007).

The EWS demonstrated its efficacy in February 2007, when the FAO and the Ministry of Agriculture in Eritrea sent a control team to the coastal desert area of Eritrea in response to the satellite images, and found Desert Locusts. A warning issued by FAO led to effective control with pesticides. Since then, the FAO has regularly updated maps, based on climate and environmental conditions derived from the IRI EWS, showing the potential spread of the locusts in the adjacent countries (Fig. 5).

The IRI collaborates with institutions in Uruguay (INIA) and Paraguay (UCA) to develop an IDSS to improve their capability to assess climate risks in agricultural production and explore interventions that reduce those risks.[5] Within a multi-scale GIS, the IDSS combines (a) maps and associated databases of soils, weather, land use, political divisions, market centers, routes, rivers; (b) national and sub-national statistics; (c) prices of inputs and products; (d) remotely sensed vegetation and climate; (e) simulation models (crops, pastures, trees); (f) automated land use evaluation; and (g) soil organic matter and nutrient dynamics models. The IDSS is being developed with the capability of characterizing the mean and variability of climate variables (e.g., rainfall, temperatures, frosts) that are relevant for agricultural production. It includes analyses of the mean and variability of water stress based on remotely sensed vegetation indices, and on a water satisfaction index based on a simple soil water balance model (Frere and Popov, 1979; Frere and Popov, 1986) that takes into consideration rainfall, temperature, soil characteristics and crop or pasture water requirements through the growing season. Another component of the IDSS applies remote sensing to monitor crop and pasture status. IRI-INIA and UCA collaborated with Farmer NGOs and with the private sector to identify land uses (crop and pasture species) using remote sensing. Collaborating agronomists used GPS to geo-reference fields with known crop species or pastures and databases are being compared with corresponding MODIS images to develop methods for identifying different land uses. The MODIS images are also being used to estimate the status of the crops and pastures and will be integrated into yield forecasts. The IDSS is also used for monitoring the risk of several crop diseases (e.g., white blotch for wheat and barley, phomopsis in sunflower).

In Uruguay, the IDSS approach has already been used to: (a) assist government agencies to prioritize aid under emergency conditions (e.g., during severe drought in Uruguay in the La Niña of 1999-2000); (b) evaluate production risks to support rural insurance and credit programs; (c) assess the impact of introducing annual crops in a region under natural grasslands; (d) define land use feasibility classes; (e) improve crop and pasture production forecasts; and (f) establish drought and flood alert systems. It is being developed to explore opportunities for the agricultural and forestry sectors to participate in carbon markets (based on the Kyoto protocol). The same tools are being

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[5] The work, in collaboration with the Uruguayan National Institute for Agricultural Research (INIA) and the University N. S. Asunción (UCA), is being partially funded by FONTAGRO a special fund sponsored by the Inter-American Development Bank (IADB) and the Inter-American Institute for Cooperation in Agriculture (IICA).

applied at different spatial scales – national, sub-national, basin and individual farms – depending only on the scale of the input data.

3.2. Forecasting Agricultural Production

Advance estimates of agricultural production are an essential input to a range of contingency planning, food crisis management and market applications. Early information about production shortfalls is necessary (but not sufficient) for effective response, as delay in initiating response greatly increases the humanitarian and livelihood impacts of a food crisis, and the cost of aid (Barrett et al., 2007b; Broad and Agrawala, 2000; Haile, 2005). Because climate-related fluctuations in production can have large impacts on price and hence accessibility of staple foods, the use of production forecasts to manage markets and strategic grain reserves to stabilize prices is an appealing food security intervention. Although experience with this type of application in developing countries is still rather limited, economic equilibrium modeling in Mozambique suggests considerable potential (Arndt and Bacou, 2000).

A number of countries, regional institutions and food security organizations routinely produce food and forage production forecasts based on simple water balance models, monitored rainfall and sometimes satellite vegetation indices. In most cases, accuracy (at a given lead time) or lead time (at a given level of accuracy) can be improved by incorporating additional information. Crop forecasts integrate several types of information, including historic, monitored and predictive climate information (e.g., Hansen et al., 2004b). Because the proportion of total uncertainty that is due to climate decreases through the growing season, the relative benefit of climate prediction (decreases in importance through the season) and monitoring (increases in importance) depending on the timing of the crop forecast (Hansen et al., 2006b). For this reason, seasonal climate forecasts are potentially valuable in instances where more effective action depends on earlier production assessments. Several methods (reviewed in Hansen et al., 2006b) are available for incorporating seasonal climate forecasts into model-based crop yield prediction. Further improvements in accuracy can be obtained by reducing crop model error through, e.g., modeling additional yield-limiting factors, improved measurement or calibration of model inputs such as soil properties, and assimilating remotely-sensed vegetation indices.

The IRI, AGRHYMET and CIRAD are exploring options for improving crop monitoring procedures for the West African Sahel. The current food crop monitoring system (Traoré et al., 2006) uses monitored rainfall information with a water balance-based model to determine when sowing conditions have been met, monitor water stress and estimate yields. Accuracy is acceptable only starting the end of August – late in the growing season. In a proof-of-concept study, incorporating seasonal climate forecasts consistently improved sorghum yield predictions earlier in the growing season, relative to predictions based on monitored weather alone. Other enhancements under consideration include: (a) upgrading to a process-level crop model that accounts for phenology, carbon balance, and the influence of solar radiation (increasingly important toward the south) and temperature; (b) use of improved satellite-based estimates of rainfall and other meteorological variables; (c) assimilation of remote-sensed vegetation indices; and (d) improved estimation of areas under given crops.

We see technical contributions to crop forecasting systems as an entry point to work with users of the information products to improve information design and dissemination, and foster capacity to use information more effectively to improve management. Existing institutional procedures that require a high degree of certainty before taking action appear to contribute to delays in responding to food crises (Broad and Agrawala, 2000; Haile, 2005). More explicit presentation of uncertainty in crop production assessments as the growing season unfolds would make the tradeoff between certainty and efficacy more apparent, and perhaps contribute to more flexibility to take more timely action.

4. Innovations in Insurance

Insurance is a major component of climate risk management for agriculture in more developed countries. In developing countries, problems with information flow and transaction costs have generally made traditional insurance unviable for the smallholder farmers who need it most. While traditional insurance insures against actual loss (e.g. crop failure), index insurance insures against an objectively-measured index, e.g., rainfall deficit, that is correlated to loss, and thus removes a portion of production risk without accounting directly for the actual loss (Skees et al., 1999). This method addresses moral hazard (incentive for farmers to let their crops fail to receive a payout) and adverse selection (less skilled farmers preferentially purchase insurance, increasing premiums and payouts) associated with traditional crop insurance. Eliminating the need for in-field damage assessment reduces cost. Index insurance therefore reduces some of the problems associated with traditional insurance, and has begun to make insurance more accessible to smallholder farmers in developing countries (World Bank, 2005; Hess and Syroka, 2005; McCarthy, 2003; Skees and Enkh-Amgalan, 2002; Skees and Leiva, 2005; Varangis et al., 2001).

However, it introduces basis risk, which results when the index does not capture the cause of actual damage on a given farm, and hence does not compensate for the actual loss. Because index insurance does not protect against all risks, it must be carefully designed as a component of a comprehensive risk management policy (Morduch, 2001).

The role of index insurance and the appropriate client vary depending on the particular risk management problem being faced (see section 5). The IRI works with the World Bank on index insurance pilot projects for farmers in southern and eastern Africa and in Central America, and with the Millennium Village Project on index insurance designed to protect the gains from ongoing development activities, across its network of locations, against devastation from drought or flooding.

4.1. Insurance to Overcome Barriers to Adoption of Improved Technology

Index insurance appears to hold considerable promise in overcoming climate risk as a barrier to adoption of improved technologies in low income areas. Lenders share risk with farmers, and influence the choices available to farmers. Even if a loan would lead to high yields and reliable repayment four years out of five, the threat of drought leading to widespread crop failure and large scale loan defaults in only one year out of five might dissuade a micro-finance lender from lending to smallholder farmers, and hence prevent the farmers from accessing the quality inputs needed to increase productivity and income. Drought insurance has shown promise as a way to overcome this problem. Insuring farmers so that they can repay loans during droughts has unlocked credit so that farmers can take advantage of the good years.

In Malawi, the IRI designed the contracts for a drought insurance scheme that provides the backbone of a package of loans, seed of a groundnut hybrid developed by ICRISAT, and maize inputs for smallholder farmers. The insurance targets the financing risk, allowing farmers access to loans that, in turn, provide access to inputs and the cash necessary to pay for the insurance premium. The number of farmers who purchased insurance increased from 892 in 2005 to several thousand contracts in the 2006-2007 season. Because of the increases in productivity due to the improved inputs, the program is financially self-sustaining; with farmers paying their own input costs, insurance premiums, interest, and even taxes using their increased revenues. Farmers have reported that they rely on the insurance bundle as their primary mechanism to adapt to climate change.

In design of the insurance bundle currently implemented, ICRISAT experts noted that there may be substantial benefits of integrating the insurance design process into the breeding programs. Adapting a cultivar to the local climate involves trade-offs of productivity for drought tolerance during the weeks of the growing season that have a high probability of dry spells. It may be worthwhile to use rainfall insurance to protect against the risk of dry spells rather than sacrificing substantial yield potential when relying on plant genetics to tolerate the risk. Thus, there are likely to be gains in carefully designing insurance into a cropping system, allowing the insurance to protect from risks that practices and plant genetics are not well suited to address.

4.2. Insuring Food Crisis Response

At the national level, index insurance has been used for famine relief by governments and international organizations. The uncertainty of information from early warning systems and the consequences of making an “incorrect” choice if a crisis does not materialize can dissuade a decision maker from taking timely appropriate action, performing the necessary analysis, or marshaling the resources or necessary approvals for coordinated action. In many cases, it may be possible to use historical data to identify preventative actions that would be worthwhile to take in response to a trigger level of a monitored parameter, forecast, or early warning system. An index insurance contract can be written so that whenever the trigger is reached, the budget for the action is paid.

In Ethiopia there is an index insurance project designed to address national food security (Stayton and Hess, 2006). The insurance, developed in cooperation with the WFP, is purchased by the Ethiopian government to provide funding for food aid in response to large droughts. The index is based on rainfall. When rainfall across several locations in Ethiopia is low enough that it is likely to lead to substantially lower maize yields, the WFP receives an insurance payout to supplement its relief budget for those years, which are highly likely to have increased demands. Due to basis risk, there will be famine years in which the index does not indicate a payout (for example, during a food crisis driven by locust). In this case, relief agencies who hold the contract maintain reserves from unused payouts to address food crises that are not indicated in the index. Thus, the insurance assists agencies to have more stable annual budgets and quicker and more efficient responses to indexed risks.

4.3. Insurance and Advance Information

Advance information and financial instruments are not independent (Cabrera et al., 2006). Financial interventions provide flexibility to respond to information. Forecast information has the potential to undermine insurance or weather-linked credit through inter-temporal adverse selection when premiums are set before, but contracts are sold after a forecast becomes available (World Bank, 2005). Yet, the potential synergy can be exploited if prices are adjusted in response to forecast information (Carriquiry and Osgood, 2006). Then the insurance becomes more expensive when there is an increased probability of reduced rainfall and less expensive when there is an increased probability of increased rainfall. In addition to restoring the solvency of the insurance, this strategy has the potential to provide a useful market signal to implement high productivity/high risk strategies when wet years are expected and return on input is greater, but more conservative choices when dry years are expected. Thus, index insurance can be structured to directly protect against the uncertainty of the forecast, allowing effective action to be taken without placing the decision-maker under unnecessary risk.

Based on the insurance structure for maize in Malawi, it was determined that substantial productivity gains might be realized if the forecast was designed into the insurance structure. With historical rainfall data, a series of hypothetical payouts were generated using one of the 2006-2007 maize contracts. Payouts were extremely rare in La Niña years, as these years were much less likely to have dry spells that would damage maize production. This means that insurance prices could be much lower in La Niña years. For the same premium, a farmer could insure a much larger loan in La Niña years. In El Niño years, the farmer would be much more likely to default, having lost the seed and fertilizer investment due to drought.

In project discussions, smallholder farmers expressed frustration that they would like to adjust their input use and choice of varieties to take advantage of forecasts based on ENSO but did not have the resources or markets to do so. To explore the potential for integrating the forecast into an insurance bundle, we examined an illustrative package in which farmers pay the premium level currently utilized for maize in the Malawi contracts. Insurance prices were adjusted based on ENSO phase, with input loans scaled to what the current premium would be able to guarantee. The farm was assumed to be split between as much fertilized hybrid maize as the loan would allow with the balance of the land dedicated to traditional, non-fertilized maize. Applying historical district yield figures for fertilized hybrid and non-fertilized traditional varieties, economic simulations indicated that farmers might be able to more than double their gross revenues (as compared to a non-scaling index insurance bundle) through scaling up use of fertilized hybrid maze in La Niña years, which indicated a crude forecast for a good rainfall year. Farmers were protected from risk, since if a drought occurred in a La Niña year, the farmer would receive a payment. In addition, by being more conservative in other years, for which the forecast probability for a drought was higher, the farmer put fewer resources at risk, earning higher returns in the long run (Osgood et al., 2007).

5. Targeting CRM in a World of Poverty Traps

The dynamics of poverty are central to understanding vulnerability to climate change, and to targeting interventions that reduce vulnerability to a changing climate in smallholder agricultural systems in developing countries. Figure 6 shows expected future wealth conditioned on current wealth for a livelihood system characterized by dynamic poverty traps. It extends a common simplified representation (i.e., ignoring stochastic drivers) of a dynamic poverty trap to include three distinct, stable equilibria represented by points A (above the poverty line), B (a poverty trap) and C (irreversible destitution or physical impairment). Between each pair of stable equilibria is an unstable equilibrium (points 1 and 2), about which wealth bifurcates. It highlights three populations impacted in different ways by climate risk, assuming the sort of multiple dynamic equilibria demonstrated in Kenya, Ethiopia, Ghana and South Africa (Adato et al., 2006; Barrett et al., 2006; Lybbert et al., 2004; Santos and Barrett, 2006; Vanderpuye-Orgle, 2007). In this context, Chris Barrett (Barrett et al., 2007b) proposed three distinct but complementary targets for CRM intervention. The first role, “productive safety nets” (Barrett et al., 2007a), involves safeguarding productive assets to prevent the non-poor (point A) from falling below poverty trap threshold (point 1) in a shock. Diversified farming systems and traditional crop insurance – to a large degree farm-level decisions – fit within this category. The second role, what Barrett (pers. commun.) termed “cargo net” interventions, seeks to facilitate exit from a poverty trap (i.e., movement from point B to above point 1) e.g., by improving access to credit, land and labor productivity, technology adoption, efficiency of input use, market participation. Index insurance bundled with credit, and climate forecast information can contribute, but only in the context of comprehensive efforts to support appropriate intensification for the transition from subsistence production to more profitable livelihoods. This suggests that cargo net interventions generally require coordinated action on the part of farm households and other institutional actors. The final role is safety nets intended to avert humanitarian disaster by protecting those in poverty from permanent destitution or health impacts (point C) in the face of shock. CRM can contribute to timelier and better-targeted response through enhanced use of improved early warning systems, and potentially through weather index-based pre-financing instruments. This type of safety net targets populations with little capacity to weather severe shocks, and therefore requires action at primarily an institutional and policy level – often by a different set of institutions than those that deal with poverty-linked chronic food insecurity through agricultural development.

This typology suggests a suite of CRM interventions, targeting the different ways climate risk impacts the chronically poor and the non-poor but vulnerable, may be needed to reduce rural poverty in the face of a variable and changing climate. Because such a comprehensive approach depends on action by farmers, NARES, market institutions, food security early warning and response institutions and climate institutions, building bridges across these communities is perhaps the greatest current challenge to climate-proofing poverty reduction and food security.

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References:

Adato, M., M.R. Carter and J. May. 2006. Exploring poverty traps and social exclusion in South Africa using qualitative and quantitative data. Journal of Development Studies 42(2):226-247.

Antle, J.M., S.M. Capalbo, E.T. Elliott, and K.H. Paustian. 2004. Adaptation, spatial heterogeneity, and the vulnerability of agricultural systems to climate change and CO2 fertilization: an integrated assessment approach. Climatic Change 64:289-315.

Archer, E.R.M. 2003. Identifying underserved end-user groups in the provision of climate information. Bulletin of the American Meteorological Society 84:1525-1532.

Arndt, C., and M. Bacou. 2000. Economy wide effects of climate variability and prediction in Mozambique. American Journal of Agricultural Economics 82:750-754.

Barrett, C.B. 2005. Rural poverty dynamics: development policy implications. Agricultural Economics 32:45-60.

Barrett, C.B., and M.R. Carter. 2001. Can't get ahead for falling behind: development policy, poverty, and relief traps. Choices Winter 2001-2002:35-38.

Barrett, C.B., and B.M. Swallow. 2006. Fractal poverty traps. World Development 34:1-15.

Barrett, C.B., P.P. Marenya, J. McPeak, B. Minten, F. Murithi, W. Oluoch-Kosura, F. Place, J.C. Randrianarisoa, J. Rasambainarivo, and J. Wangila. 2006. Welfare dynamics in rural Kenya and Madagascar. Journal of Development Studies 42:248-277.

Barrett, C.B., M.R. Carter, and M. Ikegami. 2007a. Poverty Traps and Social Protection. Working paper, Cornell University and University of Wisconsin.

Barrett, C.B., B.J. Barnett, M.R. Carter, S. Chantarat, J.W. Hansen, A.G. Mude, D.E. Osgood, J.R. Skees, C.G. Turvey, and M.N. Ward. 2007b. Poverty Traps and Climate Risk: Limitations and Opportunities of Index-Based Risk Financing. IRI Tech. Rep. No. 07-02. International Research Institute for Climate and Society, Palisades, New York, USA.

Basher, R., C. Clark, M. Dilley, and M. Harrison, (ed.) 2001. Coping with Climate: A Way Forward. Summary and Proposals for Action. International Research Institute for Climate Prediction, Palisades, New York.

Binswanger, H., and D.A. Sillers. 1983. Technological priorities for farming in Sub-Saharan Africa. World Bank Research Observer 3:81-98.

Bliss, C.J., and N.H. Stern. 1982. Palanpur: the Economy of an Indian Village Clarendon Press, Oxford.

Broad, K., and S. Agrawala. 2000. The Ethiopia food crisis -- uses and limits of climate forecasts. Science 289:1693-1694.

Cabrera, V.E., C.W. Fraisse, D. Letson, G. Podesta, and J. Novak. 2006. Impact of climate information on reducing farm risk by optimizing crop insurance strategy. Transactions of the ASABE 49:1223-1233.

Cane, M.A. 2001. Understanding and predicting the world's climate system, p. 1-20, *In* C. Rosenzweig, et al., eds. impacts of El Niño and Climate Variability on Agriculture. American Society of Agronomy, Madison, WI, USA.

Carriquiry, M., and D. Osgood. 2006. Index Insurance, Production Practices, and Probabilistic Climate Forecasts. The International Research Institute for Climate and Society in the Earth Institute at Columbia University.

Carter, M.R., and C.B. Barrett. 2006. The economics of poverty traps and persistent poverty: an asset-based approach. Journal of Development Studies 42:178-199.

Carter, M.R., P.D. Little, T. Mogues, and W. Negatu. 2007. Poverty traps and natural disasters in Ethiopia and Honduras. World Development 35:835-856.

Cash, D., and J. Buizer. 2005. Knowledge-action systems for seasonal to interannual climate forecasting: summary of a workshop report to the Roundtable on Science and Technology for Sustainability, Policy and Global Affairs. National Academy Press, Washington, DC.

Cash, D.W., J.C. Borck, and A. Patt, G. 2006. Countering the loading dock approach to linking science and decision making: comparative analysis of El Nino/Southern Oscillation (ENSO) forecasting systems. Science, Technology & Human Values 31:465-494.

Ceccato, P., K. Cressman, A. Giannini, and S. Trzaska. 2007. The desert locust upsurge in West Africa (2003-2005): information on the desert locust early warning system, and the prospects for seasonal climate forecasting. International Journal of Pest Management 53:7-13.

Ceccato, P., M.A. Bell, M.B. Blumenthal, S.J. Connor, T. Dinku, E.K. Grover-Kopec, C.F. Ropelewski, and M.C. Thomson. 2006. Use of remote sensing for monitoring climate variability for integrated early warning systems: applications for human diseases and desert locust management, pp. 270-274 Proceedings of the IEEE International Geoscience & Remote Sensing Symposium. IEEE, Denver.

Childs, I.R.W., P.A. Hastings, and A. Auliciems. 1991. The acceptance of long-range weather forecasts: A question of perception? . Australian Meteorological Magazine 39:105-112.

Dercon, S. 1996. Risk, crop choice, and savings: evidence from Tanzania. Economic Development and Cultural Change 44:485-513.

Dercon, S. 2004. Growth and shocks: evidence from rural Ethiopia. Journal of Development Economics 74:309-329.

Dercon, S., (ed.) 2005. Insurance Against Poverty. Oxford University Press, Oxford.

Dilley, M. 2001. Institutions and sustainability, p. 122-131, *In* R. Basher, et al., eds. Coping with the Climate: A Way Forward. Preparatory Report and Full Workshop Report. International Research Institute for Climate Prediction, Palisades, New York.

Easterly, W. 2001. The Elusive Quest for Growth MIT Press, Cambridge, Mass, USA.

Elbers, C., J.W. Gunning, and B. Kinsey. 2007. Growth and risk: methodology and micro evidence. World Bank Economic Review 21:1-20.

Fafchamps, M. 2003. Rural Poverty, Risk and Development Edward Elgar Publishing, Glos, UK.

Frere, M., and G.F. Popov. 1979. Agrometeorological Crop Monitoring and Forecasting Food and Agriculture Organization of the United Nations, Rome.

Frere, M., and G.F. Popov. 1986. Early Agrometeorological Crop Yield Assessment Food and Agriculture Organization of the United Nations, Rome.

Gaiha, R., and G. Thapa. 2006. Natural Disasters, Vulnerability and Mortalities – A Cross-Country Analysis. International Fund for Agricultural Development, Rome.

Goddard, L., S.J. Mason, S.E. Zebiak, C.F. Ropelewski, R. Basher, and M.A. Cane. 2001. Current approaches to seasonal to interannual climate predictions. International Journal of Climatology 21:1111-1152.

Gong, X., A. Barnston, and M. Ward. 2003. The effect of spatial aggregation on the skill of seasonal precipitation forecasts. Journal of Climate 16:3059-3071.

Haile, M. 2005. Weather patterns, food security and humanitarian responses in Sub-Saharan Africa. Philosophical Transactions of the Royal Society B: Biological Sciences 360:2169-2182.

Hansen, J.W., and M. Indeje. 2004. Linking dynamic seasonal climate forecasts with crop simulation for maize yield prediction in semi-arid Kenya. Agricultural and Forest Meteorology 125:143-157.

Hansen, J.W., S. Marx, and E. Weber. 2004a. The Role of Climate Perceptions, Expectations, and Forecasts in Farmer Decision Making: The Argentine Pampas and South Florida. IRI Tech. Rep. No. 04-01. International Research Institute for Climate and Society, Palisades, New York, USA.

Hansen, J.W., A. Potgieter, and M. Tippett. 2004b. Using a general circulation model to forecast regional wheat yields in Northeast Australia. Agricultural and Forest Meteorology 127:77-92.

Hansen, J.W., M. Hellmuth, M. Thomson, and J. Williams, (eds.) 2006a. A Gap Analysis for the Implementation of the Global Climate Observing System Programme in Africa. IRI Tech. Rep. No. 06-01. International Research Institute for Climate and Society, Palisades, New York, USA.

Hansen, J.W., A. Challinor, A.V.M. Ines, T. Wheeler, and V. Moron. 2006b. Translating climate forecasts into agricultural terms: advances and challenges. Climate Research 33:27-41.

Hellmuth, M.E., A. Moorhead, M.C. Thomson, and J. Williams, (eds.) 2007. Climate Risk Management in Africa: Learning from Practice. International Research Institute for Climate and Society, Columbia University, New York.

Hess, U., and J. Syroka. 2005. Weather-based Insurance in Southern Africa: The Case of Malawi. Agriculture and Rural Development Discussion Paper 13. The International Bank for Reconstruction and Development / The World Bank, Washington, D.C.

Hoddinott, J. 2006. Shocks and their consequences across and within households in rural Zimbabwe. Journal of Development Studies 42:301-321.

Huda, A.K.S., R. Selvaraju, T.N. Balasubramanian, V. Geethalakshmi, D.A. George, and J.F. Clewett. 2004. Experiences of using seasonal climate information with farmers in Tamil Nadu, India, *In* A. K. S. Huda and R. G. Packham, eds. Using Seasonal Climate Forecasting in Agriculture: a Participatory Decision-making Approach. Australian Centre for International Agricultural Research, Canberra.

Ingram, K.T., M.C. Roncoli, and P.H. Kirshen. 2002. Opportunities and constraints for farmers of west Africa to use seasonal precipitation forecasts with Burkina Faso as a case study. Agricultural Systems 74:331-349.

Jochec, K.G., J.W. Mjelde, A.C. Lee, and J.R. Conner. 2001. Use of seasonal climate forecasts in rangeland-based livestock operations in West Texas. Journal of Applied Meteorology 40:1629-1630.

Kebede, Y. 1992. Risk behavior and new agricultural technologies: the case of producers in the central highlands of Ethiopia. Quarterly Journal of International Agriculture 31:269-284.

Lybbert, T.J., C.B. Barrett, S. Desta, and D.L. Coppock. 2004. Stochastic wealth dynamics and risk management among a poor population. The Economic Journal 114:750-777.

Lynam, J. 2006. Climate Change and Agricultural Development in Africa Climate and Development in Africa: Gaps and Opportunities, Columbia University, New York.

Madden, B., and G. Hayes. 2000. Building dairy farmer demand for climate information Proceedings of the Conference on Managing Australian Climate Variability. Albury, NSW, Australia, 23–25 October 2000.

Marra, M., D.J. Pannell, and A.A. Ghadim. 2003. The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve? Agricultural Systems 75:215-234.

McCarthy, N. 2003. Demand for Rainfall-Index Based Insurance: A Case Study From Morocco. EPTD Discussion Paper 106. Environment and Production Technology Division, International Food Policy Research Institute, Washington, D.C.

McPeak, J.G., and C.B. Barrett. 2001. Differential risk exposure and stochastic poverty traps among East African pastoralists. American Journal of Agricultural Economics 83:674-679.

Meinke, H., R. Nelson, P. Kokic, R. Stone, R. Selvaraju, and W. Baethgen. 2006. Actionable climate knowledge: from analysis to synthesis. Climate Research 33:101-110.

Mendelsohn, R., A. Dinar, and A. Sanghi. 2001. The effect of development on the climate sensitivity of agriculture. Environment and Development Economics 6:85-101.

Morduch, J. 1990. Risk, Production and Savings: Theory and Evidence from Indian Households. Harvard Univ., Dept. of Economics, Cambridge, Mass.

Morduch, J. 2001. Rainfall insurance and vulnerability: Economic principles and cautionary notes. New York University, New York.

Moron, V., A.W. Robertson, and M.N. Ward. 2006. Seasonal predictability and spatial coherence of rainfall characteristics in the tropical setting of Senegal. Monthly Weather Review 134:3248-3262.

Nelson, D., and T. Finan. 2000. The emergence of a climate anthropology in Northeast Brazil. . Practicing Anthropologist 22:6–10.

Ngugi, R.K. 2002. Climate Forecast Information: The Status, Needs and Expectations Among Smallholder Agro-pastoralists in Machakos District, Kenya No. 02-04. IRI, Columbia Earth Institute, Columbia University, Palisades, NY.

O'Brien, K., L. Sygna, L.O. Næss, R. Kingamlono, and B. Hochobeb. 2000. Is Information Enough? User Responses to Seasonal Climate Forecasts in Southern Africa Center for International Climate and Environmental Research, Oslo.

Orlove, B.S., and J.L. Tosteson. 1999. The application of seasonal to interannual climate forecasts based on El Niño-Southern Oscillation (ENSO) events: Lessons from Australia, Brazil, Ethiopia, Peru and Zimbabwe. Institute of International Studies, University of California, Berkeley.

Osgood, D.E., M. McLaurin, M. Carriquiry, A. Mishra, F. Fiondella, J.W. Hansen, N. Peterson, and N. Ward. 2007. Designing Weather Insurance Contracts for Farmers in Malawi, Tanzania, and Kenya Final Report to the Commodity Risk Management Group, ARD, World Bank. International Research Institute for Climate and Society, Palisades, New York.

Pagano, T.C., H.C. Hartmann, and S. Sorooshian. 2002. Factors affecting seasonal forecast use in Arizona water management: A case study of the 1997-98 El Niño. . Climate Research 21:259-269.

Patt, A., P. Suarez, and C. Gwata. 2005. Effects of seasonal climate forecasts and participatory workshops among subsistence farmers in Zimbabwe. Proceedings of the National Academy of Sciences 102:12623-12628.

Patt, A., G., and C. Gwata. 2002. Effective seasonal climate forecasts applications: examining constraints for subsistence farmers in Zimbabwe. Global Environmental Change-Human and Policy Dimensions 12:185-195.

Patt, A.G., L.J. Ogallo, and M. Hellmuth. 2007. Learning from 10 years of climate outlook forums in Africa. Science 318:49-50.

Paxon, C. 1992. Using weather variability to estimate the response of savings to transitory income in Thailand. American Economic Review 82:15-33.

Phillips, J. 2003. Determinants of forecast use among communal farmers in Zimbabwe, p. 110-126, *In* K. O'Brien and C. Vogel, eds. Coping with Climate Variability: The Use of Seasonal Climate Forecasts in Southern Africa. Ashgate Publishing, Abingdon, UK.

Phillips, J., and B. McIntyre. 2000. ENSO and interannual rainfall variability in Uganda: implications for agricultural management. . International Journal of Climatology 20:171-182.

Phillips, J.G., L. Unganai, and E. Makaudze. 2001. Current and potential use of seasonal climate forecasts for resource-poor farmers in Zimbabwe., p. 87-100, *In* C. Rosenzweig, et al., eds. Impacts of El Niño and Climate Variability on Agriculture. ASA Special Publication no. 63. . American Society of Agronomy Madison, Wis., USA

Pope, R., and R. Just. 1991. On testing the structure of risk preferences in agricultural supply analysis. American Journal of Agricultural Economics 73:743-748.

Roncoli, C., C. Jost, P. Kirshen, G. Hoogenboom, K. Ingram, M. Sanon, L. Somé, J. Sanfo, C. Sia, and F. Ouattara. Submitted. From accessing to assessing forecasts: an end-to-end study of participatory climate forecast dissemination in Burkina Faso (West Africa). Climatic Change (submitted).

Rose, E. 2001. Ex ante and ex post labor supply response to risk in a low-income area. Journal of Development Economics 64:371-388.

Rosenzweig, M.R., and O. Stark. 1989. Consumption smoothing, migration and marriage. Journal of Political Economy 97:905-926.

Rosenzweig, M.R., and H.P. Binswanger. 1993. Wealth, Weather Risk and the Composition and Profitability of Agricultural Investments. The Economic Journal 103:56-78.

Santos, P., and C.B. Barrett. 2006. Informal insurance in the presence of poverty traps: evidence from southern Ethiopia." Working paper, Cornell University.

Skees, J., P. Hazell, and M. Miranda. 1999. New Approaches to Crop Yield Insurance in Developing Countries 55. International Food Policy Research Institute, Washington, DC.

Skees, J.R., and A. Enkh-Amgalan. 2002. Examining the Feasibility of Livestock Insurance in Mongolia. The World Bank Policy Research Working Paper Series: 2886.

Skees, J.R., and A.J. Leiva. 2005. Analysis of Risk Instruments in an Irrigation Sub-sector in Mexico. Global Ag Risk report Submitted to the Inter-American Development Bank

Stayton, M., and U. Hess. 2006. Ethiopia Drought Insurance Update and 2007 Weather Risk Management Workplan. World Food Programme, United Nations, Rome.

Sun, L., H. Li, M.N. Ward, and D.F. Moncunill. 2007. Climate variability and corn yields in semiarid Ceará, Brazil. Journal of Applied Meteorology and Climatology 46:226-240.

Tarhule, A., and P.J. Lamb. 2003. Climate Research and Seasonal Forecasting for West Africans. Bulletin of the American Meteorological Society 84:1741-1759.

Traoré, S.B., B. Sidibe, B. Djaby, A. Samba, A.B. Kaba, B. Sarr, A. Amani, B. Some, and J. Andigue. 2006. A review of agrometeorological monitoring tools and methods used in the West African Sahel, pp. 209-220, In R. P. Motha, et al., (eds.) Strengthening Operational Agrometeorological Services at the National Level. Proceedings of the Inter-Regional Workshop, 22-26 March 2004. USDA, Washington, DC; WMO, Geneva, and FAO, Rome, Manila, Philippines.

Vanderpuye-Orgle, J. and C.B. Barrett. 2007. Risk management and social visibility in Ghana. Working paper, Cornell University.

Varangis, P., J. Skees, S. Gober, R. Lester, and V. Kalavakonda. 2001. Developing Rainfall-Based Index Insurance in Morocco. The World Bank Policy Research Working Paper Series: 2577.

Vogel, C. 2000. Useable science: An assessment of long-term seasonal forecasts amongst farmers in rural areas of South Africa. South African Geographical Journal 82:107-116.

World Bank. 2005. Managing Agricultural Production Risk. Innovations in Developing Countries 32727-GLB. The World Bank Agriculture and Rural Development Department, Washington, D.C.

Ziervogel, G. 2001. Perceptions of normal and probabilities in Lesotho: Data from surveys undertaken in Dec–January 2001, southern Lesotho.

Ziervogel, G. 2004. Targeting seasonal climate forecasts for integration into household level decisions: the case of small farmers in Lesotho. The Geographical Journal 170:6-21.

Zimmerman, F.J., and M.R. Carter. 2003. Asset smoothing, consumption smoothing and the reproduction of inequality under risk and subsistence constraints. Journal of Development Economics 71:233-260.

Figure 1. Index of West African Sahel annual rainfall, with (a) total variability partitioned into linear trend, (b) decadal variability (using a 10-year frequency filter) and (c) residual interannual variability. Data from O. Ndiaye

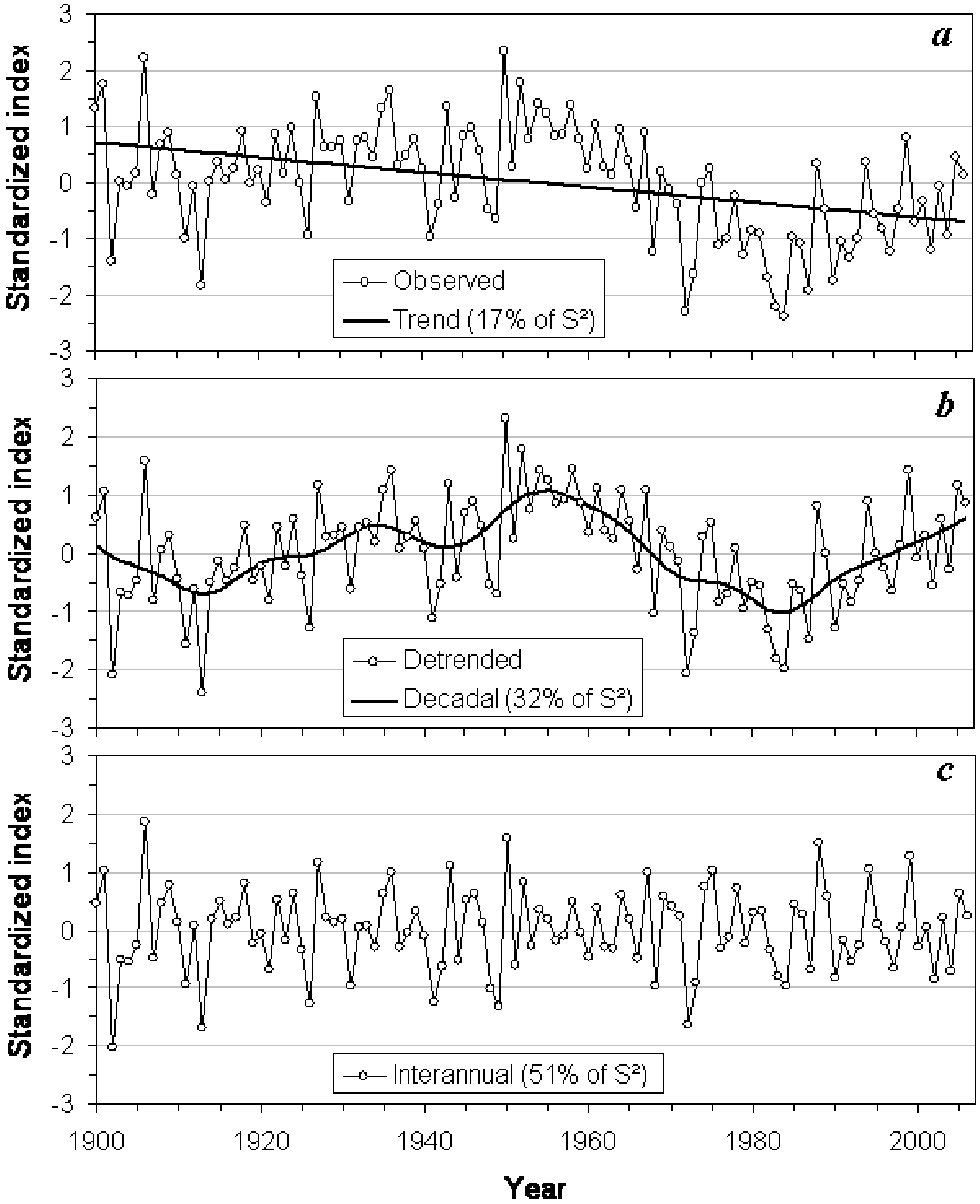

Figure 2. Idealized representation of impact of climatic risk associated with different portions of the distribution of some climate-sensitive outcome

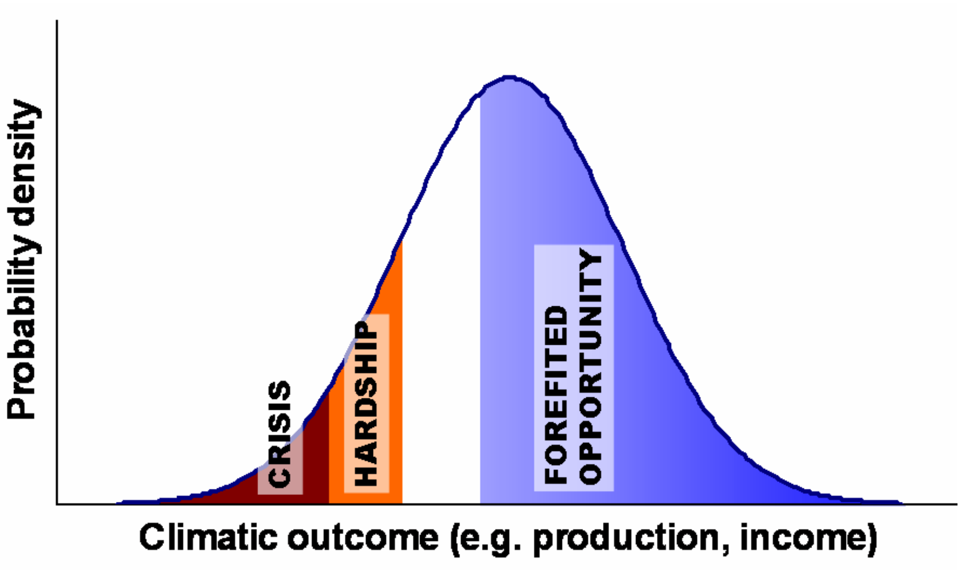

Figure 3. Greater Horn of Africa Climate Outlook Forum (GHACOF) consensus climate outlook for September to December 2007. Source: ICPAC

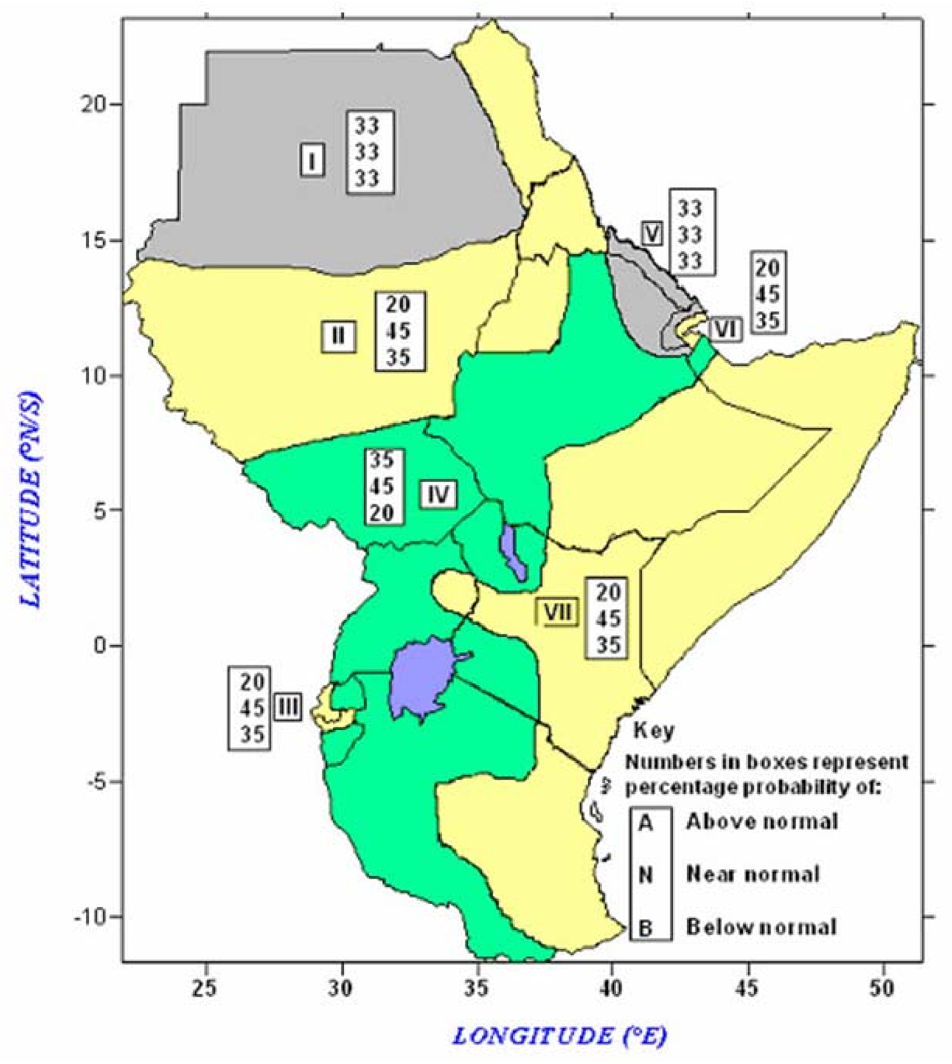

Figure 4. Downscaled forecast of 2004 October-December rainfall total (a, b) and frequency (c, d) for Katumani, Kenya, presented to farmers in August 2004

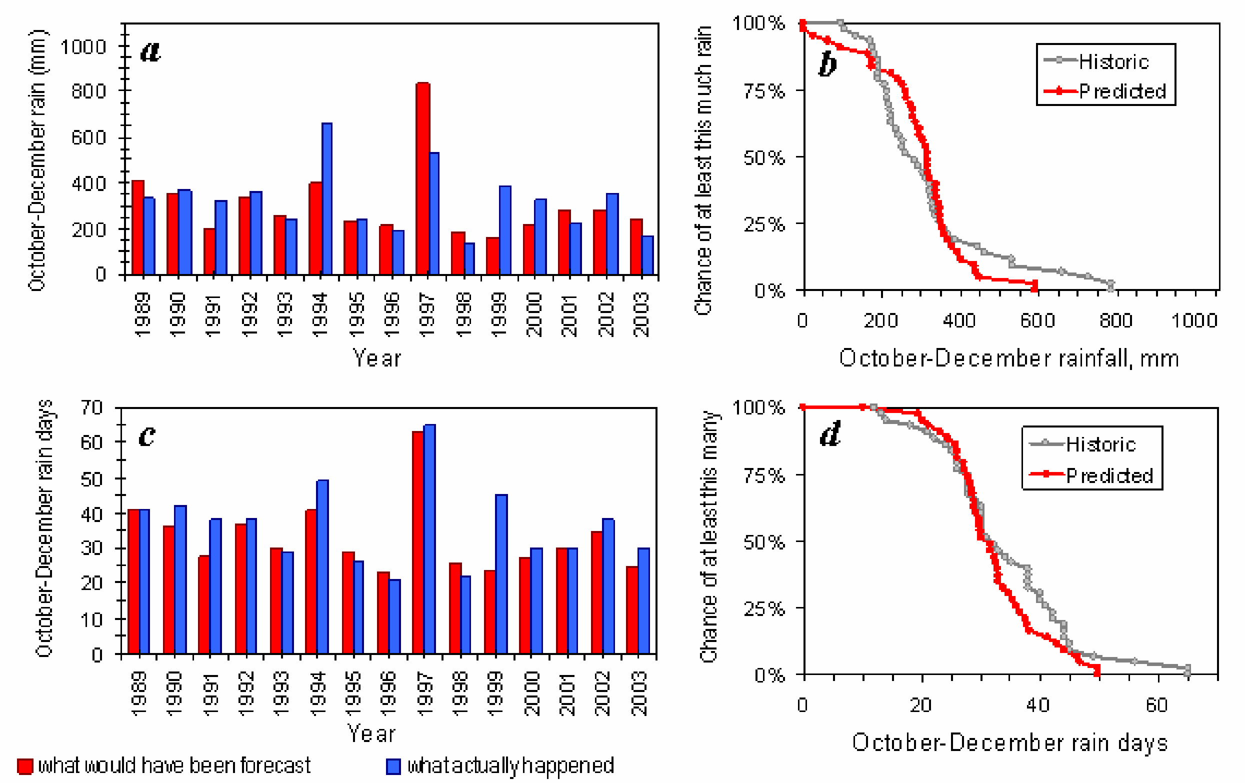

Figure 5: Satellite image from the TERRA-MODIS sensor as provided via the IRI data library showing in green the presence of vegetation along the Red Sea coast in Eritrea (February 2007). Subsequently FAO sent an alert showing the presence of Locust and possible migrations to surrounding countries

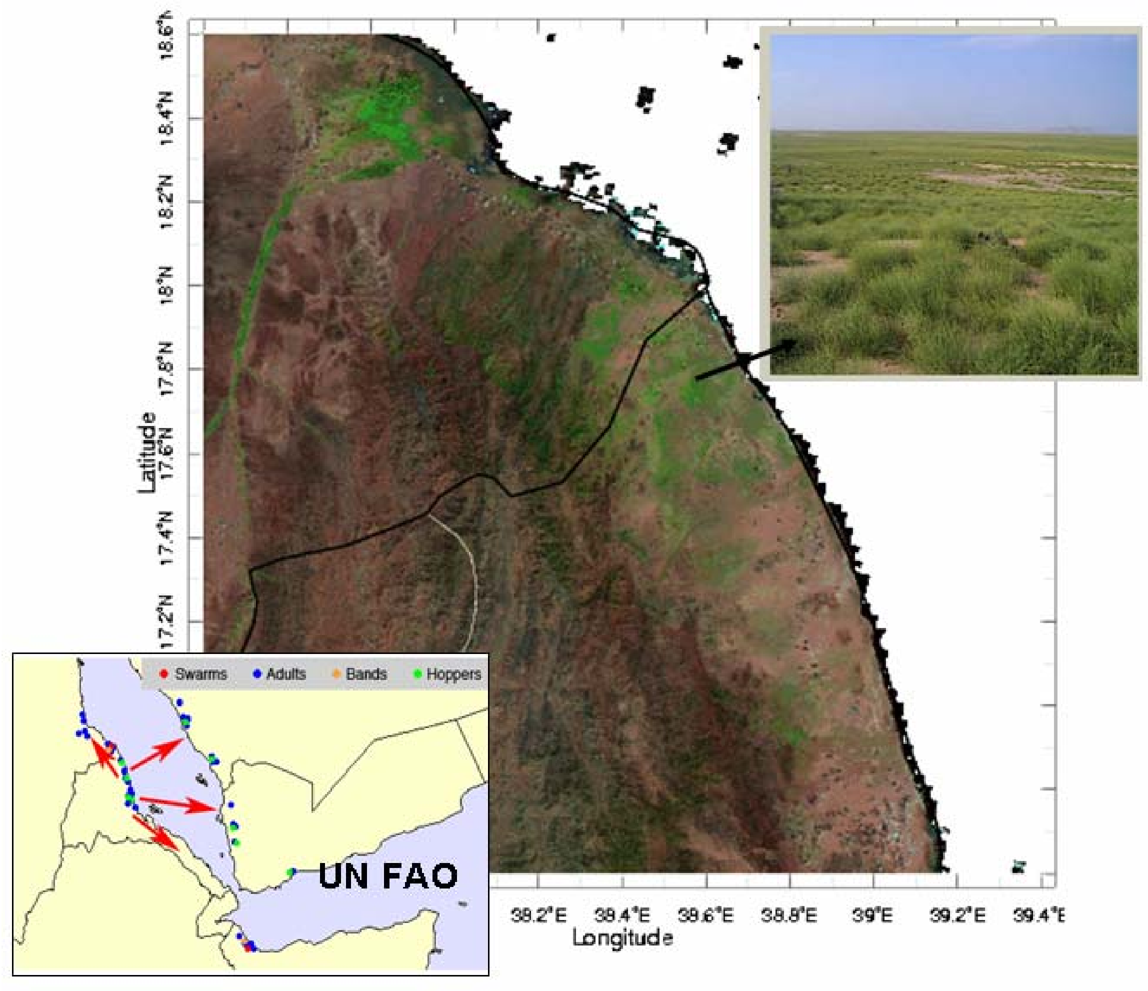

Figure 6. Representation of a livelihood system with three dynamic equilibria, one above a standard poverty line and one at the extreme of death or permanent destitution. After Barrett 2007b