Cross-scale interactions- Yet a challenge in vulnerability and adaptation analysis!

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Abstract

Vulnerability assessments performed for long term environmental changes in the global, sub global, national or local level regularly employ up-scaling and down-scaling of information. Such techniques do not always account for the interplay of the factors across the levels in different scales. As a result, the current studies may give an incomplete understanding of the dynamics of a complex adaptive system (CAS) that is responsible for shaping its vulnerability to a risk. This working paper is an attempt to understand the concepts of dynamic complexity in a CAS and reasons for complementarity and contrast when observed through different scales of analysis. Through a literature survey we arrive at a point that there is no single solution in scientific studies or management approaches for understanding and solving systemic problems in a CAS like socio-ecological system (SES). This leads us to look towards approaches that facilitate learning from different understandings of the same problem and negotiation among groups with different viewpoints. Finally, a case of an agro-ecosystem in the Brahmaputra basin in India is cited to illustrate such complexity and problems for decision making for adaptation. We pose three research questions-

- How can we have an integrated model of the causal mechanisms that lead to an irreversible change in a multilevel SES?
- How do we form an appropriate and acceptable strategy for adaptation when the state of a system changes?
- What is the appropriate form of governance which can maintain the ecological resilience for adaptation during periods of environmental change?

Introduction

The necessity for decision makers, to design adaptive strategies in tandem with emerging risks of long term environmental change and implementation of such decisions for purposeful adaptation of communities, has been felt (Adger et al., 2005). However, the quality and acceptance of such intervention will both depend on how well the strategies match with the scales of the problems, which is often perceived to be either in the level of the drivers of change of any resource or the resource users (Adger, 2001). Design of such strategies is often influenced by discourses from different world views through which experts perceive the inherent causes of vulnerability in any system (Adger et al., 2001). Such world views can dictate particular scales of analysis to understand a problem, and also form different perspectives for policy intervention. As a result, the choice for a particular design process can be a political one and may not match with the real world problem (Stephen and Downing, 2001, Stephen, 2004). The quality and acceptance for implementation of such strategies remain questionable, as they lack a holistic understanding of the vulnerability of a system, and itself remain vulnerable to sabotage by proponents of other world-views (Verweij et al., 2006).

Local communities, apart from the impacts of climate variability over their sources of livelihood and natural resources, face risks from multiple drivers like public policy or market shock at any given time. They devise their own coping mechanisms based on their perceptions of risk and culture which again are constrained by a plethora of socio-economic and political factors from higher levels. However such local responses can spread to distant locations and form sources of systemic change, if provided with an appropriate window of opportunity (Eakin et al., 2008, Gunderson and Holling, 2001). Hence, a lack or even a partial understanding of the dynamic complexity of a system at risk, may lead to inappropriate interventions, which may themselves become sources of risk.

The success of the design and implementation of adaptive strategies will depend on the understanding of the causal mechanisms of inherent vulnerability of any system at risk, its response feedbacks and how best the strategy can match the local perceptions of the problem with the analytical perspectives. Thus this calls for an analysis of the implicit scale related problems in each step of the design process to secure the broader goals of effectiveness, efficiency, equity and legitimacy in decisions for adaptation to systemic changes (Adger, 2005).

This working paper is an attempt to understand the concepts of dynamic complexity in a system and reasons for complementarity and contrast when observed through different scales of analysis. Through a literature survey we arrive at a point that there is no single solution in scientific studies or management approaches for understanding and solving systemic problems. This leads us to look towards approaches that facilitate learning from different understandings of the same problem and negotiation among groups with different viewpoints. Finally, a case of an agro-ecosystem in the Brahmaputra basin in India is cited to illustrate such complexity and problems for decision making for adaptation. We hypothesize that the problem calls for an understanding of the linkages between risks-outcomes and responses in multiple levels of the system for the appropriate design of adaptive strategy.

1. Research Issue

In adaptation to climate change phenomenon, major research efforts have been made on guiding policy intervention to regions and sectors of relatively higher vulnerability and low adaptive capacity, cost-benefit analysis of planned adaptation options and mainstreaming adaptation into existing policies. The analysis of vulnerability and adaptation to the impacts of long term environment change phenomenon like climate change encounters a high degree of uncertainty. The complex relations and time delays between the drivers of change, their impacts and corresponding responses makes it difficult to construct any causality chain for a predicted outcome (Patt et al, 2005). Therefore majority of the frameworks for vulnerability assessment focus on a particular system of concern (which can be a natural system, social-ecological system or region or community, etc.), a hazard or hazards (referred to as external stressor/s to the system of concern), specific variables of the vulnerable system and a time period of interest (Fussel, 2005).

The Intergovernmental Panel for Climate Change (IPCC) defines vulnerability as-

The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed[i]*, its sensitivity*[ii] *and its adaptive capacity*[iii](IPCC, 2007).

The definition sends a strong message that both socio-economic and natural systems are important subjects of analysis (Adger, 1996). But there is still a dilemma as to what should be the appropriate scale of analysis so as to match the scale of assessment with the scale of management. National and regional scale studies are cost effective and often aid into decision making but can mask local variations and priorities whereas local level assessments can provide an understanding of the coping mechanisms and perceptions of risk, but again can incur a huge expenditure. Besides, transferability of the local approach to another scale or different region incurs loss of information and suffers from the limitation of data availability (Fekette, et al, 2009, Stephen, 2004). In order to alleviate this scale discordance problem (Cash and Moser, 2000), assessment is performed for particular scales of analysis which often, are prescribed by the discourses followed by and needs of client/funding organizations (Stephen, 2004, Stephen and Downing, 2001). For example, national and regional scale assessments which rely on composite index construction for relative scoring of vulnerability are preferred by policy makers to identify target sectors or groups for intervention and/or fund allocation (Stephen, 2004). On the other hand, a local level case study approach is sought by community based organizations and aid organizations like Red Cross which are interested with the underlying causes of vulnerability and process of implementation of adaptive strategies among communities (Alast et al.,2007).

1.1 Index construction

The aim of vulnerability index construction is to demonstrate the variance in distribution of risks among sectors, social groups or places. This is achieved by assigning relative vulnerability scores by measuring variables selected on the basis of deductive criteria and preparing indices of exposure, sensitivity and adaptive capacity. The application of such an analysis is to focus adaptation intervention to area or social groups with highest exposure/sensitivity and least adaptive capacity. Such efforts evolved from a generation of impacts centric analysis for climate change, became more focused on decisions for adaptation rather than mitigation, as they considered vulnerability as an existing characteristic of any society only to be altered to varying degrees by impacts of a global change phenomenon (Burton et al, 2002, Obrien et al., 2004a, Smit and Wandel, 2006, Adger, 2006, Fussel and Klein, 2005). Although, there is an understanding of the dynamic property of vulnerability (Alwang et al, 2001) and there have been attempts to incorporate it in such an analysis through choice of appropriate indicators (Adger, 1999, Leichenko and Obrien, 2001) and GIS mapping (Obrien et al., 2004b), the approach has not demonstrated any study of the linkages between risk-outcomes and responses at different scales which are responsible for the dynamics within a system (Eakin and Luers, 2006). It leaves behind the process of policy and decision making as a passive part, under the assumption that the vulnerability ranking within the system of analysis will direct attention to the elements of highest vulnerability and lowest adaptive capacity (Smit and Wandel, 2006).

1.2 Case study approach

In order to make the analysis of vulnerability and adaptive capacity more grounded, a case study approach in local level is also undertaken. Such studies try to understand the sources of risk for a community, the causes of vulnerability to such risks and also investigate adaptive needs by involving participatory techniques like participant observation and consultation with stakeholders rather than depending on a-priori selected list of variables. The focus of such an approach is to document the experience of change conditions in the system and investigate emergence of means of improving adaptive capacity within the decision making process of the system or how best it can accommodate designed adaptive strategies. For analysis of vulnerability to long term environmental change, current vulnerability to risks identified by the community is first documented, followed by assessing future vulnerability to climate risks based on predictions of the IPCC. The investigation also tries to gain insights on constraints and opportunities to long term adaptation by structuring interviews on community behavior and means of management of resources under changed conditions. Such an approach recognizes adaptation as a continuous process and the difficulty of designing any strategy for a single stressor like climate change. It recommends for mainstreaming or incorporating adaptive strategies into ongoing development policies for achieving the goal of sustainability (Young et al., 2010, Smit and Wandel, 2006, Aalst et al., 2007, Ford and Smit, 2004, Keskitalo, 2004, Morduch and Sharma, 2002, Smith, 2000). However, a methodological challenge still remains as how to integrate information from secondary sources as that of climate change information (Aalst et al., 2007) as down-scaling of climate information may not be precise (Burton et al, 2002) and even not possible to local levels like a village. Moreover the studies based on such approach are not designed to be scaled up to give information on aggregate vulnerability or adaptive capacity of a region or nation (Smit and Wandel, 2006).

1.3 Influence of cross-scale dynamics- Yet a challenge!

Up-scaling or downscaling of information is often used for index construction or for framing climate risks in local level studies using techniques of statistics, geographic information system (GIS) and/or climate modeling. As observed from ongoing research in global changes, such methods may not always map processes or causal relationships correctly across scales (Root and Schneider, 1995, Robinson, 2009, Fekette, 2009). Such a methodological challenge occurs due to the non-linearity in the processes, presence of heterogeneity, dominance of different processes at different scales, cross-scale interactions and property of emergence or self organization in any system (Peterson, 2000, Gibson et al., 2000). However, apart from the differential and dynamic character of vulnerability, there is also an understanding of the scale-dependent characteristic of vulnerability. The outcome of any vulnerability assessment depends on the chosen scale of analysis, generalizations from aggregated scores at broader scales like a region or nation may mask process at finer scales like a village (Birkmann, 2006, Obrien, 2004b). Hence, multi-scale approaches have been attempted which tend to first find zones of high vulnerability in national, regional or sub-national scale and then try to "ground truth" or validate the findings by case studies in the local level of these high vulnerability zones (Obrien et al.,2004a, Fekette et al., 2009). But cross-scale interactions, the influence of processes that interact between levels in different scales, on the dynamics of human vulnerability yet remains to be incorporated in the analysis (Fekete et al, 2009). A neglect of these interactions which are the key for maintenance of organization within any system, its disruption and emergence of a new form of organization (Peterson, 2000), will give an incomplete understanding of the dynamics of vulnerability and hence lead to inappropriate decisions for adaptation.

The inseparability of multiple drivers of exposure and sensitivity and lack of recognition of the feedbacks from the adaptive responses at different spatial and temporal scale adds to the uncertainty in vulnerability assessments (Eakin and Luers, 2006). However, there is a growing theoretical and empirical understanding that the vulnerability of a system is driven by the dynamics of non linear interactions between human activity and processes of environmental change within and across scales (Holling et al., 2002, Eakin et al., 2008, Adger, 2009). The sustainability framework of Research and Assessment Systems for Sustainability Program provides us with an opportunity to analyze the dynamic linkages between sources of risk, outcomes and responses in multiple scales (spatiotemporal as well as functional) by observing any context as a coupled human-environment system. Although it guides towards a grounded approach by focusing on particular place, it still recommends for incorporating local to global linkages both in social and environmental domains (Turner et al., 2003a, Turner et al., 2003b). Such an approach may not be useful to analyze present or future impacts on a system or identify vulnerable elements but can be helpful in illustrating the processes within and across different scales that shape vulnerable conditions (Eakin and Luers, 2006). However, it remains silent on any analytical approach to be taken for empirical study or provides no respite from the methodological challenges associated in incorporating cross-scale interplay.

In order to explore into this research issue, in the next section we first attempt to understand the concept of a coupled system, level, scale and its related dynamics .

2. Understanding organization and its dynamics in Complex Adaptive System

2.1 Complex adaptive system

A coupled human-environment system or social-ecological system (SES), a space of continuous interactions among organizations of society and ecology for resource use, is essentially a complex adaptive system (CAS) (Janssen and Ostrom, 2006). CASs like an immune system, political party, ecosystem or society are complex as they comprise of a network of multiple agents or elements working in parallel, self organized as coherent behavior emerges by competition and co-operation among agents, hierarchal as they are organized into successive levels with agents at one level as building blocks for agents at a higher level, adaptive as they can revise and re-arrange the building blocks with experience, anticipatory as they can predict on the basis of assumptions and always in transition between different states due to scope of perpetual novelty (Waldrop, 1993, pp 145-147). The elements in a CAS continuously interact with each other to form a complex structure that again dictates or constrains the type of interactions among its elements. For example, atoms search for a minimum energy state by forming chemical bonds with each other and thereby leading the way to form emergent structures named molecules, organisms co-operate and compete with each other while co-evolving with nature to form ecosystems, human beings try to satisfy their material needs by buying, selling and trading and leading to growth of markets. However, such an order in CAS is not fixed; it can occasionally be disrupted only to give way to new order to fit better with changed conditions (Waldrop, 1993, pp 288-294). The understanding of the hierarchal organization of the elements and their interaction within and across levels is central to the notion of vulnerability to change within a CAS (Holling, 2002).

2.2 Hierarchy and nestedness

A hierarchal organization emerges as it offers more stability against disturbances to a system. Under favorable conditions, patterns emerge in slower and larger levels out of spatial and temporal interactions of structures and processes functioning in lower levels. These patterns can in turn interact with other higher level processes and patterns and form nested hierarchies (Peterson, 2000). In order to detect these patterns and their interactions within nested hierarchies, the concept of scale is crucial. For instance, if we take the classic example of boreal forest system, then at the level of patches in a spatial scale of 0.01 to 0.03 kilometers (kms.) and temporal scale of 10 to 1000 years, trees interact to shape fuel accumulation in the level of tree stands in a spatial level of 0.03 to 1 km and temporal scale of 10 to 100 years. It is at this level that large scale processes like fire interacts with the fuel accumulation to produce stand replacing forest fires. The pattern of forest stands, in the level of landscape at a spatial scale of 1 to 100kms and temporal scale of 100 to 100 years, again influences large scale processes like weather and foraging which again shapes forest at zone level which can be detected at yet higher spatial and temporal scale i.e. 100 to greater than 3000kms and 1000 to 10,000 years respectively (Holling, 1992, Peterson, 2000). Examples of emergence through interactions among nested hierarchies can also be found in coupled human-environment system. At the scale of ecology, a species similar to human SARS is found in the level of masked civet cats and also raccoon dogs. Due to interaction of humans engaged in wildlife trade, the virus jumped the species level and effected individuals who handled live animals. Soon, through flows of resources and people in global commodity chains, SARS spread from Guangdon Province in China to world over causing the emergence of an epidemic in southeast Asia and produced a risk world over in 2003 (Adger, et al., 2009). Thus, different processes interact with emerging structures in different spatial and temporal scales to provide an order in the system.

2.3 Dynamics in hierarchy

However, such hierarchal organization is dynamic and there is always chance for a particular order of a CAS to be disrupted to give way to a new order. We can again take the example of forest stand to understand such dynamics. A young forest stand becomes denser as it grows gradually, accumulates fuel and becomes vulnerable to fire. After a fire event, the stand is re-organized as new plants germinate from roots or seeds, thereby giving way to new forest stand. In such a dynamic scenario, we often see systems fluctuating between emergent patterns or stability states owing to the diversity in interactions among the structures and processes along spatial and temporal scale. As fire, outbreak of spruce budworm is a natural phenomenon of renewal of forest in eastern Canada and the United states. In this example two stability states exist, one is with low budworm population and other is with high budworm population. As the tree stands are young, the density of budworm feeding on them is low enough to maintain equilibrium with its own avian predation. However, as the stands mature and gain more foliage, the density of budworm population increases such that is dilutes the effectiveness of budworm predation by insectivorous birds. Thus, the stability collapses and an insect outbreak is released which ushers a new state (Holling and Gunderson, 2002, pp 30). Similar dynamics can also be assumed in human management systems like bureaucracy. Gunderson et al. (2002) provides the example of the Corps of Engineers and South Florida Water Management District in United States. Generally these organizations spend time and resources in implementing public policies and monitoring key indicators in ecosystem. But during a natural crisis, any activist or group would criticize the policies claiming them to be no longer practical. This would trigger engagement of temporary groups outside the bureaucratic system which design alternative policies for the decision makers. In this case the activists can be compared to be the spruce budworm of management institutions and the temporary groups providing alternative futures (Gunderson et al., 2002, pp 327).

2.4 Adaptive cycle and resilience within

This dynamics or shift between stability states is explained by the adaptive cycle metaphor which describes how systems shift between 4 phases namely; exploitation, conservation, release and reorganization (see Annexure 1). The reorganization to a stable state however depends on the resilience of the system, which in turn dictates the vulnerability to shift to an altered state. Resilience is a dynamic property which changes as the system traverses through its adaptive cycle. Minimum resilience is during the phase of high connectedness as capital in any system grows from exploitation to conservation phase and maximum when there is release of capital followed by system reorganization. The latter is the phase of low connectivity among structural and process variables and novel entrants, like mutant species in an ecosystem or innovations in markets, which accumulate but are, kept out from expressing themselves during growth get a chance to compete with left overs of previous cycles like elements of matured forest or established markets. New interactions can be triggered while resilience is high during reorganization which will help the system adapt and remain functional in an altered environment. Such interactions, like that of a meeting of some entrepreneurs under a conducive market environment may lead to implementation of a new idea or association of migrant populations of different species which took place during the retreat of ice sheets may have led to emergence of ecosystems as we observe today. Thus the diversity or heterogeneity in a system can organize and reorganize in different ways to adapt to changing environment (Holling and Gunderson, 2002, pp 40-48).

2.5 Nested cycles

The understanding of the dynamics of emerging pattern will be incomplete without special reference to the interactions between different adaptive cycles. If we refer back to the example of Boreal forest, Holling in his classic work on nested cycles analyzes the levels within the forest system as adaptive cycles, with each level going through its own phases of birth, growth, death and renewal (as explained by 4phases of adaptive cycle). At relatively faster and smaller scales, as that in the level of patch, the structures are mediated by biophysical processes of interspecies plant competition for nutrients, light and water which influences local species composition and regeneration. At the meso-level of tree stands, disturbances like processes of fire, storm, insect outbreak and mammalian herbivory influence structure and successional dyanamics. At even larger and slower scales, as that of landscape, climate, biogeographical and geomorphological changes alter ecological structures (Holling et al., 2002, pp 69, Holling, 1992). In the same way, key variables of a human disease system like the disease organism, vectors and their susceptibles and human population can also be understood to be operating in three different levels with three different speeds i.e. fast, intermediate and slow (Holling et al., pp 69, MacDonald, 1973), to which we can also assume three different spatial attributes considering our previous example of SARS (Adger, 2009). But, it is the interaction among the adaptive cycles in different levels operating at different scales, which hold the key for understanding the dynamic features of hierarchal organization.

2.6 Panarchy

The Hierarchy theory explains that hierarchies are not static but the individual levels are transient structures maintained by interaction of processes across scales (Allen and Starr, 1982). However, the theory explains only one asymmetry of interaction between levels, i.e. of larger, slower levels constraining the behavior of faster, smaller levels which would again lead to the assumption of hierarchal organizations to be static without the possibility of novelty in the system. Although it is true, such that tree stands moderate the climate within the stand to narrow the range of temperature variation for individuals within it, but it is partial as it ignores the dynamics phase transitions in each level. As explained earlier, there is scope of re-organization in adaptive cycles of each level and novel associations among fresh entrants can lead to alternate states. There can be multiples connections among the nested cycles, each moving in different spatial and temporal scale and hence the terminology explaining it has evolved from that of hierarchy, often confused with top down control, to that of Panarchy after the Greek god Pan which symbolizes pervasive control of nature and also frequent disruptions of organization as reproduced in the word panic (Holling et al., 2002, pp 72-74) (see Annexure 2).

2.7 Cross scale interactions within a panarchy

In a panarchial system, out of all the connections between the phases of levels moving in different scales, two most important for maintaining the resilience of the system, are termed to be “Remember and Revolt”. “Revolt” is an upward moving disturbance from fast and smaller levels to slower and larger levels whereas “Remember” is a constraint from the latter to the former.

“Revolt” can happen when a level in a panarchy enters the release phase and tries to re-organize in uncertain ways. A collapse of any level can cascade up to next higher level and pose a risk of collapse of the entire panarchy if the higher level is in its matured growth phase and has lost its flexibility. An ecological example of “Revolt” can be fire events which start from a small ground fire triggered by conditions of local ignition and spread to crown of a tree to patches in the forest (Holling et al., 2002, pp 75-76). Socio-political examples can be of political uprisings like that of Sepoy Mutiny in colonial India of 1857 which started in a Military cantonment in a place named Meerut, in north Indian state of Uttar Pradesh and had spread to different parts of the country. It is regarded as the First Battle of Indian Independence by historians and had led to change of political authority of the country from the East India Company to the British Crown (Bayly, 1998). “Remember” in contrast is a connection in the opposite direction and is important during times of change and renewal. Once a collapse like situation is triggered in any of the levels in the panarchy, stored capital of a higher level in matured stage is drawn upon for reorganization of the lower level (Holling, et al., 2002, pp 76). This capital can be in the form of institutional memory (Berkes and Folke, 2002) or seed banks and surviving species accumulated during the growth phase, which help in the survival of a community (Fekette, 2009) during natural hazard or revival of a forest patch (Holling, et al., 2002, pp 76).

2.8 Resilience and its perspectives

Resilience, as described here, recognizes presence of multiple equilibrium or stability states and surprise events of change phenomena. It is defined as the magnitude of a disturbance that triggers a shift between alternative states. However it is mostly a perspective of ecological resilience, which suggests that it is an inherent adaptive property of a system which allows its fundamental function to persist even in times of extremes and disturbance. There also exists an engineering perspective of resilience, which defines it as rate of speed of recovery of a system following a disturbance or shock. It assumes the presence of a single equilibrium and describes systems behavior as one that resists departure from a particular stable state. Thus, ecological resilience focuses on the role of positive feedbacks, its ability to push system behavior away from any stable state and diversity generated within the system. On the other hand, engineering resilience stresses on negative feedbacks that reinforce stability by bringing it back to a single stable state and predictability of system behavior. Thus engineering resilience, which is generally concerned with mathematical representation of a recovery time of a system to its equilibrium, is more applicable to a linear system or when a non-linear system is nearing one of its equilibrium states. There is a tendency, among scientists or decision makers subscribing to this perspective, to concentrate only with one or a small group of variables (a-priori selected) and their scales of analysis or management are also often too narrow to witness the interactions of variables moving with different speeds (Gunderson and Allen, 2010, Allen et al., 2010).

The marked differences among the two perspectives also signify the difference in knowledge traditions and management approaches. The ecological perspective is more often used by scientists, with a biological tradition, who build up their research on empirical observations and try to integrate science with policy and management. On the contrary, engineering resilience is subscribed by scientists, within engineering and applied mathematics tradition, following mostly a deductive approach. The difference in management approaches renders from the difference in treatment of uncertainty within the two perspectives. The followers of engineering perspective rely on the predictability of the system by trying to control the disturbance events and optimize the conditions for only those interactions that lead to growth of resources (eg. fishes in a fishery or tress in forest) in the system which can meet with a social, economic or engineering objective. By increasing homogeneity, it reduces the functional diversity of a system, which is seen as the key to maintain its adaptive capacity. By controlling disturbance events like fire or insect outbreaks in a forest system, it inhibits the structuring processes that could usher novelty into the system and keep it adaptive to any external change, it makes the system vulnerable to an irreversible change (Holling, 1996). An example is of the suppression of spruce budworm populations in Canada during the 1950s and 1960s. In order to preserve the pulp and paper industry, insecticides were used which reduced the defoliation by the insect and hence tree mortality was delayed. This led to growth of pulp mills, and at the same time left the economy vulnerable to a sever downfall owing to the rising vulnerability of the forest to an intense outbreak due to rise in the homogeneity of the foliage. This again demanded more vigilance and control over the forest resources by the management institutions (Holling, 1996, p 59).

Thus, trying to engineer the system to maintain a particular equilibrium or stable state may lead to less resilient and more vulnerable ecosystem, rigid and unresponsive management institutions and more dependent societies. Holling (1996) provides evidence for the hypothesis of loss of variability to loss of resilience from biological system. Ectotherms i.e. cold blooded animals have a higher range of viable internal body temperature as compared to water ectotherms or even more in case of endotherms i.e. warm blooded animals which regulate their body temperature to a narrow range. Although such regulation seems to render endotherms vulnerable but they have a range of mechanisms to control temperature which can extend from evaporative cooling to metabolic heat generation. Each mechanism has different but again overlapping range of conditions and different efficiencies for response. It this overlapping “soft” redundancy that marks the difference between regulation of biological systems and those proposed by engineering resilience paradigm. Even examples from ecosystems can provide the importance of role of such redundancy in maintaining consistency. Holling, once again returns to his example of predation of spruce budworm in the forests of eastern Canada. He observed that some species of insectivorous birds predate moderately over a broad range of prey densities, while some other species predate heavily over narrow ranges of prey density while there are some which maintain their predation between high and low. The density at which predation impact is maximal also differs according to species. Through intra-species completion, the aggregate predation effect is kept low when there are large numbers of predator and very less prey whereas it increases with the reverse condition. Thus it seen that the risks and benefits are widely spread to retain consistency in performance irrespective of the fluctuations in individual species. This, Holling explains as the "heart of role of functional diversity" in maintain ecosystem structure and function (Holling, 1996, pp 61-62).

Another important feature in natural systems that is important for its consistency is the tendency to function at the edge of instability i.e. at the boundary of a stable state. Holling, once again cites the example of endotherms, which can maintain high body temperature, at the edge of one of their stability domain i.e. life itself. Speed and stamina increase and endotherms can maintain activities at both high and low temperatures and exist in habitats unbearable for ectotherms. Thus here we can see that variability is not eliminated but curtailed at one place and transferred from animal's internal environment to external environment as a result of allowing the animal to explore for opportunity and change. Inferences from such examples from nature suggest that control of internal dynamics at the edge of instability generates options for exploration into uncertainty of the external world. Although of controlling is part and parcel of engineering resilience, the creation of opportunities at the edge of stability is a component to be pondered upon (Holling, 1996, pp 62-63).

Thus, management practices have to see beyond their scales of operation and the strategies will have to designed not so much for maximizing productivity but for the interrelationship between people and resources such that they can be sustained in times of crisis and "surprises". Thus ecological resilience paradigm calls for integration of sciences, knowledge at different levels and public participation for exploring alternative futures. However, movement towards such a paradigm is only seen when the very goal maintained by rigid institutions is abandoned. Holling (1996) cites the example of control of budworm and growth of pulp industry in New Brunswick in Canada. The rigid control gave off when a forest inventory report indicated insufficiency of wood stock to sustain the industry in future which ushered new laws of restructuring management policies and created opportunity for local industries for innovation (Holling, 1996, pp 64-65).

However, such management practices can be sustained only when there is ecological resilience as well as trust on the management (Holling, 1996) which again illustrates the importance of design and acceptance of adaptive strategies after a crisis.

3. Concept and challenge of Scale

We have already used the term scale and level while describing hierarchy and its dynamics in a system. In this section, we try to understand them as concepts that are referred in different literature and point out the challenges that the uses of these concepts pose for scientific analysis or assessments and decision making.

3.1 Scale of analysis versus scale of phenomenon

In order to observe and analyze the patterns emerging out of different interactions among structures and processes, different scales are used. Accordingly, scale is defined as the spatial, temporal and analytical dimensions used by scientists to measure and analyze objects and processes (Gibson, 2000, Fekete, 2009). Gibson describes levels as distinct regions in a measurement scale, as Macro, Meso and Micro are levels in spatial scale describing large, intermediate and small size phenomena or long, medium and short durations are levels in temporal scale representing relatively slow, intermediate and fast processes. Every scale incorporates an extent which is described as the magnitude of dimension used to measure a phenomenon, and a resolution which refers to the precision of the measurement (Gibson, 2000). A social scientist may fix his extent to the level of a village and use a resolution of households in a jurisdictional scale. The Millennium Ecosystem Assessment (MEA) (2003) explains that a level of an organization (as described in this text) is not equivalent to a scale, but can be measured or analyzed through a scale. It further differentiates scale into a unit of observation of a process and an intrinsic characteristic of a process. The former i.e. scale of observation (referred as scale of analysis in this paper) has been described as a "filter or window of perception" through which assessments can be conducted, observations can be made and information and knowledge acquired. Through this description, it can be imagined that patterns observed through the scale of observation of a watershed will be different as through an ecological zone, as both are different levels of an agro-ecosystem (Dalgard et al., 2003), each in its own dynamics. However, MEA differentiates the scale of phenomenon as the extent or duration of any social or ecological process, defined as its "characteristic scale", for example change events like El Nino have a characteristic return time. Therefore we can assume an incomplete or total lack of understanding if the scale of observation/analysis does not match with the characteristic scale of any phenomenon or process (MEA, 2003). In order to simplify, Fekete et al. (2009), attempts to connect this scale of phenomenon with magnitude, amplitude or extent as used in common English while renaming 'extent' of any spatial, temporal or analytical scale as a "Research Area" and resolution in it as "Units".

Hierarchies and associated dynamics, as explained here, exist in all complex systems ranging from cells and ecosystems to social systems (Gibson, et al., 2000, Westley et al., 2002). In order to grasp the emergent patterns of such dynamics, there is a need to incorporate conceptual scales apart from spatial and temporal scales in any framework for scientific analysis. Westley et al. (2002) explains that the sense making behavior of humans lead to abstraction which facilitates their organization according to paradigms or "structures of signification" (Westley et al., 2002, Westley, 1995). The systems created through their sense making consist of their own levels which may or may not match with the levels in the real world (Westley et al., 2002). Such social systems can be institutions of culture or decision making, which emerge out of interactions among reflexive human beings. Thus there have been attempts to dissect abstract systems of power (Lukes, 1973) economy (Whitaker, 1987) and society (Westley, 1995) into distinct conceptual levels on the basis of functional relationships (Gibson et al., 2000). Due to this buffer between the real world and the systems created by human ingenuity, there is always scope for mismatch between scales of human actions, social structure and ecological systems which can lead to incomplete understanding of the real world and also inappropriate and unacceptable decisions (Mclaughlin and Dietz., 2008).

3.2 Challenges of scale

Willibanks and Kates (1999) explains that even if we ignore the fact that different processes operate in different scales, still our understanding of the world is influenced by scale. In the context of global change, they describe how complex relations among society, economy and environment can be persuaded in local level studies with smaller resolutions as they bring out the entire variance without being masked by generalizations in broader scales. They also point out how perspectives vary over a problem when observed through different scales of analysis, due to identification of different patterns of same problem. They cited the example of the problem of cost of energy efficiency improvement, where macro scale economics suggested a significant net cost to national economy in United States of America while micro scale work of many regions within the same country often estimated a net benefit (Willibanks and Kates, 1999).

Problems of scale mismatch may arise when a particular problem is known only at a certain level while the decision for intervention has to be taken at different level. This challenge is termed as the “scale discordance” problem and the glaring example can be of climate change studies. In this case, information is often sought at lower levels of jurisdiction like nation or states by decision makers for understanding impacts and planning for adaptive strategies, while predictions from climate models increasingly lose their precision at lower scales of analysis. Scale mismatch is also evident when a level of decision making in a jurisdictional or any other management scale does not match with the extent (also “characteristic scale” as in MEA, 2003) of a problem being faced. This challenge is termed as “institutional fit problem” and the best example can be of transboundary air or water pollution which is a problem in the basin level and is beyond the national level management of individual countries in the basin.

In the efforts to account for these mismatches, science and decision making often arrive at a particular scale of analysis and then up scale or down scale information for use at an agreed upon level. As mentioned before, reliance on such techniques may again lead to the ignorance of important cross scale interactions which are found to be crucial in maintenance of the system (Cash and Moser, 2000, Cash et al., 2006). In order to widen the knowledge base and distribute responsibility and power for better management of resources, co-management strategies are often recommended. It creates a scope for engagement and learning among institutions, operating in different spatial and management levels, as for example state and resource user committees However such approaches also have to deal with the “plurality” of outcomes due to different interactions within and across scales (Cash et al, 2006). Under such a management system, actors can associate in a myriad of ways within and across the levels of management according to their own perceptions of costs and benefits out of the collaborations. The different combinations of partnerships can give rise to different outcomes from the management regime which can again levy different costs and benefits on the actors (Adger, 2006).

3.3 The challenges- From a disciplinary approach

For a better understanding of the problems of global change, a need to integrate disciplines of social science with those of natural science has already been felt. But the conceptualization of scale always offers one of the primary challenges for the union of the sciences. Scale has always been the focus of any discipline when it comes to identification and explanation of emergent patterns, derivation of theory by generalization of pattern in one level observed through a particular scale to levels in different scales and optimization of processes in levels of interest. Physics with its theories of mechanics and ecology with its hierarchy theory have dealt intensively with the issue of scale and dynamics. However multiple interpretations of scale among disciplines of social sciences have inhibited its common understanding in social sciences, let alone between social and natural sciences. In varying versions of its extent component, scale finds its mention in levels of input-output in micro-economics, enterprises or households within an economy as in ecological economics, size of population, active labor force, number of households, value added to production processes within a territory and spatial area as in urban studies or explicitly as spatial scales as in physical geography (Gibson et al., 2000).

The relevance of cross level interactions across different scales has also been demonstrated in various disciplines. The most significant of them are in the macro-economics branch of economics discipline, political science, political economy and human geography branch of geography. In macroeconomics, Dasgupata (1997) has studied the influence of individual decision making by and to emergent features of society like cultural values or national income. He differentiates emergent features into fast moving variables like changes in national income and rate of inflation and slow moving variables like cultural values, norms or institutions. Many sociologists have also pointed towards the importance of interactions within levels in different spatial and temporal scales while understanding historical and social systems The study of federalism in political science points out the linkages in multiple tiers of a governance system which fall in different levels of a jurisdictional scale (Gibson et al., 2000). Much of the work on the process of diffusion of policy innovations and lobbying of networks of organizations at the same level for changes in a higher level addresses the horizontal and vertical linkages among levels in the governance system (Schreurs, 2008). In political economy, the social choice theory by Kenneth Arrow proves that it is impossible to scale up from an individual preference function to a group preference or public interest function which could satisfy a set of desirable properties of aggregation process. Similar work in this discipline suggests that in a situation of multiple policy choices, a common agenda is often accepted by domination of certain preferences (Gibson et al., 2000). Ellinor Ostrom's theory of collective action also points at a different set of criteria for optimal outcomes in a collective level as compared to an individual level in the scale of management of resources (Ostrom, 1990, Gibson et al., 2000). In human geography branch of geography, the issue of scaling spaces comes under the scanner as a political process between various mobilizing social groups in the local level and ideologies and social structures (Marston, 2000). Social groups may "jump scales" to form networks and use ideologies beyond their scale of operation for the representation of their causes (Jones, 1969). The point of consensus of these different conceptualizations lies in the need for multi level studies of any system by incorporating different scales of analysis and finding possible points for policy intervention in different levels for the same problem (Ostrom, 2010). However, a neglect of the plurality challenge of scale dynamics can lead to the wrong hypothesis of an existence of single solution of complex problems and ignorance of uncertainty in any scientific analysis (Ostrom, 2007).

3.4 Plurality of scale dynamics to plural ways of knowing

Human geographers question the process of shaping of scales in this world, which are otherwise treated as absolute by physical geography and also its related discipline of GIS. They regard scale as a social construct which emerges from a political struggle between structures of society and local action and is therefore a dynamic concept (Jones, 1969, Marston, 2000). This discipline tries to explain the shift of scales of the same space, as for example the shift of neighborhood scale to metropolitan scale of a city after it has gone through a process of urban planning. As urban planners introduced modern techniques like geometrical planning, zoning and social cartography to understand the city, the way of knowing the city was altered and a casual observation became trivial (Jones, 1969). Similarly, the way of knowing a particular problem i.e. the selection of a scale of analysis of a problem can depend on the power of a paradigm and/or on the interests of certain actors. Such politics in scaling is exemplified in selection of national scale analysis of vulnerability to food crisis in Ethiopia. National level had been selected as the scale of analysis as it helped the donors to channelize funds while also provided a scope for the decision makers of the country to attract funding by showing the required numbers (Stephen, 2004). In this regard, work in political economy also shows that politics arising out of plurality challenge of scale is not restricted to scales of analysis. It may also find its place in variable selection while analyzing any level and also in selection of actors for collaboration in networks for co-management (Adger et al., 2006, Ostrom, 2007).

Multiple outcomes may emerge due to combinations of different variables within and across levels in different scales (Ostrom, 2007). Therefore even in a multilevel study, there can be plurality in identification of emergent patterns due to selection of different variables in any level in a scale. This may lead to different interpretations of the same problem and hence different perspectives for problem solving. Ostrom explains that a reduced set of variables by Garett

Hardins in his classic study on common pool resources led to an incomplete understanding of commons management problem and finally recommend either a state or private intervention for saving “tragedy of commons” like scenarios. However, inclusions of variables like norms and social capital in the level of Users in an interlinked SES comprising of Resources system (eg. a pasture), Governance system (formal or informal governance actors), Resource units (eg. grazing animals) and Users (eg. herders) can change the outcome of such “social dilemma” and lead to an efficient and effective community management regime (Ostrom, 2007).

As mentioned before, similar to different outcomes in a scientific assessment by combining different variables, interactions of different actors across institutions in different levels of management can lead to emergence of different outcomes from co-management regimes. The differential access to information on resources by governance structures may create a power struggle among resource users bonded by social capital, to mobilize through horizontal linkages. Such mobilizations may find partners beyond a single community, and can also find collaborators in other levels of the co-management structures on the basis of commonality of interests, like media or Non- governmental organizations to rally for a change. But this is only one aspect; there can be interactions within levels which may benefit solely regulators, as for example workshops and forums between policy makers and scientists without leaving scope for inclusion or dissemination of knowledge in the level of resource users. Therefore the interplay of the associations between actors of same and different levels within and across scales can lead to variance in costs and benefits among actors and time (Adger et al., 2006). Therefore be it a multilevel study of a system or a co-management approach, it is difficult to find a “panacea” (Adger, 2006, Ostrom, 2007) for understanding and solving systemic problems like vulnerability to risks.

3.4 Search for a way, away from “Panaceas”

From the above discussion it is evident that there cannot be a single way of understanding and solving the problems shaped by cross scale linkages due to plurality in emergence and differences in methods of identification of patterns in a system. Challenges of scale have been dealt intensively in the discipline of ecology (Levin, 1992) from where theories of hierarchy and lately panarchy have been adopted as theoretical frameworks or paradigms to study social and socio-ecological systems (Peterson, 2000, Petrosillo et al., 2010). However, as Adger argues, issues of power are intrinsic to each level of any organization and cannot be studied merely by dissecting it as one of the subsystems of a bigger system. Power can be manifested while selecting any paradigm to frame a problem by a researcher or adhering to any ideology by a decision maker while designing response to a risk (Adger, 2006). Therefore, partitioning SESs into multiple levels according to a pre-decided criteria and analyzing the influence of linkages among the levels by any researcher can bring one close to a real system but again there is always scope for other versions of reality by use of different criteria (Checkland, 1985, Ostrom, 2007).

In this regard we can look towards soft systems approach which provides for means of group modeling and shared understanding of any systemic problem among researchers following different discourses and decision makers with different mindsets. It denotes the understanding of any problem in a system through paradigms and corresponding frameworks as systems of “logic” and differentiates it from the problem as seen in the context or empirically, which is again denoted as systems of “culture” (Checkland and Scholes, 1992). It tries to bring together the systems of “logic and culture” to give a wider understanding by the recognition of the diversity of factors involved in a problem. Such an approach offers an involvement of stakeholders in various levels of the system and hence a point of intervention can be sought through a negotiation process (Bayer, Vari and Thompson, 2006). Though, such an intervention may not be exactly the optimal for the system but it will have the acceptance of all the stakeholders which will in turn facilitate its implementation (Ostrom, 2010). Hence, any decision for intervention in a system reached through such a process is often referred as-“systemically desirable and culturally feasible” (Checkland and Scholes, 1992). However, this would require a thorough understanding of the challenges of group modeling methods, selection of discourses to fit systems of logic and the negotiation process before its use in looking into problems of vulnerability and adaptation to long term environmental change (Venix, 1996).

4. Risk of irreversible change in ecosystem to vulnerability of collapse of the SES – The logic of the problem

4.1 Novelty and collapse in panarchy

The seeds of change in any panarchial system lie in its nested cycles. The ushering in of novelty in any adaptive cycle can cascade upwards through the connected cycles and change the entire system as we knew it. Holling et al. (2002, p 89), citing the example of evolution from chimpanzee to humans as they share 98.4 percent of same DNA (Deoxyribonucleic acid), explain that such change is not the result of point mutations but rather the new combination resulting with the existing genes which can lead to new adaptive pathways for selection. Similarly, the industrial revolution in Europe was not due just due to invention of steam engine, but the socio-economic context of that era reinforced the novelty and led to a transformation of the system. However, evolution in ecosystems is a slow process as it rare that cycles in different levels will enter through a vulnerable stage at the same time i.e. either in the release phase or become excessive connected, that it can be changed completely by any lower level disturbance (Holling et al., 2002 p 90). But such makeover is more often seen in social systems which can undergo organizational changes due to “surprise” or crisis events that were not anticipated by their sense making (Holling et al., 2002, Janssen, 2002, Holling, 1995).

Apart from novelty to adapt to any change event in the environment, episodes of collapse also trickle down the nested cycles of a panarchy. Novelty is systemic as it accumulates within the system; collapse is due to a stochastic event external to the system. It can overcome any sustaining property of panarchy and trigger devastating cascades down the levels of the system. A glaring example can be of the loss of biodiversity due impact of asteroid that had hit Earth almost 70 million years ago. Such an event, not only eradicated species but also destroyed the ecological niches, the mesh of interactions which sustains life itself. As a result recovery was slow, and new species, families and orders derived the opportunity to interact and a new way of life emerged which ushered the dominance of mammals and extinction of the dinosaurs (Holling, et al., 2002 pp 91-92). Similar examples are also seen in social system during breakdown of a governance regime in a state where collapse of the system is succeeded by slow reversals.

Like ushering of novelty into the system, collapse also starts in any one level going through a vulnerable phase of its cycle. The diversity in any system is the storehouse for resilience of the system which helps it to stay adaptive in the face of environmental change. The loss of diversity and potential to accumulate due to misuse or an external force can lead to a "poverty trap" which is a perverse state in the normal adaptive cycle with low potential for accumulation of resources, low connectedness among the elements as well as low resilience. Such a situation in any level can lead to a cascading effect eroding levels of the panacrhy. The example of such trap can be found in the history of economic and ecological imperialism which finds its collapse stages in episodes of famines. In another extreme, a system may be sustainable but "maladaptive" when the potential for accumulation is high, connectedness is high but at the same time, unlike a normal adaptive cycle, even resilience is high. This would mean that the system focuses just on those connections that lead to its accumulation and tries to keep any novel entrant at bay. The accumulation can be measured in terms of wealth and connectedness can be maintained through strict rules (Holling et al, 2002, p 96). The ideal examples can be of heightened bureaucratic control of resources for serving a scientific objective or democratic goal (Prtichard and Sanderson, 2002) and the Hindu caste system which initially started for sustainable use of land resources (Holling et al., 2002, pp97-98). However collapse of such rigid and maladaptive social systems can be associated with the simultaneous collapse of resource system to control which such systems emerge at first. This can be supported by myriad of examples of changes from control and command mechanisms to participatory mechanisms of governance as fish stocks disappear in a fishery or agriculture comes to a standstill during periods of draught ((Prtichard and Sanderson, 2002). The caste system also disorganized after the degradation of the natural resource base during the British Raj in India (Holling et al, 2002, p 97).

4.2 Irreversible change

Ecosystem states vary between certain known stable states but seldom move towards irreversible state which poses as surprise to a management institution and from where recovery becomes very difficult. Collapse of a SES is mostly attributed to a slow change in the resource system which is often not observed by the management due to its narrow focus on certain key variables which it perceives as important for accumulation of resources. The system which has lost its diversity due to control of disturbance factors moves to a very different state when such a slow change accumulate and ultimately pushes the adaptive cycle to its release phase. Even the accumulating slow change may actually be a result of any myopic management policy which then goes unnoticed due to its narrow focus (Holling, 1995). Due to the initial success of such maximizing policy, societies become increasingly dependent on the resources and as the resource system flips into a surprise or irreversible state, there is loss of trust on the management institution which may destabilize the governance regime (Janssen, 2002, Holling, 1995).

There are ample evidences of such surprises due to lack of understanding of the non linearity in system and ignorance of changes in slow moving variables. One of the classic examples of failure of optimization is the myth of maximum sustainable yield of fisheries. As the fish stock decreases beyond a certain level due to harvesting, a different set of processes like depensation and switching behavior of predators take over which makes the recovery of the stock very difficult. Hence if the variability of the processes is taken into account in a fish stock assessment, it can lead to a collapse of the fishery. In another example of a modeling exercise of a fishery lake, it was observed that economic incentives led to change of the riparian forest by cutting trees near the lake to facilitate boating and fishing activity. This changed the slow variable-habitat of the fishery (fallen trees) which controlled the fish population dynamics. The model showed that apart from normal year to year fluctuations, there was gradual decrease in stock and there was an abrupt release phase in the system. There was a collapse of the desirable state (here one with abundant fish stock) and fishers left the system which brought down the economic indicators. Similar collapse is also seen in agro-ecosystems with phosphorous levels in surface water. Phosphorous was measured in three different levels of the system in western Great Lakes region of North America, in soil (slow turnover), lake mud (intermediate turn over) and lake water (fast turnover). As a result of phosphorous intensive farming practices, there is slow growth of soil phosphorous, cycles in mud phosphorous of around 200years and occasional outbreaks of high lake water phosphorous. The policy maker sets a goal only for phosphorous level in lake water with dual objective of maintaining farm yields and water quality. Thus there are cycles of high phosphorous in the lake which leads to decline of farm practices. But as there is halt of phosphorous intensive practices, the stability state of low phosphorous level in water returns which again attracts farm practices (Carpenter et al., 2002).

The research question important for adaptation is not so much about when and how collapse may occur or how much a SES is vulnerable to collapse, but it is more about pathways of reorganization after a cycle of collapse. As we saw from previous section that there is no panacea in understanding or managing a SES, so there will always be uncertainty of outcomes. Narrow focus on objectives set by polity or market rationalists may lead to biasness of a control over uncertainty which may ultimately lead to rigid institutions and destruction of diversity. This in turn renders the resource system vulnerable to collapse as a result of a stochastic event and finally destabilization of the SES due to loss of trust on the governance regime (Prtichard and Sanderson, 2002, Carpenter et al., 2002, Janssen, 2002). Cycles of collapse and renewal is inevitable in ecosystem, so the question important to ponder for sustainability of SES are the following-

- How do we form an appropriate and acceptable strategy for adaptation when the state of a system changes?
- What is the appropriate form of governance which can maintain the ecological resilience of system for adaptation during periods of environmental change?

But the answer to these questions lies partially in the understanding of the pathways that lead to irreversible state change of a managed ecosystem which can further pose the SES vulnerable to collapse. Such attempts to unravel the intrinsic dynamics of a SES that can lead to irreversible change in its resource system leads us to looks towards the context of irreversible change from lush paddy fields to sand filled landscapes in an agro-ecosystem of Brahmaputra basin in India.

5. The context

5.1 The *Mishing* Community

The *Mishing or Miri*[iv] community residing along the Assam-Arunachal Pradesh border of India, by the banks of the river Brahmaputra and its tributaries like Subansiri and Ranganadi, has always experienced annual floods during the monsoon period. Through their coping mechanisms, like special types of huts over tree stumps, boating skills, shifting livelihoods between agriculture, fishing and animal husbandry, they have adapted to a particular pattern of the flood hazard. There is strong social cohesion among the community and they have local institutions for early warning before the hazard. However, the change in the type of hazard itself has created new risks for the community. Massive amount of agricultural land has been submerged, embankments have been breached and deposition of silt is changing the context within which the community used to thrive[v].

There are scholarly articles which relate the *Mishing* tribe with the hill tribes of Arunachal Pradesh like the *Adi* community. However, there is also evidence that they arrived from Howang ho-Yangtze valley of China merely approximately 300 years ago unlike the tribes of Arunachal who's arrival dates back to even 2200BC (Phukan, 2010). They arrived at a time when there were already chiefdoms in hills of Arunachal Pradesh and established kingdom of the *Ahom* dynasty (established in 1228AD) in the plains of Assam. As a result, they served as middlemen between the hill tribes and the kingdom, and slowly gained trust of the *Ahoms*. Soon, they were given settlement places in flood prone areas of now Dhemaji, Lakhimpur and Jorhat district of Assam, some which were formerly vacated by the *Ahoms* themselves due to recurring floods. The community learnt to live with the annual floods with shifting livelihoods, *Chang Ghars* (local term for house over tree stumps) and more or less a nomadic lifestyle[vi].

5.2 The Agro-ecosystem

The Matmora Gram Panchayat with 16 revenue villages, under Dhakuakhana sub-division of Lakhimpur district tells a story of bust and boom in paddy production. The entire district has fertile alluvial soil for paddy cultivation and even its name resonates with wealth *(Lakhi*- Hindu goddess of Wealth). The Mishing farmers of Matmora area were the major rice producers in the district till 1998. From 1964 to 1998, they became so self-sufficient in food production that they had to just buy salt and kerosene from the market (Das, 2009).

The 1950 earthquake in Assam which changed the course of the Brahmaputra and its tributaries aggravated the flooding of its plains. As a result the state government, following a technocratic paradigm of jacketing rivers, built mud embankments wherever they were missing. However, embankments or *Mathauri*/*Garhs* (local name also found in historical records or *Buronjis* prepared by *Ahoms*) were not new to the region as it was the *Ahoms* who introduced them. But the striking difference in the design process is the issue of soil moisture testing to construct the embankments away from the play zone of the river. The rivers of northern part of Assam have always been prone to course change due to close to site of their origin in the Himalayas. Hence, there used to be royal soil testers of the *Ahoms* who had their own know-how of predicting the play zone of the river by licking the soil to measure its moisture content (referred to as *Maticheleka Barua* in *Ahom Buronjis)*. However in the colonial times and more so now in the present times, a rise in population along with settlement structures inhibits the continuation of such a practice (Phukan, 2001).

The Matmora embankment was constructed in 1964 to protect the villages from the floods of Brahmaputra River. The dependence of the *Mishing* population thriving in the area over this structure led them to forget their nomadic lifestyle and become settled paddy farmers. However, the embankment slowly changed the river character and as already in the play zone of the river, led to a problem of embankment erosion. After 34 years of its construction, in 1998, two and half kilometers of the embankment was finally washed away. The pattern of the floods also changed and the inhabitants observed a rise in flooding events per annum. During this time, the embankment was rebuilt every time it is eroded and the Public Works Department (PWD) tried to shift its position to match the lateral movement of the river. This resulted in a continuous displacement of the villages which led to migration and also settlements started right over the embankment adding further pressure on the structure (Das et al., 2009).

The final blow came in 2007 to 2009, when there were incidences of flash floods along with huge amount of silt deposition by the river. Some of the villages like Khamon Birina and Janjidangdhora of the area are casted in sand as high as 7feet from ground and crop area has reduced to nil[vii]. The state government reacted in 2009, by shifting from age old mud embankments only to latest technology Geo-tubes to protect the villages from future flood. However, the sand is still there in the agricultural land and no strategy has yet been planned for adaptation, rehabilitation or mass clearing of the land. The policy of the state government has always been a technocratic one with fixing its solution in the village level. The slow change of the river character by embankments has mostly gone unnoticed.

5.3 The Political issue

In the midst of the priorities of the dominant Assamese middle class for achieving economic growth at par with the rest of India and ending insurgency in the state, the concern of the tribal *Mishing* community has more often been left aside from any political debate. However the latest turn of events, have drawn attention of the local egalitarian civil societies like the Krishak Mukti Sangram Samiti (KMSS), media, academicians and activists from *Mishing* community as well as other parts of the nation. However, the primary focus of the political struggle has been to stop the dam construction in the Subansiri River and expose plots of corruption in rehabilitation of flood victims and also construction of embankments. There is no debate over any strategy for adaptation of the *Mishing* community of Matmora area to this new type of hazard. Such farmers along with their counter parts from Arunachal, Manipur and Nagaland have joined in protests and demonstrations triggered by KMSS which have sometimes turned violent[viii]. Moreover in a state like Assam which had violent student revolution and insurgency problems, there is always a risk to the polity that areas like Matmora can turn into recruit grounds for the insurgency groups, due to separatist sentiments, material gains or merely due to the sense of being marooned.

5.4 Search for causal mechanisms

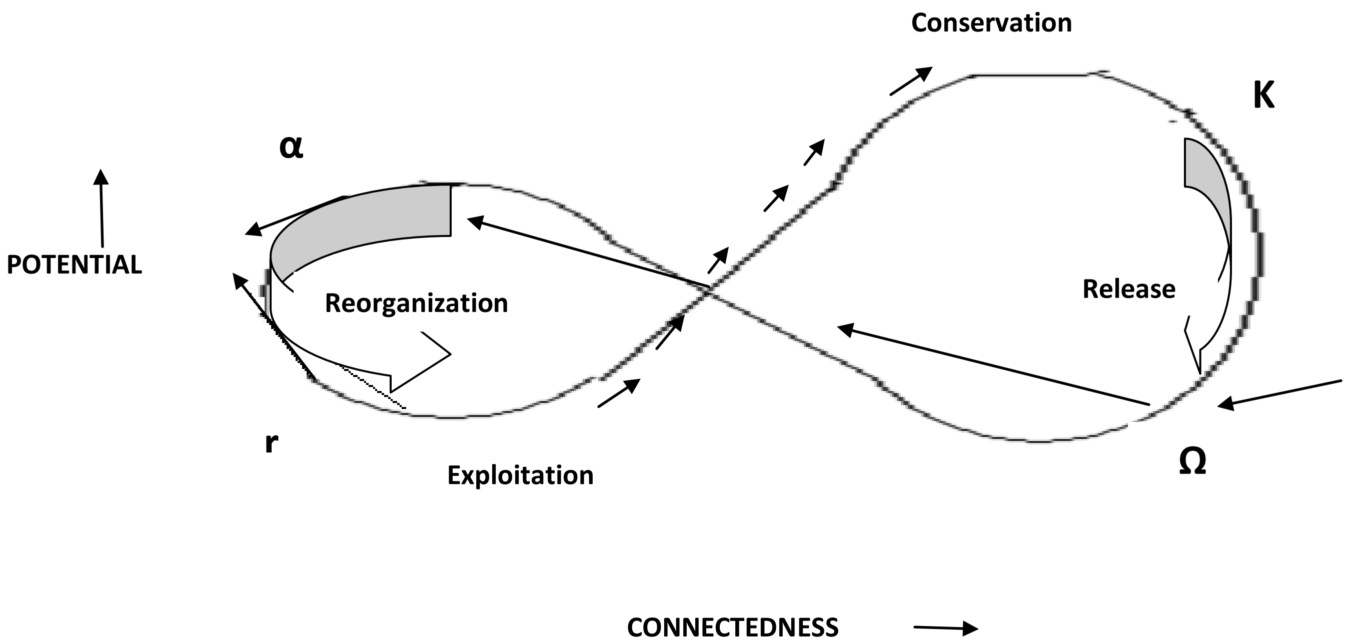
The reasons for such a bulk of silt carried by the river is attributed to many factors like upstream development work in Arunachal Pradesh, dam construction in tributaries like Ranganadi and Subansiri, increased rate of erosion in upstream owning to change in monsoon pattern and failure of flood control measures and nexus of corruption (Gohain, 2008, Das, 2009). However, there is still a lack of understanding how all the potential factors interacted to lead to the present state of the ecosystem. We hypothesize that factors in multiple levels of both ecological and socio-economic domains, operating in different scales interacted to lead to this state.

Such an understanding will be crucial for planning and implementation of an efficient, effective and just decision for adaptation of the *Mishing* community. However, going back to the issue of differential outcomes and different ways of knowing, such an understanding by any modeling exercise will be partial. This leads to add our first research question-

- How can we have an integrated model of the causal mechanisms that lead to an irreversible change in a multilevel SES?

Annexure 1

Figure 1



The above figure (Holling, 2001) depicts the adaptive cycle of a system where in there is first accumulation of capital (which may be biomass and nutrient in an ecosystem or even economic or social capital in a social system) from r to K phase in which the elements and processes of the system becomes tightly connected and the system itself slowly moves towards a particular equilibrium. Although the capital is stored for reaching a particular matured stage, it provides potential for alternative stages in future by accumulating chance mutations to arrive at another ecosystem or networks of human relationships for a regime shift in social system. However it is only due to an external disturbance, like a forest fire or insect outbreak in a forest there may be release of biomass or nutrients from the soil and loss of the tight organization. Similar kind of losses and finally a collapse can be apprehended even in a social system, for example, at the onset of a societal revolt against a rigid political set up. This starts the 'back loop' of the cycle which is a phase of radical change as oppose to the former incremental growth. The phase from Ω to α is a phase of rapid reorganization where elements that were in isolated connections in the prior phase recombines to form novel linkages which pave the path for innovations in the next cycle. This phase is highly unpredictable and uncertain as previously accumulated mutations, inventions and capital can organize into new order providing new opportunity. Hence this adaptive cycle represents two objectives- the first is of 'production and accumulation' (which builds up the 'potential or wealth' of the system that can be utilized in all future options) and second is of 'invention and reassortment', both of which cannot be maximized simultaneously but can occur only sequentially (Holling, 2001).

In the above figure, the short arrows represent a slow changing situation whereas the long arrows represent the rapid changing situation. The third dimension of the adaptive cycle namely resilience, remains high in the 'back loop' of the cycle where connectivity and regulation is low and conditions for facilitating experimentation is escalated. Whether the liberated resources during the change event, are lost to the system or captured and reorganized back into the same order, is decided in the α phase of the cycle. If there is too much of distortion or loss during the change or if there is insufficient 'memory' for reconstruction, then the system may shift to a new regime with different actors, species and functions. If the system starts on a new path, then in the r phase, the self organizing attribute of the interactions facilitate the positioning of the new actors into a new mesh of relations, which identify the new regime (Holling, 2001).

Annexure 2

Figure 2

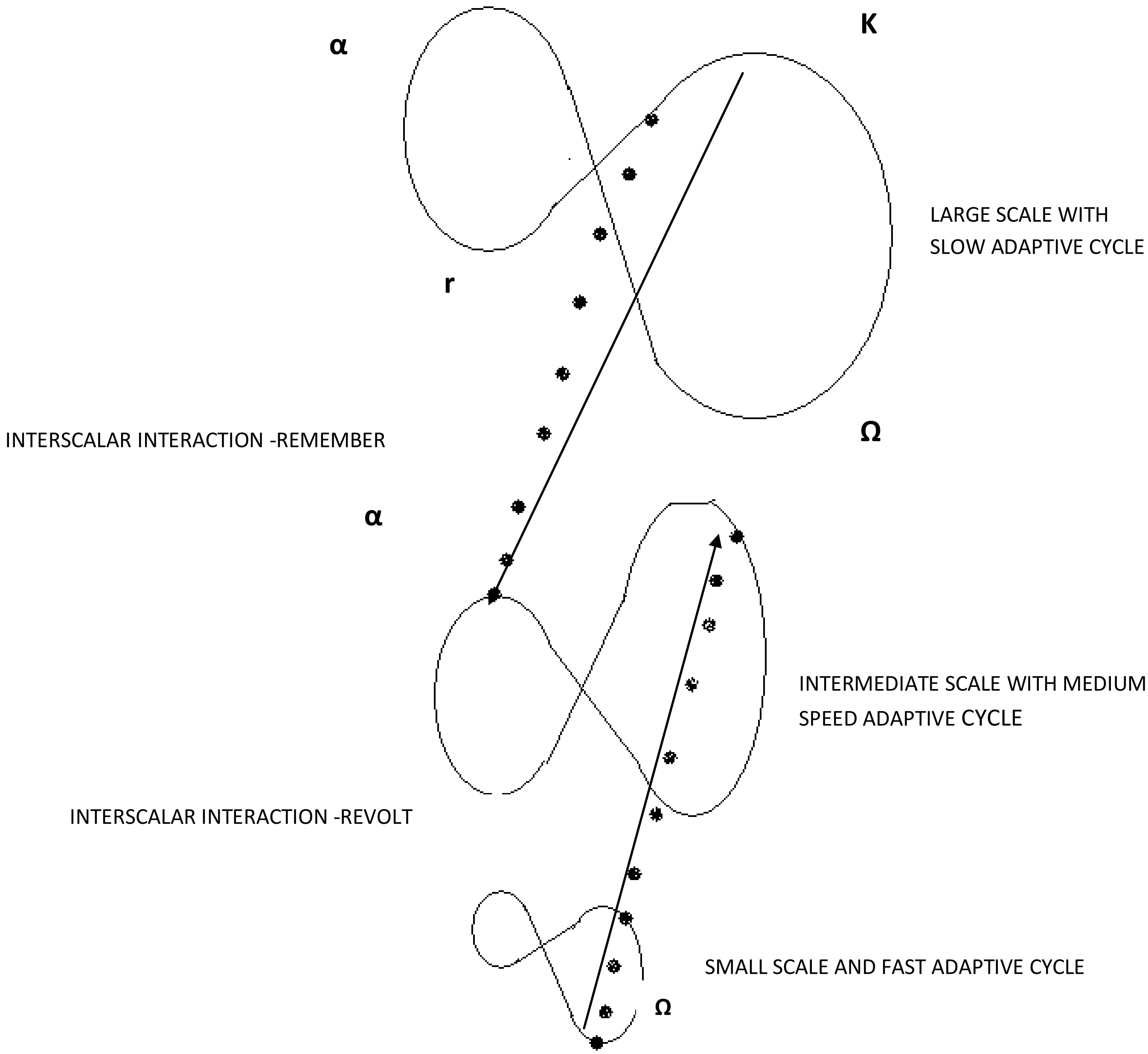


Figure2 demonstrates the hierarchical arrangement of adaptive systems in different spatial and temporal scales (Panarchy). It also demonstrates the cross-scalar interactions which provides scope for change ('revolt' from experimentation and creativity in smaller scales) as well as serves as a source of stability (interaction represented as 'remember', which provides capital and memory during periods of change in the intermediate scale). The whole panarchy is thereby sustainable as it is both "creative and conserving".

It provides scope to create, test and maintain adaptive capacity. (Holling,B. 2001). But large stochastic events can cause a collapse of panarchies by destroying levels within it, wherein systems may be in a vulnerable stage of their respective adaptive cycle, caught in a poverty trap (a state of low potential, low connectedness and low resilience) or have become maladaptive (a state of high potential, high connectedness but also high resilience) and trigger destructive cascades down the successive levels. Such events can overcome the sustaining ability of panarchies and lead to a crisis of the CAS only to usher in a new order. However such transformation in a panarchy may only occur when neighboring systems in adjacent levels accumulate enough recombinations and inventions and are vulnerable for a switch in regime, all at the same time.

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[i] The degree, duration, and/or extent in which the system is in contact with, or subject to, the perturbation (Adger, 2006).However, exposure is often described as inseparable from the notion of sensitivity (Smit and Wandel, 2006).
[ii] The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli (McCarthy et al.,2001).
[iii] The ability of a system to adjust to climate change, including climate variability and extremes, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences(McCarthy et al., 2001).
[iv] As found in *Ahom buranjis*
[v] Observation made in the field through participant observation for two weeks
[vi] Interviews and discussions with Dr Sarat Kumar Phukan, author of Onomastics Assam and The study of Hodonomy

[vii] Information gathered from Agriculture Sub-division Office, Dhakuakhana Sub division, Lakhimpur district, Assam

[viii] From news paper articles in TIMES OF INDIA, Guwahati edition in the month of July, 2010