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Environmental Change and Sustainability

Edited by Steven Silvern and Stephen Young

ENVIRONMENTAL CHANGE AND SUSTAINABILITY

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and **Stephen Young**

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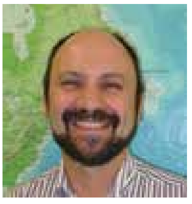
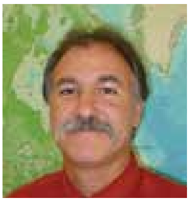
Meet the editors



Editor, Dr. Steven Silvern is an Associate Professor of Geography at Salem State University where he is teaching. His research interests focus on indigenous peoples, environmental sustainability, and sustainable food systems in the United States and the Middle East. He has studied and written about the complex political and cultural geographies of Native American sovereignty and hunting and fishing treaty rights. His most recent research has centered on the development of local and regional food systems in Northeastern North America. Dr. Silvern's research has appeared in journals such as Political Geography, Historical Geography, American Indian Culture and Research Journal and recently in Food: An Atlas (2013). Dr. Silvern is the editor of The Northeastern Geographer: Journal of the New England-St. Lawrence Valley Geographical Society (a regional division of the Association of American Geographers), an annual peer-reviewed publication. He received his Ph.D. in geography from the University of Wisconsin-Madison, a M.A. in geography from the University of Illinois-Urbana and a B.A. in biology from Clark University.



Co-Editor, Professor Stephen Young is a former chair of the Department of Geography at Salem State University where he focused on remote sensing, vegetation change and the geography of Asia. His recent work has centered on environmental change in NE North America, the mapping of lands vulnerable to sea level rise, and nature conservation in China. Dr. Young's research has appeared in journals such as: Biological Conservation, Biotropica, Forest Ecology & Management, International Journal of Remote Sensing, Photogrammetric Engineering & Remote Sensing, International Journal of Applied Geospatial Research, Mountain Research and Development, and Vegetation. He received his Ph.D. in geography from Clark University, a master's degree in environmental science from Yale University and a B.A. in environmental studies from the University of Vermont. In addition to his environmental research, he bridges the arts and sciences through art gallery exhibitions which expose the public to science and geography. His exhibition, The Earth Exposed, has been displayed in over a dozen galleries including the headquarters of the National Science Foundation as well as being displayed in Australia and Tunisia.

Contents

Preface

Around the globe, environmental change is rapidly occurring as a result of human actions to transform the earth into a livable home. Such human-induced or anthropogenic environmental change is hardly a new phenomenon. Historically, humans have modified bio-physical environments in order to satisfy and meet basic biological needs such as food and shelter. Whether it has been the intentional burning of grasslands, clearing forest for agriculture, the draining of wetlands, mining for minerals or fossil fuels, reshaping coastal ecosystems, polluting freshwater systems, overharvesting of fish stocks or the production of greenhouse gas and other toxic emissions, humans have altered the earth's bio-physical environments in myriad ways. The alteration of the environment – its humanization – has had unintended and often negative impacts on human societies. According to many scientists, global climate change currently poses the greatest threat to human health and socio-economic welfare of all human-induced environmental changes. The task for environmental and social scientists is to use available scientific tools and technologies to document and understand the causes of environmental change and to develop more sophisticated theoretical models and concepts to understand the dynamics and impacts of such changes. With an increased understanding of the people-environment interface and the bio-physical and socio-economic consequences of environmental change, policy-makers, communities and individuals can chart more appropriate responses to environmental and global climate change. The goal is to enhance our knowledge of environmental changes and map out a range of possible human responses to such changes; responses that will enhance socio-economic resiliency and reduce human vulnerability to the risks and hazards associated with environmental changes occurring at the local, regional and global spatial scales.

Over the last thirty-five years, sustainability and sustainable development has emerged as a policy-making guide for scientific and lay discussions over how states, cities and communities ought to respond to the threats and risks posed by environmental change. Major world institutions, such as the United Nations, the World Trade Organization and the World Bank see sustainable development as one of their primary policy goals. The basic and most widely disseminated definition of sustainable development was articulated by the United Nations sponsored World Commission on Environment and Development (referred to as the Brundtland Commission) in its landmark 1987 report, "Our Common Future." The Commission defined sustainability as development that "seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future." The Commission recognized the importance in minimizing the risks and hazards associated with environmental changes: "policy makers guided by the concept of sustainable development will necessarily work to assure that growing economies remain firmly attached to their ecological roots and that these roots are protected and nurtured so that they may support growth over the long term. Environmental protection is thus inherent in the concept of sustainable development, as is a focus on the sources of environmental problems rather than the symptoms."

Since Brundtland, sustainability has come to be defined as a balancing act: promoting economic growth in order to reduce poverty and inequality, enhancing social equity and community development, and at the same time protecting the overall integrity and functioning of the environment. Each of these so-called "realms" are no longer conceptualized as separate or independent of one another. Rather, sustainability recognizes the interdependence of economic development, protection of the environment and the enhancement of social and community well-being.

The present book brings together a group of international scholars examining environmental change and sustainability from different theoretical perspectives and in different geographic contexts. The advantages of this approach and thus the relevance of the current volume is that it demonstrates that place and context matters; that the impacts of environmental change varies and that human responses to environmental change is dependent on the environmental, historical, cultural, demographic and economic context of a specific place. In particular, the volume demonstrates that for developing regions responding to environmental change and the crafting of policies that promote sustainable development is particularly challenging as these regions confront specific environmental (e.g. tropical environments, "fragile lands"), demographic and economic conditions (e.g. poverty) that differ from more developed regions.

We hope this book will demonstrate the continuing relevance of the Brundtland Commission's definition of sustainability; a definition that is broad enough to be used in different times and places and yet specific enough to give meaning and direction to efforts from local communities to the international community to debate and implement particular policies and actions. We agree with the Commission's conclusion that "No single blueprint of sustainability will be found, as economic and social systems and ecological conditions differ widely among countries. Each nation will have to work out its own concrete policy implications. Yet irrespective of these differences, sustainable development should be seen as a global objective."

Three themes inform and are reflected in the eleven chapters in this book. The first section of this book brings together papers that use the tools and techniques of the natural sciences to identity and assess changes in the environment (e.g. hillslopes, deserts, coral reef ecosystems, contamination of sites); the idea is that such primary knowledge is essential for identifying, debating and implementing policies to ameliorate environmental change, reduce risks and promote sustainability. In the second part of the book, the spotlight shifts to a focus on the key role that human perception and attitudes play in understanding and responding to environmental change. Human perception and changes in public discourses are key determinants of how and why policy choices are being made. The chapters in this section examine the roles of external events and institutions in shaping how we conceptualize and socially construct environmental problems. In the last section of the book, the emphasis is on the importance of community and bottom-up approaches to reducing the risks and vulnerability to environmental change. Sustainability will only be achieved when local, indigenous and traditional knowledge of the environment and environmental management are combined with the techniques and understandings generated by modern environmental science. Place and context matter. Sustainable development, in the face of global environmental changes, will be best achieved when it is rooted in the local community and not merely imposed by policy-makers and decision makers divorced from the local context. The editors hope that you enjoy reading the diverse group of papers and find them useful as we move humanity to a more sustainable transformation of the earth to ensure that we have a livable earth for future generations.

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Section 1

Physical Dimension

Chapter 1

Environmental Change and Geomorphic Response in Humid Tropical Mountains

Wolfgang Römer

Additional information is available at the end of the chapter

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1. Introduction

The tropics encompass a wide variety of environmental conditions sharing high radiation and high temperatures, whilst the timing and annual amount of the rainfall and the seasonal moisture pattern enable the distinction between humid tropical, seasonal wet tropical and arid tropical zones and of the savannah and rain forest environments [40]. As a result of its great areal extent, the tropical zone encompasses a wide range of tectonic regimes, structural and lithological settings and landscapes [38].

The understanding of environmental changes in the tropics appears to be of particular importance as this zone encompasses 35 to 40 per cent of the land surface of the earth and includes about 50 per cent of the world's population [67]. Tropical countries are characterized by a rapid growth in the population and a rapid development of urban areas [6, 45]. This has resulted in increasing demands on fresh water, food, arable land and energy and mineral resources, leading to an increase in per capita consumption and severe environmental degradation.

Tropical ecosystems have been subjected to human interference for thousands of years in the form of traditional land use of many and varied kinds [87, 38]. However, rapid growth in the population and the technical advances of the last 100 years have increased the human impact on physical environments to a much higher degree than the thousands of years of human activity before that. Human interference and environmental change have been rapidly increasing since the mid-twentieth century. Gupta quotes a mean annual loss of rain forest of 174,000 km^2 during the decade 1980 to 1990 [38]. Agriculture and urbanization have modified and transformed large parts of the physical environment and have altered the operation of the geomorphic process-response systems [36]. According to [2], the annual deforestation rate of rain forests ranges from 0.38 to 0.91 per cent in Latin America, Africa and

Southeast Asia with extraordinary high rates of 5.9 per cent in Sumatra and 4.9 per cent in Madagascar. More recent estimates of gross forest-cover loss in the first decade of the 21st century indicate no reversal of these trends [39]. Recent studies indicate an increase in hazards in many regions in the tropics. These appear to be linked to changes in global climate, an accelerated and disorderly process of urbanization, deforestation and the associated loss of hydrological storage capacity, particularly in mountainous domains and to the concentration of settlement activity in potential high-risk areas [44].

However, the severity of their impact varies spatially, and the intensity and course of the response to environment changes varies in the different physiographic domains depending on the nature and severity of the change and the sensitivity of the landscape. Landscapes can be viewed as systems consisting of various interconnected components or subsystems [15]. As the subsystems tend to interact on different spatial and temporal scales via different feedbacks, they may dampen or reinforce the effects of environmental changes depending on the coupling strength existing between the system components. The crossing of thresholds, on the other hand, causes a sudden change in the landscape or in the geomorphic processes, and the mutual operation of feedbacks and thresholds within the geomorphic system tends to induce a complex response to changes in environmental conditions. A consequence of these interactions is that the rate of change of landscapes as well as the severity of the geomorphic response to environmental changes is extremely variable.

1.2. Purpose and objectives

The understanding of developmental patterns in respect of the diverse and complex environmental controls and geomorphic responses in the tropics appears to be an essential prerequisite for the assessment and distinction of climatically-driven and humanly-induced environmental changes as well as for the planning of technological, social and political measures and a sustainable development. The objective of this paper is to demonstrate the role of the geomorphic response to environmental changes on a variety of temporal and spatial scales. However, a comprehensive and balanced view of the wide range of geomorphic process responses to environmental change, their causes and functional relationships is beyond the scope of this study. Instead, this study attempts to concentrate on the response of hillslope processes and their specific controls in the humid tropics, and, in particular, on the stability of hillslopes, on the role of surface wash processes in accelerating soil erosion, and on the role of weathering processes from the point of view of the availability of nutrients in the soils and the geotechnical properties of the weathered materials. A further objective of this study is to highlight some aspects of the role of the long-term development paths of the landscapes as this factor may provide some indication of susceptibility and of a potential response to environmental changes on the part of larger-scale landscape units.

The second chapter encompasses a discussion on the various factors which determine rapid mass movements in humid tropical mountains, and provides an overview of the role of extreme rainfall events in triggering landslides. As the responses of hillslopes are often predisposed by virtue of long-term evolutionary processes, the chapter also includes some case studies on the role of long-term hillslope development and of the effects of susceptibility on landslide hazards in rural and urban areas.

The third chapter is focussed on different aspects of soil erosion, land degradation and soil fertility. The fourth chapter highlights some factors which determine the intrinsic complexity of geomorphic response, interaction between human interferences, the role of changes in the frequency and magnitude of external events and the importance of interdisciplinary approaches.

2. Landsliding and environmental change in tropical mountains

2.1. Landslides in humid tropical environments

Rapid mass movements are important processes in mountainous landscapes and include a wide range of types and sizes of landslides and styles of movement (Table 1). Landslides have been documented in nearly all tectonic settings within the tropical area [80, 87]. However, large single landslides and landslide events encompassing hundreds to thousands of landslides tend to occur most frequently in tectonically active mountain belts and, although with a somewhat lower frequency, in highly elevated pericratonic areas, whilst landslide events appear to be relatively rare in cratonic areas. [14, 31, 38]. The frequent occurrence of landslides in tectonically active mountains and pericratonic areas can be attributed to a specific set of conditions, which include high escarpments, long steep hillslopes in ridge and ravine landscapes, copious rainfalls (high annual rainfall totals and high short-term intensity rainfalls), and highly weathered surface materials [59]. Earthquakes, volcanism and rapidly incising streams are further factors acting as trigger mechanisms for rapid mass movements, particularly in tectonically active mountain ranges [55, 80, 87, 12, 56, 38].

Type of movement	**Regolith**		***Rock***
Type of movement	**Fine-grained**	**Coarse grained**	
Falls	Earth fall	Debris fall	Rock fall
Translational slides	Earth slide	Debris slide	Rock slide
Rotational slides	Earth slump	Debris slump	Earth slump
Flows	Earth flow	Debris flow	Rock flow
Avalanche		Debris avalanche	Rock avalanche

Table 1. Modified after [84] and [75]A simplified classification of rapid mass movements

In many tropical mountains, landslides are part of a highly dynamic hillslope system, which is characterized by high temporal variability, cyclic changes in stability thresholds and temporal tendencies of recovery. This system is superimposed by climatic conditions, the effects exerted by the tectonic regime, lithology and structure, weathering processes and the rate of river incision. Where landsliding is the dominant formative process, changes in the environmental conditions are likely to influence the response of hillslopes by causing changes in the frequency, size and style of landsliding [58, 13, 56]. The off-site effects of large landslide events are the blocking of streams and valleys with landslide debris, and rapid sedimentation in the river channels promotes flooding in the downstream parts of the drainage basins. In a study on the impact of the hurricane Hugo in Puerto Rico it has been estimated that about 81per cent of the material transported out of the drainage basin had been supplied by landslides [47]. As events of a similar magnitude tend to occur once in 10 year the total rate of denudation due to landsliding has been suggested to range to about 164 mm/ka [47]. In Papua New Guinea, earthquakes provide an additional trigger mechanism, and estimates of denudation by landsliding indicate rates of 1000mm/ka [72, 34]. However, our understanding of the long-term contribution of landslides to the total denudation is fragmentary and the extrapolation of denudation rates to larger areas is subject to serious constraints.

Even in the case of shorter time scales, the triggering of slope failures depends on several interconnected and interacting factors. Site-specific factors such as slope, the relative relief, the degree of dissection of the landscape, the density of the vegetation cover, the geotechnical properties, the thickness of the material on the hillslopes and the intensity of land use determine the susceptibility of hillslopes to landsliding. Earthquakes and rainfall amounts are commonly the decisive triggers of landslides [76, 72, 38]. The incidence of landslides is closely associated with the timing, intensity and duration of the rainfall and the antecedent rainfall amounts [78, 1, 33]. These factors control the accumulation of moisture in the regolith and, hence, are associated with the likelihood of high pore water pressures. Hillslope steepness, on the other hand, controls the downslope directed forces and the rate of downslope subsurface water flow whilst the planform of the hillslopes determines the convergence and divergence of the surface and subsurface water flow lines and controls the size of the moisture-supplying area. The thickness of the weathering cover, its weathering degree, layering and textural characteristics, on the other hand, controls the hydrologic behaviour of the slopes and the type of movement. The accumulation of water by subsurface flow and infiltration in the regolith may also control the position of landslides on the hillslopes. In Puerto Rico most hillslopes failed at an elevation range of 600 to 800m because of the supply of water from higher elevated hillslope units [71]. Similar inferences concerning the position of landslides are indicated in studies of [48]. These indicate that slope failures resulting from extreme rainstorms are triggered on the middle or lower slope units of the hillslopes whilst landslides triggered by earthquakes tend to occur on the upper slopes.

Although landslide events are closely associated with high intensity rainfall events or periods of prolonged rainfall, there is no direct link between rainfall amount, rainfall intensity and the number and volume of landslides. Several studies have shown that rainfall events of similar order are capable of triggering different landslide volumes and of producing different landslide occurrences and landslide types [49, 37, 24]. This indicates that different thresholds are involved in the occurrence of landslide episodes. These thresholds are often interconnected by various feedbacks, resulting in complex relationships between the threshold of slope failure and the accumulation of moisture during the rainfall season and antecedent seasons, and the intensity of the rainfall event triggering the landslide [33, 62].

Instability thresholds of this type often depend on a number of site-specific factors. These may be associated with the impact of previous landslides on hillslope form, hillslope hydrology, regolith thickness, and with materials which are inherited from former landslide events.

However, even in tropical mountains with a high relief, steep hillslopes, high rainfalls and a high likelihood of high-pore water pressure, high-intensity landslide events may be rare [27]. Several factors have to work synergistically in order to trigger large-scale landslide events. Apart from bioclimatic conditions and specific structural and tectonic settings, the state of the landscape controls the response of hillslopes to environmental changes as the magnitude-frequency relationship of landslide events depends on the long-term association between overall denudation rates and the renewal of regolith by weathering. Studies on shallow landsliding in Borneo have demonstrated that under a given set of climatic, geological/structural conditions, landsliding is only possible where weathering processes are able to maintain a regolith thickness that is equal to or thicker than the threshold of critical sliding depth [27]. This indicates that on hillslopes where the regolith remains below the thickness necessary to trigger landslides, as the rate of regolith renewal is unable to keep pace with the gross denudation rate and the rate of river incision is too slow to steepen hillslopes towards a new threshold angle for landsliding, at a lower regolith thickness, large landslide events will be rare. However, this type of "regolith-supply limited" or "weathering limited" conditions appears to occur more often in tectonically active mountain belts or in terrains underlain by highly resistant rocks. As high weathering rates are characteristic features in many hot and humid tropical regions, the weathering processes and the geotechnical properties of the weathering mantles are of prime importance for an understanding of the landslide dynamics in tropical mountains.

FThe important role of chemical weathering in the development of impermeable layers in the regolith, and the importance of the highly variable geotechnical properties of the saprolite, soil and colluvium on hillslopes of the Serra do Mar (Brazil) has been emphasized by several authors [32, 46]. Another set of factors is associated with the coupling strength of hillslopes and rivers, the imprints of formerly different climatic conditions including hillslope deposits with variable geotechnical properties as well as the delayed response of hillslopes to the change from dry to humid conditions in the transitional periods from the Pleistocene to Holocene and their influence on the developmental paths of hillslopes [81, 82, 61]. The interaction of these different factors may result in hillslopes which are highly prone to landsliding, though the trigger mechanisms often depend on a site-specific combination of factors as different landscape components of the mountainous terrain are affected.

Human interference in the form of deforestation and urbanization and increased rural land use coupled with infrastructural measures and construction resulting in an oversteepening or undercutting of hillslopes and changes in hillslope hydrology frequently exacerbate the susceptibility of hillslopes to landsliding. The combined sum of the effects of human modifications and alterations in the mountainous domains has increased the socioeconomic impact of landsliding and also the risks in areas with a much lower natural susceptibility to landsliding [41]. Although the contemporary landscape setting, the geotechnical properties of the material, climate and the impact of human alterations determine to a large degree the incidence of mass movements, the triggering of slope failures may be also associated with processes that occurred in the past. The landscapes in which mass movements occur are often a composite of forms and deposits that are genetically linked with actual process dynamics on the hillslopes. The long-term component in studies of mass movements has often been neglected because of the underlying assumption that the current state of a hillslope or landscape is ascertainable from an analysis of the contemporary process-response system. In many cases, this assumption appears to be justified. However, the knowledge of the long-term developmental paths of landscapes may lead to predictions of the susceptibility or sensitivity to react to environmental changes or may lead to predictions on the consequences and impacts of past events which were caused by environmental change.

2.2. Form-process relationships and geomorphic response in south-eastern Brazil

2.2.1. Landsliding in the Serra do Mar

The Serra do Mar forms the elevated passive margin along the Brazilian Atlantic coast and extends from Rio de Janeiro to Santa Catarina with elevations ranging from 700 to about 2000 m. Most of the area consists of folded and faulted metamorphic and plutonic rocks from the Precambrian age and landscapes range from highly elevated plateaus with steep escarpments to dissected ridge and ravine terrains, and muliconvex hilly terrains [3]. The climate is humid tropical with maximum rainfalls in the summer and without marked dry seasons in the winter. The mean annual rainfall totals range from 1500 to 2500 mm, though annual rainfall may rise locally to 4000mm [68]. About 70 percent of the annual rainfall occurs in the summer, which is also characterized by high intensity rainfalls [68]. The potential vegetation along the Atlantic coast is pluvial rain forest, which formed a highly diverse assemblage of trees, shrubs, lianas, tree ferns and epiphytes [42, 89]. Settlement and forest clearance have destroyed much of the original rain forest and estimates indicate that the remaining forests merely constitute 5 per cent of the original coverage [20]. Some local measures have attempted in recent decades to reverse these trends by the afforestation of pines and other tree species [7]. However, the destruction of forests by increasing rural land use and urbanization remains a major problem [53].

Over the last fifty years, the rapid growth of urban areas has resulted in marked changes in hillslope hydrology and the stability of hillslopes. These changes are also associated with an increasing influence of social and economic factors on risks associated with flooding and landsliding [5, 53]. In several regions, hillslopes, villages and urban areas are affected nearly every year by disastrous landslides, and particularly highly dissected terrains with steep hillslopes and highly weathered, thick regolith mantles are prone to landsliding even under undisturbed conditions [22, 19]. Many important roads cross the Serra do Mar and villages, industrial complexes lying at the foot of mountain slopes and escarpments or in basins and valleys are exposed to serious hazards caused by landsliding [53].

However, in many areas of the Serra do Mar, landslides were presumably the most important formative processes since the Late Quaternary period. Landscape evolution was probably non-uniform because of base level changes and climatic changes in the Quaternary, and the intensity of landsliding is likely to have varied as a function of climatic conditions and periods of river incision [17, 18, 61]. The various controls are often genetically linked with the sensitivity to landsliding and concern several aspects of the long-term development of hillslopes.

2.2.2. *Some aspects of the role of long-term process-response systems*

Predictions about the way hillslopes tend to respond to changes in environmental conditions may be gained from studies of the long-term development of hillslopes. Of particular importance in this respect are the roles of inherited materials and the effects of a differing hillslope-channel coupling strength. Inherited materials may provide information on the processes that have acted during past environmental changes. This enables predictions on the vulnerability of hillslopes with respect to specific slope processes or supports regional surveys on hazards with respect to the geotechnical properties of soils, weathering layers or colluvial deposits. In the Serra do Mar, several lines of evidence suggest that mass movements have occurred alongside periods of intense colluvial accumulation in the Pleistocene and early Holocene [8, 83, 54].

The accumulation of the colluvium occurred as a result of relatively dry climatic conditions in the Pleistocene and the higher frequency in the magnitude of storm events in the early Holocene. The areal extent of land surfaces currently underlain by colluvial deposits in São Paulo is estimated to be in the range of 50 per cent [30]. Today, the knowledge of the complex stratigraphy, the geotechnical properties and of the distribution pattern of the colluvial deposits is important as these deposits are often associated with debris flow hazards which often occur after vegetation clearance [46, 19].

The tendency of landscapes to react to environmental changes by landsliding may be also indicated in the hillslope development paths. Many ridge and ravine landscapes in the Serra do Mar encompass steep hillslopes, which are covered by a moderately thick weathering mantle. In southern Sao Paulo, this terrain-type is underlain by mica schists and phyllites and often exhibits summit heights, which are dictated by the steepness of the valley-side slopes and by the spacing of the rivers [61]. These terrains are characterized by v-shaped valleys and straight valley side-slope profiles with a relative relief of 120 to 200m. The valley side slopes exhibit a narrow range of slope angles ranging from 26° to 34° for the mean slope angle and the mean maximum segment slope angle. A consequence of the geometric control of summit height by slope angle and valley spacing is that areas with similar drainage density and stream spacings are characterized by accordant summit heights [61, 60]. Such an adjustment is unlikely to result from short-term changes because the incision of the drainage net, the fixation of rivers in valleys and the development of steep valley side slopes with a mean relative relief of 120 to 200m are unlikely to have been accomplished within a period that is shorter than 10^5 years. Conversely, in order to maintain the geometrical expression, the hillslope processes and the hillslope-channel coupling have had to operate throughout the Holocene period.

Horizon	clay	silt	sand	cohesion	friction angle
units		weight- per cent		kPa	degree
B	54.3	26.4	19.3	10.5	31.5
B	47.2	23.8	29.0	6.6	30.2
B	67.8	15.3	16.9	13.7	29.9
T	28.8	19.1	44.9	1.9	30.4
S	20.7	28.5	50.8	0.9	38.0

Table 2. Geotechnical properties of the regolith on mica schistsB- textured B-HorizonT – transitional zone between B-Horizon and SaproliteS – SaproliteShear strength was determined by direct shear tests after consolidation to allow excess of pore pressures

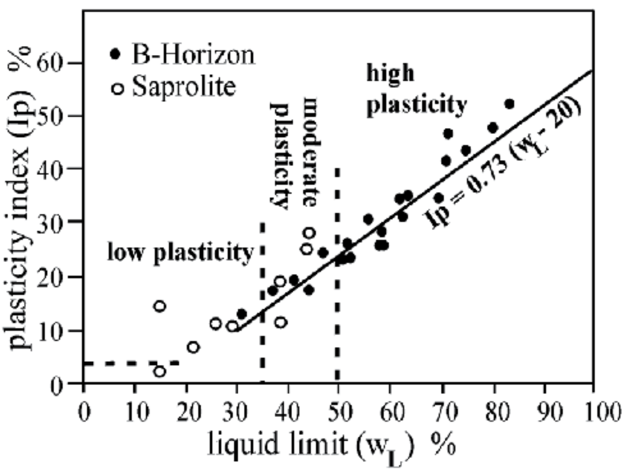

Figure 1. Range of plasticity index and liquid limits of B-Horizons and saprolitic weathering products of mica schists (modified after [61]).

Most valley side slopes in the area are covered by numerous landslide scars and landslide deposits of various ages indicating that the important formative hillslope process is shallow landsliding. The valley side slopes are covered by red-yellow podzolic soils, which show marked differences in the geotechnical properties of the soil horizons (Table 2, Figure 1, Figure 2). Particularly, at the contact of the B-Horizon to the transitional layer the decline of the cohesion tends to facilitate the development of a subsurface plane of failure. This is also indicated in the location of slip surfaces of relatively recent landslides, which occurred at a depth of 0.9 to 1.2m below the surface. This depth coincides roughly with the depth of the transitional layer.

Figure 2. Shallow translational landslide and earthflow which resulted from a single rainstorm and the high moisture content in the regolith. (Photo Römer).

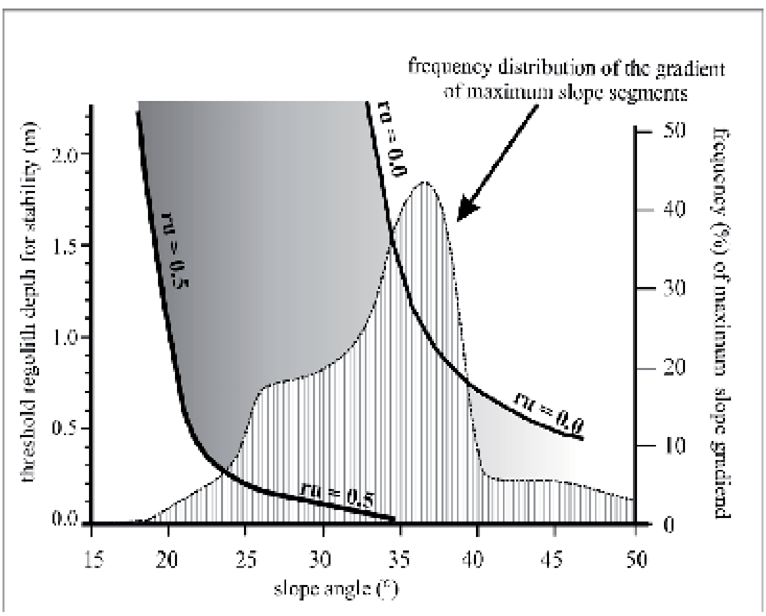

Figure 3. Limiting regolith thickness for a safety factor of slope stability (F =1.0) as a function of pore pressure ratio (ru) and the distribution of maximum segment slope angles on hillslopes underlain by mica schists. The bulk unit weight of the regolith ($\gamma = \rho$ g) = 17.4 kPa, the cohesion (c) = 1.9 kPa, and the friction angle (φ) = 30.4°. The limiting regolith thickness has been calculated by using the infinite model for translational landslides [11]. The factor of safety (F) has been calculated by $F = c + (\gamma d \cos^2\alpha - ru\ \gamma d) \tan\varphi / (\gamma d \sin\alpha \cos\alpha)$ with d = regolith depth (m), α = slope angle (°), $ru = \rho_w g\ d_w \cos^2\alpha / \gamma d$; ρ_w = density of the water (kg m^{-3}), g = gravitational acceleration (9.81 m s^{-2}), d_w = vertical height of the water table above the slide plane (modified after [61]).

A back calculation of the slope failures indicates that most valley side slopes are stable in a dry state, but tend to become instable at pore pressure ratios of 0.1 to 0.5 (Fig. 3). The close coincidences between the slope angle of the maximum segments, the threshold slope angle for failure and the threshold regolith depth indicates that the long-term formative process on the hillslopes is landsliding. This implies that as long as river incision enables the maintenance of steep slope angles, all hillslopes are likely to be affected by reoccurring landslides in the same places as long as weathering processes supply enough material to cross the threshold regolith thickness for slope failure with respect to the slope angle and the geotechnical properties again. However, the study also indicates that the form-process relationship is associated with events that are characterized by a low frequency and high magnitude reoccurring at temporal scales of several decades to centuries rather than being the result of continuously acting formative processes. It is easy to suppose that landscapes originating from such a process-response system where hillslope evolution resulted in the development of slopes close to the threshold of slope failure tend to respond violently to environmental changes and human interferences.

2.2.3. Extreme rainfall events and landsliding

Apart from human interferences, the high relative relief, steep hillslopes and the thick weathering layers, the most decisive factor contributing to landsliding is high rainfall. In the Serra do Mar landslide events are likely to occur independently of antecedent rainfalls and regardless of the vegetation cover and human interferences where rainfall exceeds 250 mm/24h [37]. Furthermore, the occurrence of landslides is promoted on most hillslopes which are steeper than 40% [32].

Since 1928, the Serra do Mar has been affected by about 25 to 30 extreme landslide disasters due to intense rainfall events, which have caused thousands of deaths and extensive damage to the infrastructure and various structures, though many smaller landslide events resulting in various degrees of damage tend to occur every year [23, 32, 19]. In the period from 1988 to 2000, the number of landslide fatalities in Santa Catarina, São Paulo, Rio de Janeiro, Minas Gerais, Bahia and Pernambuco averaged between 13 to 50 and locally, in coastal areas, between 51 to 364 [5]. About 85 percent of the landslide disasters occurred during the summer season, and most of the larger events that are documented in the scientific literature concentrate on the period between December and March [46, 53, 19, 68]. However, an extraordinary rainfall event was recorded in the winter of 2004. The event was caused by a cold frontal passage which became stationary in the coastal area of south-eastern Brazil [68]. Once the initially cold post-frontal anticyclone had acquired barotropic equivalent characteristics, a persistent southerly and south-easterly flow of winds became established which was impeded along the rise of the Serra do Mar causing advection and high rainfall. The event caused serious flooding and landslides along the coastal region of São Paulo [68].

Although any generalization of the functional relationships between the incidence, type and rate of movements may be overridden by local site-specific factors, the results of studies on landsliding in south-eastern Brazil suggest that most landslides occur in the late rainy season when the accumulation of moisture in the regolith has attained a temporal maximum [1, 19]. The increase in moisture in the regolith causes a rise of the pore water pressure and hence, results in a lowering of the threshold rainfall intensity necessary to trigger landslides. However, the triggering of landslides is also a function of slope angle, slope form and of the material on the hillslopes. On steep hillslopes with a relatively thin weathering cover, shallow landslides appear to occur mostly on the middle and upper hillslope segments. This landslide type is triggered during the wet season by rainfalls of long duration and moderate intensity or at the end of the wet season during heavy storms [25]. Failure may result from the increase in pore-water pressure or from the elimination of soil-suction and the reduction of the apparent cohesion [88, 46]. Debris flows, on the other hand, are triggered in the late rain season in hillslope hollows, on the lower slope segments and on steep hillslopes when the regolith is saturated with water. The incidence of debris flows is associated with high-intensity rainfall occurring in the late rain season and appears to be strongly associated with a destruction of the vegetation cover [19].

2.2.4. Urbanization, environmental change and landslide hazards

The rapidly growing population in the cities in south-eastern Brazil, the unplanned growth of urban areas and the inability to house the growing number of people have resulted in human occupation of geologically and topographically hazardous terrains, which are often characterized by an inappropriate infrastructure and precarious residences [5, 53]. The combined sum of these changes has also increased the risk of landsliding even in urban areas with a much lower natural susceptibility to landsliding.

The areal extent of the alterations in urban areas has often resulted in a reinforcement of the intensity of the hillslope processes as the affected subsystems tend to work synergistically. Urbanization is associated with a sealing of the surface, a lowering of the infiltration rate, a reduction of the water storage, and an increase in surface runoff. Soil erosion resulting from vegetation-clearing measures causes the development of gullies. Large gullies tend to affect the flow pattern of rivers by decreasing the baseflow whilst the stormflow is increased [21]. This leads to more intense floods and more events where hillslopes are undercut by rivers. Deforestation of hillslopes, on the other hand, tends to increase the likelihood of debris flows as a function of the decrease in root strength [19]. Road cuts or excavations destabilize hillslopes as the material supporting the regolith or rocks on the slopes is removed. Human settlement along streams and in valleys with houses perched on steep valley side slopes next to rivers increases the risk of disasters as hillslopes are undercut by rivers. The destruction caused during a landslide event also varies with the type, size and rate of movements. Disastrous effects are often associated with large debris flows which are induced in the late rainy season by heavy rainfalls once the material on the hillslopes has become saturated with water. During the 2011 landslide disaster in the vicinity of Rio de Janeiro, cascades of mudflows and debris flows destroyed houses and buildings. As the slipped debris moved downslope, water contribution from the surrounding areas resulted in an increased fluidization of the debris, which moved rapidly into the valleys and caused an increase in sediment load and in the flooding. Flooding and landsliding resulted from unusually persistent rain and an interspersed extreme storm rainfall event which had a devastating impact along the south-eastern Brazilian coast.

3. Soil erosion and land degradation

3.1. Soil erosion in humid tropical environments

Over the last four decades, deforestation and human interference with the environment have increased in nearly all tropical rain forest environments around the world [39]. The impact has caused increasing land degradation and is often accompanied by changes in the hydrologic regime, severe soil erosion and a declining productivity of cultivated areas [87, 36]. Recent developments in agricultural techniques, the increased use of agricultural machinery and the replacement of subsistence-orientated agriculture by export-orientated agriculture have resulted in a rapidly increasing and unfavourable change in environmental conditions.

Most studies on the role of soil erosion in rain-forest environments indicate that soil erosion in undisturbed rain forests rarely exceeds rates of 1t ha^{-1} a^{-1} as the canopy and understorey protect the soil from the impact of raindrops [59, 38]. In rainforests, much of the rainfall is intercepted and evaporated in the canopy and understorey, and permeable litter layers support high infiltration rates. Consequently, only a small fraction of the rain water remains available for overland flow [73]. The litter cover on the surface on the other hand, tends to dampen the forces of the impact of heavy raindrops. This cover is highly permeable. The permeability results from macro-pores provided by roots, which reduce the generation of erosive runoff [59]. Under natural conditions, with a continuous cover of litter layers, the water movement occurs as over litter-layer flow and as root litter flow in pores and in shallow subsurface pipes within the root-litter carpet [19]. This water flow is mostly highly discontinuous shallow unconcentrated overland flow with a low erosive power, except in hillslope hollows, where the convergence of surface water flow lines tends to promote a concentrated overland flow.

Disturbance of vegetation in rain forest environments appear to have serious effects on erosion rates as the spatial variation in the intensity and frequency of large rainfall events tends to be higher than in savannah environments [87]. The loss of ground vegetation and litter reduces the amount of soil organic matter, which diminishes the aggregate stability and increases the vulnerability of the soil to raindrop impact and the likelihood of soil crusting [29, 36]. The destruction of the soil aggregates by raindrop impact and the formation of a fine grained crust on the soil surface tend to impede infiltration. During rain bursts, this causes a rapid increase in overland flow and favours the development of rills and gullies. Soil erosion and changes in the physical characteristics of the upper soil horizon are not the only effects of vegetation disturbance. The nutrient cycle is markedly changed as nutrients are lost by soil erosion, by leaching of the soil and by the removal of nutrients which were formerly stored in the vegetation [59]. As tropical rainforests are unable to sustain their nutrient base without sufficient vegetation, the combined effects of vegetation destruction and soil erosion tend to result in a marked depletion of the soils and in a reduction in the biodiversity [86]. The complex relationships between vegetation destruction, agricultural use, soil erosion and loss in soil fertility has been documented from several areas in the tropics, and the interaction between socioeconomic and ecologic factors appears to be of major importance.

3.2. Land degradation and soil erosion in humid tropical mountains

Land degradation encompasses various processes ranging from disturbance of the vegetation to biodegradation of the humus and litter and the deterioration of soil quality. These changes are functionally associated with the productive capacity of the soils. Measurements of soil erosion rates in tropical environments are often highly variable. Calculated erosion rates range from 0.2 to 10 t ha^{-1} a^{-1} for rain forest environments in Guyana, Brazil and the Ivory Coast [34]. In the case of erosion in the Ivory Coast, rates increased on slopes with an inclination of 6% from 0.1 to 90 t ha^{-1} a^{-1} (crop cover) and 108 to 170t ha^{-1} a^{-1} (barren) [35, p. 113].

However, a quantitative assessment of the on-site and off-site impacts of soil erosion on the landscape remains a challenge because of the wide variety of environments and the relatively small data basis. Short-term soil erosion measurements from small test-plots do not always provide representative rates for hillslopes and the extrapolation of these erosion rates to larger areas is prone to errors as physical properties of the soils, the vegetation cover and parameters such as slope length, slope steepness tend to be highly variable. A further factor is the length of the measurement period. Extreme rainfall events are highly variable in terms of space and time and hence, are often not recorded. Rainfall erosivity modelling, on the other hand, provides information on the likelihood of soil erosion, whilst the calculation of erosion rates is complicated by the high number of interacting variables [74].

Although soil erosion rates imply a continuous loss of soil, the erosive processes are triggered by separate rainfall events, and the impact of singular rainfall events on soil losses may override all preceding soil erosion rates calculated. The important role of extreme rainfall events on soil losses and on sedimentation rates on the valley floors has been documented in the drainage basin of the Tubarão river (southern Brazil) [8]. In this area, a total amount of 400mm rainfall (three days) was recorded. This event caused serious soil erosion and resulted in the accumulation of a 30 to 60 cm thick pile of sediment on the valley floor. This implies that meaningful erosion rates can be only deduced when erosion measurements are supplemented by studies of the sediment balance in the drainage basins [8]. Studies on erosion/sedimentation events in drainage basins over a longer range of time (10^1 to 10^4 years). On the other hand, are rare and often confronted with the problem of distinguishing between human induced changes and natural environmental changes. The latter applies, in particular, to cases where landforms are polygenetic and are caused by rare, high magnitude events rather than by continuous processes. However, accelerated soil erosion as a result of the increased agriculture and the destruction of the vegetation cover has been recorded in the drainage basin of the Ribeira River [9]. The drainage area of the Ribeira river covers an area of 24,200 km^2. Since the 19th century, land use has increased from the equivalent of a few per cent to an area covering about 5000 km^2 in the year 1979 [9]. The Ribeira drainage basin is underlain by deeply weathered metamorphic and plutonic rocks. Most of the lower valley-side slope segments and small hillslope hollows are covered with pedogenetically transformed, clay-rich colluvial sediments of the late Pleistocene and early Holocene age, which have been deposited above the "in situ" formed saprolite [8, 63]. However, in areas where the original forest has been replaced by shrubs or agricultural land use, the colluvial soils exhibit truncated soil horizons whilst gully incision into the saprolite has given rise to the development of shallow hillslope hollows and deeply dissected hillslopes (Figure 4, 5). Most of the eroded fine-grained material has been transported to the rivers and on to the flat valley floors [9]. In the drainage basin of the Ribeira River, the high influx of sediment into the valleys and onto the flat valley floors has resulted in the accumulation of 5 to 6 m thick clayey sediments, which are rich in organic matter. In the area surrounding the village of Sete Baras, 5.8m thick sediments have been deposited above the river gravel of the Ribeira River [9]. Radiocarbon age determination of the organic matter of these deposits from a layer located just above the river gravel indicates that the material above the river gravel is younger than 300 years [9]. This provides an approximate age for the start of the increased erosion episode resulting from humanly induced disturbance of the vegetation. The geomorphic analysis of erosional forms, of the degradation of the colluvial soils, and of the start of the increased vegetation clearance indicates that soil erosion has contributed to a loss of soil $170m^3\ ha^{-1}\ a^{-1}$ or of $235t\ ha^{-1}\ a^{-1}$ in the last 130 years [10, p. 65].

Figure 4. Accumulation of colluvium in a hillslope hollow in the drainage basin of the Jacupiranga River, which is a tributary of the Ribeira River. The colluvium has been deposited on the saprolite of the mica schists/phyllites. The colluvium was formed in the Pleistocene as a result of less dense vegetation cover and drier climatic conditions. (Photo Römer)

However, the amount of soil loss on the valley-side slopes appears to have varied in different geomorphic settings depending on the relative relief, the physical properties of the regolith cover and the process domains. Studies on ultramafic rocks in the Jacupiranga Alkaline Complex, which is part of the Ribeira drainage basin provided no evidence of an increase in soil erosion even on steep hillslopes although, mining and cultivation of tea and bananas re-

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sulted in extensive destruction of the original forest cover [57]. Hillslope development in this area is primarily controlled by chemical denudation in the highly permeable weathering mantles and, to a lesser degree, by slow mass movements, whilst surface wash is limited by the lack of a significant overland flow [60]. Nevertheless, the role of the destruction of the vegetation cover cannot be underestimated as leaching processes operate at high rates in the tropics and tend to remove nutrients from the upper soil horizon, possibly reducing the fertility of the soils.

Figure 5. Piping and gully erosion in colluvium resulting from high rainfalls and vegetation disturbance in multiconvex hilly terrain in south-eastern Brazil at Jacupiranga. (Photo Römer)

3.3. Weathering and nutrient cycle

In tropical rainforests, the biomass above and below the ground contains most of the mineral nutrients. The maintenance of the nutrient level in the soil depends on the continuous cycling of the nutrients in the canopy and on the rate of decay of organic matter in the litter-layer. The latter is controlled by biological decomposition by invertebrates, and by the physico-chemical processes responsible for the release of nutrients in the upper soil horizons [59, 67]. However, the functional dependencies in the nutrient cycle appear to be stronger in soils with a low nutrient storage and low fertility and weaker in more fertile soils. Once the vegetation cover is destroyed, the supply of organic matter and the formation of the new litter on the soil surface is slowed down whilst the breakdown of the organic matter is accelerated by solar radiation [87, p. 277].

Although the physico-chemical processes controlling the productivity and fertility of the soils and the turnovers of the nutrients are not completely understood, several lines of evidence suggest that the degree of weathering and textural characteristics of the soil play an important role in the nutrient cycle. High weathering rates result in excessive base-leaching and a low pH, creating a decline in base saturation, loss of major cations and a decrease in the cation-exchange capacity [66]. This promotes the occurrence of free iron and aluminium either in the clay complexes or as amorphous iron and aluminium oxides or hydroxides in the weathering layers. As amorphous iron and aluminium oxides readily absorb, phosphorus tropical soils with a low pH are often characterized by a high phosphorus fixation capacity, resulting in a phosphorus deficiency [85, 59]. According to studies in the Amazon of Brazil the fixation of phosphorus rather than the overall nutrient decline appears in many cases to be the cause of the decline in pasture productivity [69].

Soil erosion and intense leaching in soils are responsible for several problems concerning productivity in agricultural land use. In a case study carried out in Rwanda several green farming methods applied to highly degraded soils failed to restore the fertility of the soils [77]. Improved fallow, mulching, green manure and the use of compost and cow dung were not sufficient to maintain the nutrient levels in the soil as the rapid decomposition of the organic matter at the start of the rain season resulted in a release and leaching of high amounts of nitrogen and a rapid reduction in the fertility of the soils [77]. From the point of view of the sustainability any agricultural strategies being considered, the materials used for fertilizing the soils have to be inexpensive and available from regional or local resources. The improvement of the physico-chemical properties of highly degraded soils, on the other hand, depends on several-site specific and soil-specific factors, and additional information is frequently required on the dynamics of the soil. Important improvements usually involve increasing the pH. This reduces phosphorus fixation, the disintegration of chlorite structures and reduces antagonistic effects in cation exchange.

However, any application of material has to maintain the slow dissolution of cations from dissolved minerals and has to inhibit silica dissolution which often involves an increase in pH and results in an increase in the disintegration rate of chlorite structures [77]. In relation to the requirements specified in Rwanda, several tests with calcium carbonate, travertine and volcanic tephra indicated that the combined application of cow dung and tephra represents a measure capable of improving the agricultural capacity of the degraded soils [77]. However, soil erosion, nutrient cycles and soil fertility are highly interrelated and depend often on specific local and regional factors. Although quantitative data of soil erosion rates and depletion rates are important for the implementation of effective soil conservation measures, socio-economic factors and the understanding of the traditional/cultural background appear to be of equal importance because many conservation strategies may be impractical or too expensive or are rejected as a result of limited access to the technologies required.

4. Conclusion

Over the period of the last fifty years, most tropical mountains have experienced marked changes in their environmental conditions due to the high rate of deforestation, rural land use and urban growth. These changes have often reinforced hillslope processes such as soil erosion and landsliding and have also resulted in an increase of geomorphic hazards, even in areas with a previously lower susceptibility to soil erosion or landsliding. Increased rates of soil erosion and landsliding have been documented from regions where large areas are affected by human intervention and hillslope processes are highly interdependent and tend to reinforce each other. The changes have not only affected the hillslope system but have also influenced other subsystems of the geomorphic/ecological system, which has resulted in the coupling of different responses similar to "chain reactions". Such "chain reactions" appear to occur frequently when the urban fringe expands into mountainous terrains [38]. Urbanisation and deforestation increase the runoff and hence induce soil erosion whilst the increase in storm runoff results in the undercutting of hillslopes and landsliding, thereby increasing the supply of material to the rivers, which in turn, increases the likelihood of flooding.

However, the geomorphic response displays a high degree of spatial and temporal variability. Under similar geologic and bioclimatic settings, some landscapes tend to react rapidly to ongoing environmental changes whilst others tend to absorb the effects of environmental change, as the reaction is delayed or dampened in the various interconnected geomorphic/ ecological subsystems. Several factors contribute to the differences in the geomorphic response. The current state of the landscape, the degree of human modification of the landscape, the magnitude of climatically-driven events and the differing coupling strength between the long-term evolution of the hillslope system and the current hillslope processes. As geomorphic processes are triggered by separate events, the response to changes is a function of the magnitude and frequency of exogenous or endogenous events. With respect to rainfall-triggered events, the incidence of hillslope processes is often controlled by thresholds. However, these thresholds are continuously altered by human interference in the landscape, thereby increasing the risks of soil-erosion hazard and landsliding, though this interference is often necessary in that it benefits economic progress and advancement.

Disastrous landslide events are often closely associated with the expansion of the urban fringes into hilly and mountainous areas, and settlement activity in these areas has often resulted in the unsuitable modification of hillslopes, which, in turn, has increased susceptibility to mass movements [38, 53]. Although most of the recent landslide disasters are primarily controlled by geological, structural and environmental factors as well as by human interference, slope failure is often predisposed as a consequence of long-term evolutionary processes on the hillslopes. The dynamic coupling of existing controls and long-term evolutionary processes may result in the lowering of crucial thresholds. This includes the reduction of the shear strength by weathering processes, and the increase of shear stresses on the hillslopes caused by small subtle changes in slope angle and hydrology.

The intensity of human impact on tropical environments is documented in the large areas that have been subjected to deforestation. The impact has affected the geomorphic process-response system, the nutrient cycles, and biodiversity. Recent studies have shown that there is no reversal in the overall trend of tropical deforestation, though the rates of deforestation vary strongly from one decade to another and from one country to another, depending also on the methods used to assess deforestation [2, 28, 79, 39]. Estimates of the world-wide contribution of deforestation in the tropics to carbon emissions indicate a total emission of 810 $*10^6$ metric tonnes/year (period 2000 to 2005) excluding carbon emissions from logging, peatlands drainage and burning, and forest recovery [39]. However, the contribution of carbon emissions from tropical deforestation to global climatic change remains obscure as the turnover rates and recovery rates are related to various factors and the interaction between these factors is not completely understood [35, 38]. This applies also to the effects of global climatic change on the geomorphic process-response system as changes in magnitude and frequency of geomorphic processes depend also on all other environmental changes. Predictions on future climatic development trends in the tropics suggest an increase in summer monsoon and a decrease in summer rainfalls in Central America and Mexico and an increase in the number of cyclones, tropical storms and hurricanes [44]. However, human interference and climatic change often act simultaneously. This complicates predictions of crucial thresholds and the establishment of relationships between landsliding and large soil erosion events and the spatial distribution and the seasonal and annual variability of rainfall. The temporal clustering of landslide events in some regions, on the other hand, appears to indicate some associations. In Kenya landsliding was closely associated with the occurrence of El Niňo circulation [52]. In southern America, on the other hand, the temporal pattern of landslide events appears to coincide with the ENSO climatic cycle. However, hillslope processes are characterized by an intrinsic complexity. Many factors appear to be capable of causing changes in both frequency and magnitude on different spatial and temporal scales.

Studies on deforestation rates in several countries of humid tropical Africa have shown that the rate of forest destruction is not only a result of the growth in population but depends also on macro-economic changes. Apart from dependence on international market prices, the extent of the agricultural area appears to depend directly and indirectly on factors such as public investment, monetary policy and exchange-rate policy, urban income levels, fertilizer subsidies, and rural-to-urban and urban-to-rural migration [50, 64, 65]. With respect to the issue of sustainable development, socioeconomic factors must also be considered.

A significant statistical relationship has been determined between the decline of the cocoa and coffee prices and subsiding governmental input, which has forced farmers in Cameroon to expand their food and crop cultivation into forested areas [51]. International prices and demands on agricultural resources, on the other hand, often result in an expansion of agricultural areas at the expense of rain forests. An example is the expansion of agricultural areas for soybean production and the increase in cultivated pastures in Brazil, which resulted from the growing importance of cattle ranching. The expansion of soybean cultivation resulted in extensive clearance of savannah forests and of tropical forests and is noted to be the second most important driver of deforestation after ranching [43].

Socio-economic factors also play an important role in establishing new methods in agriculture to improve environmental quality. Financial aspects, work expenditure, the availability of resources necessary for carrying out improvements and the consideration of traditional agricultural techniques may determine the success of sustainable developments. Socio-economic aspects are also important in the mitigation of hazards in urban areas. Hillslopes prone to landsliding are often occupied as a result of the unplanned growth of cities and increases in rent and the declining availability of land for building in the cities to house the growing population [26, 4].

The complex interaction of socio-economic, biological, geological and geomorphic aspects indicates that sustainable development requires an interdisciplinary approach. With respect to environmental planning and sustainable development in the tropics, geomorphic studies of hillslope processes may contribute to unravelling the intrinsic complexity of various hillslope hazards. This takes in a multitude of objectives, which range from assessment of the severity of influences impacting on the environment, determination of the dominant processes and hazards, assessment of the vulnerability of specific sites, determination of external triggers and predictions of events which have no historically recorded precedent.

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Chapter 2

Conservation and Sustainability of Mexican Caribbean Coral Reefs and the Threats of a Human-Induced Phase-Shift

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Additional information is available at the end of the chapter

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1. Introduction

Natural ecosystems around the world are continually changing, but in recent decades it has become increasingly evident that terrestrial and marine environments are degrading. It is considered that the main cause is the rapid human population growth and increasing demand of resources for our survival. In particular for coral reef ecosystems, they are experiencing a significant change as reflected in the decline of coral cover and diversity of species [1, 2].

Coral reefs are marine ecosystems of great ecological and economic importance to mankind. These ecosystems are characterized by high productivity and biodiversity [3] caused by the high diversity of habitats created by its complex, calcium carbonate three-dimensional structure that facilitates the diversification of niches and space availability for the establishment of a variety species. Additionally, they serve as important spawning areas for breeding and feeding of the organisms that are part of the ecosystem [4]. The interactions that exist between the species that inhabit coral reefs create an ecological balance that maintains ecosystem functioning, which is reflected in its ability to maintain high productivity in these groups of reef-building coral species and fish, and play key roles in the regulation of ecological processes [2].

From the economic point of view, coral reefs supply mankind with such services as organisms for food, biochemical components, building materials, coastal protection against storms and waves, recreational opportunities and aesthetic and cultural benefits (see [4]). It is estimated that more than 100 countries have coastlines with coral reefs, and tens of millions of people depend on them as part of their livelihood or as part of their intake of protein [5]. It is noteworthy that the quantity and quality of these services depends on the health of coral reefs.

Unfortunately, many of these ecosystems are in serious state of degradation and it is considered that the health of coral reefs is in a worldwide crisis [6]. By 2008 it was estimated that coral reefs had effectively lost 19% of their original area, an additional 15% was seriously threatened and was considered to it will be lost within the next 10 to 20 years, while 20% are under threat with the possibility of being lost within 20 to 40 years. These estimates were made under a scenario of 'business as usual' and do not consider the threats posed by global climate change [7].

Paleoecologic work suggests that this pattern of degradation in various areas of the Caribbean is unprecedented within the past millennia. Also, there is no convincing evidence that global stressors (e.g. induced bleaching by temperature changes and reduced calcification rates via increasing levels of atmospheric CO_2) are responsible for the overall pattern of recent coral degradation, making it more likely that local stressors are responsible for the recent degradation occurred in the Caribbean [1]. In this sense, it is particularly evident that degradation of coral reefs occurs near densely populated areas, hence indicating that anthropogenic factors work synergistically against the stability of these ecosystems. Among these factors, the increased levels of nutrients and the over-exploitation of reef organisms are the best studied and considered to be responsible for the larger part of the impacts [8-9]. However, we cannot omit mentioning other impacts such as increased discharge of sediment and pollutants, uncontrolled tourism and introduction of new species (e.g., lionfish) and diseases [2,4, 10-11]. Added to all these factors is the threat of global climate change and the increased intensity of natural phenomena such as severe storms and hurricanes, and the development of the El Niño / La Niña - Southern Oscillation phenomenon --and their associated surface temperature change-- have contributed to the health degradation of coral reef ecosystems [12].

In many locations around the world the anthropogenic stress on coral reefs has exceeded the regenerative capacity of the ecosystems, causing dramatic changes in species composition and thus a severe economic loss [2]. This change in the structure and functioning of the ecosystem is known as “phase-shift” or alternative stable state; the most cited example is the shift from an original coral-dominated reef to one dominated by macroalgae[13-14], although several other transitions have been documented [2]. This phase-shift is a consequence of the loss of resilience, defined as the ability of an ecosystem to absorb perturbations, its resistance to change and its capability to regenerate after a natural or anthropogenic disturbance [15]. The degree to which the phase-shift --or alternative state-- is stable or reversible is poorly understood and represents one of the main challenges for research and management of coral reefs.

Given the nature of the problem and the huge importance of coral reefs to mankind, it is recognized that urgent action is needed to conserve and promote its sustainable use [7]. Thus, it is urgent to assess current management practices that focus mainly on safeguarding the biodiversity of coral reefs by delimiting marine protected areas (MPAs) where human activities are controlled, or prohibited in the case of fishing. This kind of management is increasingly prevalent. But if it succeeds by adequately fulfilling its objective, it would provide a spatial refuge for the organisms that are distributed within the area, allowing critical functional groups to persist, and so continue to build local resilience of the ecosystem. However, only a few marine protected areas meet its conservation and functionality goals. At the global scale, 18% of the coral reef area is within the boundaries of a marine protected area and only 1.6% of these are properly managed [16]. To adequately address the crisis requires that management efforts are based on a better understanding of the ecological processes that maintain the resilience of coral reefs. Managing for improved resilience, incorporating the role of human activities as shapers of ecosystems provides a basis for addressing the uncertainty of a changing environment [2].

2. The case of coral reefs in the Mexican Caribbean

The degradation of coral reefs in the Wider Caribbean is alarming. Population growth in the region has led to a combined effect of increased pollution and reduced herbivore populations as a result of overfishing and/or diseases [1,17]. These reefs are continually cited as examples of a phase-shift.

In the case of coral reefs in the Mexican Caribbean (from the Northern tip of the Yucatan peninsula to the southern international border with Belize) studies are scarce and the poor distribution of the information generated from implemented management programs limits our knowledge of these systems and the successes of the conservation programs. In this sense, the current status and health of the coral reefs of the Mexican Caribbean at the regional scale are not well known, but at the local scale, clear signs of deterioration have been reported in some reefs despite being designated and managed as protected areas. To achieve conservation and sustainable use of coral reefs requires a better understanding of the dynamics of these ecosystems and the processes that support or undermine resilience; we need reliable scientific information that can be used for management plans at local and regional levels. This study presents the ecological and hydrological characterization of thirteen coral reefs distributed within three National Parks in the Yucatan: Isla Mujeres-Cancun-Nizuc National Park (PNIMCN), the National Park of Puerto Morelos reefs (PNAPM) and Cozumel reefs National Park (PNAC) (Figure1) in order to present the current state of these reefs and identify possible causes of degradation, if present.

For the analysis of coral/benthic community structure we used the following benthic diversity indices: Margalef's D' index that measures species richness independently of the sample size, based on the ratio of the numberof species (S) and the total numberof individuals observed (N). Simpson's index of dominance (λ) that measures the probability from a non-repeated random draw of two organisms from a community, that they belong to the same species. The Shannon-Wiener's index of diversity (H') measures the degree of uncertainty in predicting to which species belongs an individual chosen at random from asample of Sspecies and Nindividuals. Pielou's index of evenness (J') which measures the proportion of the diversity observed in relation to the maximum expected diversity with values ranging from 0 to 1, where values close to1 means that all speciesare equally abundant [18]. We used multivariate techniques in order to statistically support the comparisons between localities, both in the community structure of coral and fish. A similarity matrix was generated using the Bray-Curtis coefficient of similarity; this coefficient measures the similarity between two samples with values ranging from 0 to 1, where values close to 0 correspond to different samples and close to 1 correspond to equal samples. Using the similarity matrix we performed an Analysis of Similarity (ANOSIM) for assessing the differences in community structure between locations. In addition a cluster analysis classification was performed in order to detect if a group of samples have more similarity to others within a group [19]. In the case of nutrient concentrations we applied a variance analysis (ANOVA) to detect statistically significant differences between the parks studied.

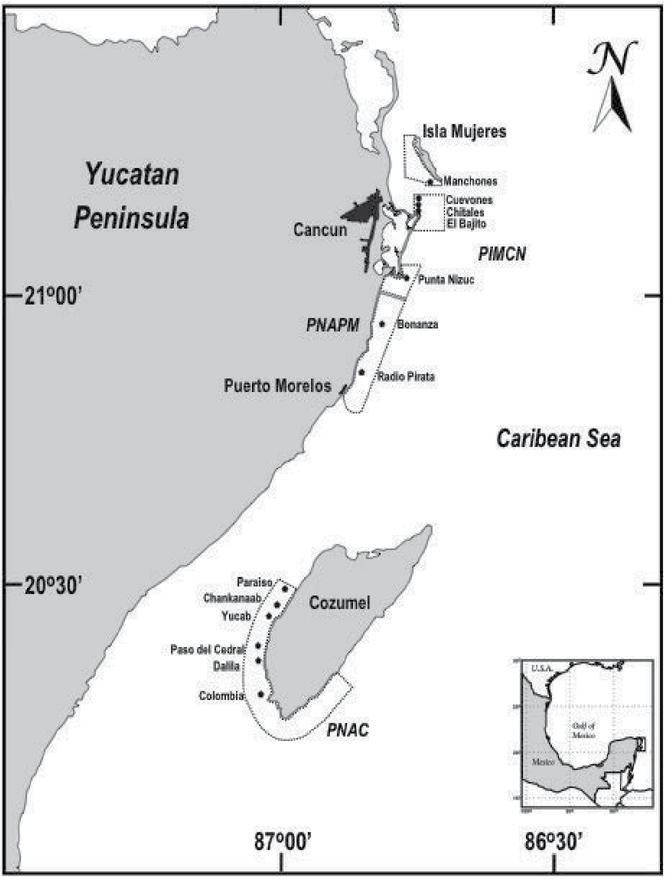

Figure 1. Sampling localities at the Marine National Parks of Isla Mujeres – Cancún – Nizuc (PNIMCN), Arrecifes de Puerto Morelos (PNAPM) and Arrecifes de Cozumel (PNAC) during 2006 - 2007.

3. Community structure of corals and benthic components

The three National Marine Parks were established to conserve the natural ecosystems found within the area, but human activities have not been restricted entirely, and instead, human settlements have increased on the coast, using these habitats for recreation and tourism as well as for fishing within in the limits of the Parks, poaching included.

In order to determine the current status of the coral reefs of the Yucatan Peninsula, an analysis of benthic components of each of these marine parks was conducted. The characterization of benthic components of the reefs provides information about the current health status of the ecosystem. The percentage of coral cover, macroalgae, seagrass, and other invertebrates, is reported from the sampled localities and subsequently analyzed their spatial and temporal variability. During the months of November 2006 (beginning of the dry season) and May 2007 (beginning of wet season) we surveyed the benthic composition of the coral reefs of the three marine parks using the Line Intercept Transect (LIT) method [20]. We surveyed five reefs at the PNIMCN, two reefs at PNAPM, and six reefs at PNAC (Table 1).

There were a total of 40 species of coral identified in the study area with the Cozumel Reefs National Park consistently containing the highest number of species: 25 coral species found at Paso del Cedral reef and 19 at Chankanaab reef (which is its maximum for this locality but the minimum for the PNAC). In general, *Porites astreoides* and *Acropora palmata* are the most abundant species in the Parks of Northern Quintana Roo, i.e., in Isla Mujeres - Cancun - Nizuc and Puerto Morelos. In the reefs of Cozumel, the most abundant species are *Agaricia agaricites* and *Siderastrea siderea*. Of all the coral reefs studied, Chitales reef, located at Punta Cancun, is the one with the lesser number of species (only seven species) (Table 1).

As for the diversity indices, we see a decrease, both in diversity and in species richness from South to North along the Quintana Roo coast; Cozumel reefs have the highest richness index, being Dalila reef the one with the highest value of D '= 6.97. Also, Chankanaab reef together with ‘Colombia’ reef presented the highest diversity values of H' = 2.19 nits/Ind and H' = 2.18 nits/Ind, respectively. Diversity indices decrease towards the North, with theChitales reef having the lowest diversity value of H '= 1.60 nits/Ind. Based on the Pielou evenness index, the benthic community structure appears to be distributed evenly because the index values are relatively high; this is reinforced by the Simpson dominance index values obtained (Table 1) for Punta Nizuc reef ($\lambda = 0.27$) and for Yucab reef ($\lambda = 0.19$).

With regard to the percentage coral cover and macroalage a trend can be observed contrary to the diversity indices and the number of species as the highest percentage of coral cover was observed in the reefs of northern Quintana Roo. Particularly Yucab reef at PNAC had the highest diversity and species richness but was the one with the lowest coral cover. In the case of algae cover there is also a decrease from North to South, as the National Reef Park Isla Mujeres- Cancun -Nizuc (PNIMCN) have the highest percentages in algal cover decreasing to 17.01% in Cozumel (Figure2). Consistently, always PNIMCN reefs have higher algal cover compared to coral. At the reefs of PNAC algal cover is consistently less than algal cover at PNPM and PNIMCN.

	Reef Loc.	Coral (%)	Algae (%)	No. of sp.	Richness (D')	Eveness (J')	H' (nits/indv)	Dominance (λ)
PNIMCN	Manchones	27.00	48.00	13	3.64	0.69	1.78	0.24
	Cuevones	26.20	41.60	10	2.76	0.73	1.68	0.24
	Chitales	16.91	49.09	7	2.12	0.82	1.60	0.25
	El Bajito	16.17	50.17	17	5.75	0.73	2.07	0.21
	Punta Nizuc	17.40	58.00	14	4.55	0.71	1.88	0.27
PNAPM	Bonanza	12.40	41.20	12	4.37	0.77	1.93	0.21
	Radio Pirata	27.60	20.60	12	3.32	0.80	2.00	0.19
PNAC	Paraiso	11.32	24.51	14	5.40	0.77	2.03	0.18
	Chankanaab	15.69	39.31	17	5.84	0.77	2.19	0.15
	Yucab	9.31	17.01	15	6.50	0.73	1.96	0.19
	Paso del Cedral	18.33	21.18	18	5.93	0.72	2.09	0.20
	Dalila	18.40	32.57	21	6.95	0.69	2.09	0.22
	Colombia	22.22	21.88	16	4.85	0.79	2.18	0.14

Table 1. Ecological Indices for the coral reefs of three marine national parks studied in northern Quintana Roo (PNIMCM: ParqueNacional Isla Mujeres,Cancún, Nizuc; PNAPM: ParqueNacionalArrecife de Puerto Morelos, PNAC: ParqueNacionalArrecifes de Cozumel)

In order to simplify comparison of benthic component data obtained from the different reef localities, we formed a single component group called abiotc components by grouping bottom components such as rocks, sand, dead coral and other non-living components.

It is important to note that while Cozumel reefs have the highest species richness and diversity, and reduced algal cover, these reefs are characterized by a higher percentage of abiotic components (above 40%). In the case of Northern reefs it is the algae that contributes to the higher percentage of benthic components (Figure3). In the case of the reef sites of Punta Nizuc, Bonanza and Radio Pirata are characterized by the presence of seagrasses.

Applying the ANOSIM similarity analysis significant differences were detected between the various reefs studied ($R = 0.497$, $p = 0.001$), except for El Bajito reef, which in terms of the structure of benthic components it was not significantly different from Chitales reef ($R = -0.006$, $P = 0.51$), being the two reefs part of the same national park (PNIMCN). At the Cozumel Reefs National Park, the Paso del Cedral reef and Delilah reef, Paraiso reef and Chankana'ab reef are the only reefs that present no significant differences in the structure of benthic components ($R = 0.047$, $P = 0.142$; $R = -0.039$ $p = 0.75$). This can be confirmed by a cluster analysis, that based on a similarity matrix generated using the Bray-Curtis, can be seen that the diagram is clearly divided into two groups separating Cozumel reefs park (PNAC) from the parks of Puerto Morelos (PNAPM) and Isla Mujeres-Cancun-Nizuc (PNIMCN); and within this latter group, the separation between Puerto Morelos and PNIMCN can be clearly seen (Figure4).

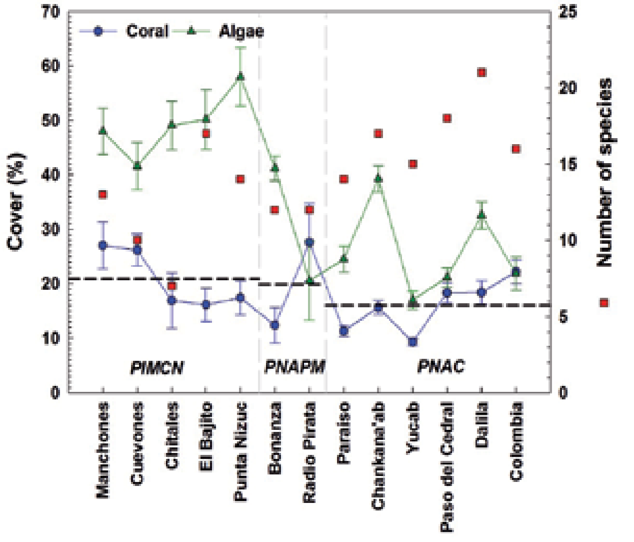

Figure 2. Coral and algal cover (percentage) at the Northern Quintana Roo National Reefs parks for the years 2006-07. The dashed line represents the average coral cover (percentage) for each park.

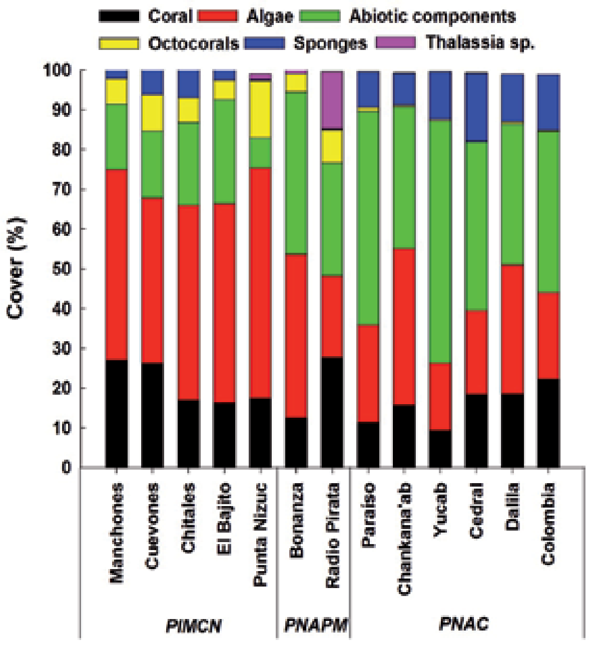

Figure 3. Benthic components of the coral reefs at three National Marine Parks in Northern Quintana Roo during 2006-2007.

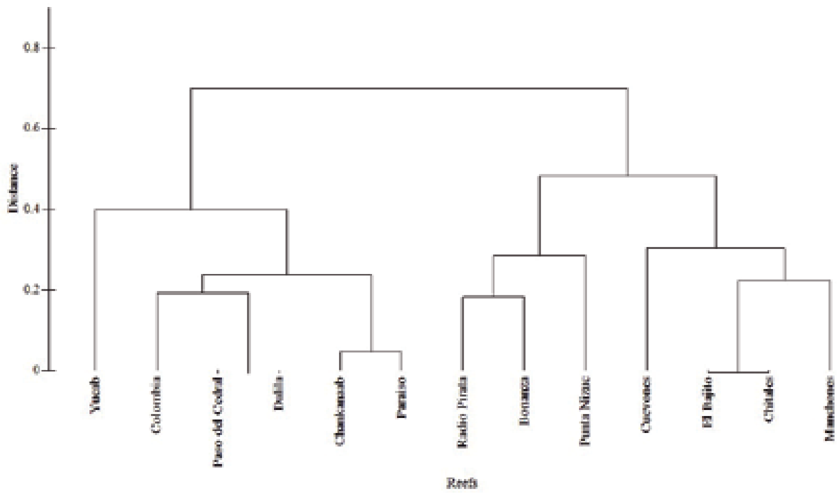

Figure 4. Cluster analysis of the coral reefs of Northern Quintana Roo (data for 2006-2007).

4. Hydrology: Nutrient concentrations

The increase of anthropogenic nutrients is attributed to be a major cause of increased algal cover in coral reef ecosystems, based on the theory that in some reefs bottom-up ecological control in food chains regulates ecosystems. In order to try to better understand the processes that regulate ecosystem resilience we additionally characterized the hydrological conditions throughout the three marine parks studied here. Samples were taken from different stations distributed on the same reefs where benthic surveying was conducted (Figure 5a,b), additionally including the hydrologic (nutrient) characterization of the Nichupte Lagoon, bounded to the north by Punta Cancun and to the south by Punta Nizuc (Figure 5a). In order to characterize the concentration of nutrients, particularly from dissolved inorganic nitrogen (DIN) species that involve inorganic nitrogen: nitrate (NO_3^-), nitrite (NO_2^-) and ammonium (NH_4), water samples were collected at two different depths: at the water surface and near the substrate. Sampling was conducted in the months representing contrasting seasonal conditions (dry and rainy seasons) in the years 2006 and 2007.

The average concentration of DIN in the sampled coral reefs is shown in Table 2. By applying a factorial ANOVA considering the different climatic seasons and parks there were no significant differences in the concentration of DIN (F = 0.422, p = 0.657) but between the dry and rainy seasons (F = 9.280, p = 0.003). Consistently, one can observe a slight increase in the concentration of dissolved inorganic phosphate (DIP) in the three parks during the rainy season; this increase is mostly evident in the PNIMCN and PNAPM, because it almost doubled the average concentration measured during the dry season (Figure 6). As was expected for Nichupté Lagoon, it was characterized by a higher concentration of DIN with respect to the levels seen at the reef sites. In addition, Ni-

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chupté lagoon presents an opposite behavior to reef sites as a function of seasonality: while during the rainy season the DIN increases reefs, the concentration decreases in the lagoon, probably due to dilution effect (Table 2, Figure 6).

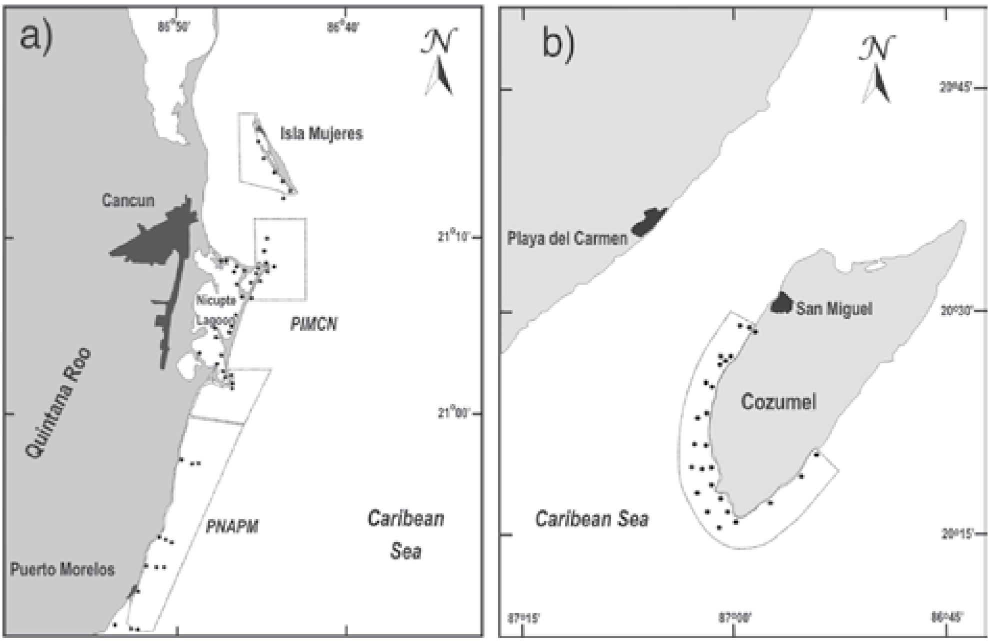

Figure 5. Sampling locations in the PNIMCN and PNAPM (a) and in the PNAC (b), used for characterizing the nutrient levels in the coral reefs of Northern Quintana Roo during 2006 – 2007.

Location	Season	DIN (μM)	Nitrate (μM)	Nitrite (μM)	Ammonium (μM)	Phosphate (μM)	Silicate (μM)
Nichupté-Lagoon	Dry	14.77	2.08	1.08	11.61	0.18	5.50
	Rainy	4.18	1.08	0.16	2.94	0.33	7.98
PNAC	Dry	1.26	0.60	0.09	0.58	0.26	6.48
	Rainy	1.96	0.54	0.09	1.33	0.29	4.58
PNAPM	Dry	0.91	0.25	0.09	0.57	0.24	3.15
	Rainy	2.15	0.53	0.04	1.58	0.16	1.85
PNIMCN	Dry	0.86	0.17	0.10	0.59	0.23	4.42
	Rainy	1.50	0.46	0.07	0.98	0.28	2.30

Table 2. Average nutrient concentration in the Nichupté-Lagoon and the coral reefs of three National reef parks of Northern Quintana Roo during 2006 – 2007.

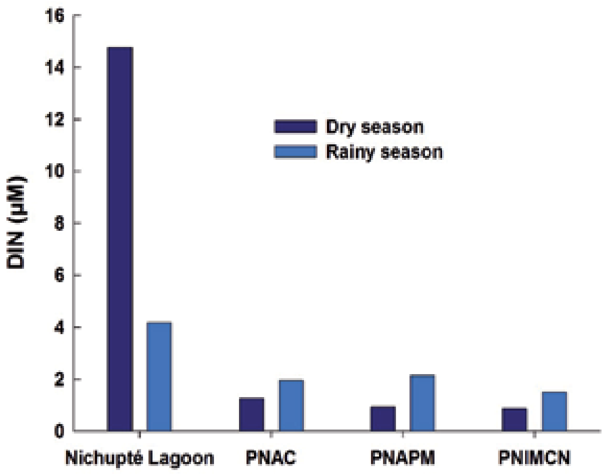

Figure 6. Average DIN concentration (µM) in in the Nichupté-Lagoon and the coral reefs of three National reef parks of Northern Quintana Roo (PNAC, PNIMCN, PNAPM) during 2006 – 2007 in two climatically contrasting seasons (rainy and dry).

Ammonium (NH_4) is the most important DIN species in the reef waters. Its concentration is consistently higher than nitrates and nitrites, except for the PNAC during the dry season in which ammonium and nitrate have approximately the same concentration (Figure 7). It was expected that ammonia were the most important DIN species, since the success of high productivity of coral reefs results from the high nutrient recycling that takes place within the ecosystem. Most of the new nitrogen entering the reef is through N2 fixation, so it is absorbed and converted to organic nitrogen which can be later consumed and passed through the food webs or returned to the system as ammonia by passing through the process of ammonification, so it is excreted in the urine of organisms [21].

During the dry season, there is no significant difference among the three species of DIN in the three parks, however the average concentration of nitrate is higher in the PNAC. During the rainy season nitrate concentration is high in all parks but ammonium is significantly higher, being PNAPM the park with the highest ammonium concentration (Table 2, Figure 7).

The hydrographic information generated in this study indicates that there is no evidence of eutrophication in reef areas in the Mexican Caribbean. In general, nutrient concentrations are low, typical of the reef zones of the Wider Caribbean. The general average of DIN (1.3 ± 1.6 µM) in the Northern Quintana Roo reef parks is lower than that reported for the Florida reef tract (4.3 ± 7.4 µM; [22]) and within the observed range of the coral reefs of Tobago (1.6 ± 1.1 µM; [23]).

It has been shown that groundwater seepage into the coastal area of this region can supply significant amounts of nutrients to the water column [24-25]. However, a study in seagrass meadows of *Thalassia testudinum* in Puerto Morelos reef lagoon has shown that water seeping through the springs (locally called 'ojos') can enrich the water column -- and seagrasses-- with phosphorus, but not with nitrogen [25]. These authors found that in *T. testudinum* meadows of Puerto Morelos, the pore water contains extremely low levels of nutrients (1.2 - 3.42 μM of ammonium and 1 - 1.5 μM of phosphate) compared with the world average for seagrass meadows (~ 86 μM of ammonium and 12 μM of phosphate). This low DIN concentration in the water column of Puerto Morelos suggests that nitrogen could be limiting the growth of seagrass meadows. The nitrogen content in the tissue *T. testudinum* in the reef lagoon (% N> 1.8), however, is high enough to not show this limitation [25].

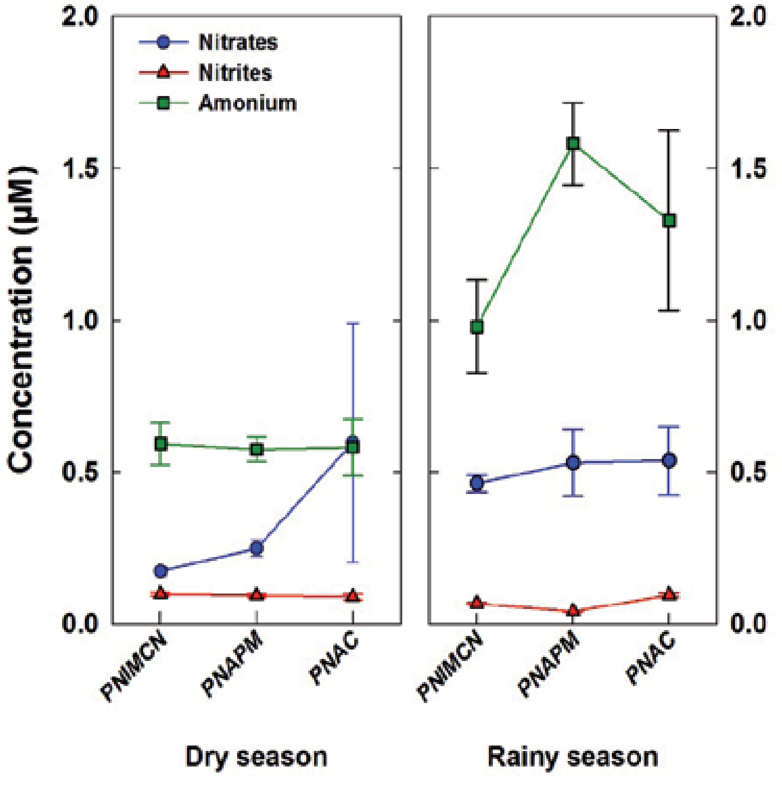

Figure 7. Average DIN concentration in the coral reefs of three National reef parks of Northern Quintana Roo (PNAC, PNIMCN, PNAPM) during 2006 – 2007 in two climatically contrasting seasons (rainy and dry). ANOVA statistical test (bars represent Std. Error).

In contrast to the typical oligotrophic conditions that characterize coral reef areas, nutrient concentration inside the Nichupté Lagoon system is much higher. The weighted average concentration of DIN inside this lagoon system (14.7 ± 11.6 μM for winter and 4.18 ± 1.98 μM for summer) is between 2-7 times higher than the DIN average measured in Puerto Morelos, the coral reef area with the highest average DIN concentration (2.15 ± 0.84 μM) of our study area. These results, however, were expected because this lagoon system receives wastewater from the surrounding developments. After a few decades of continuous supply, there are now evident signs of eutrophication [25-26]. In spite of this situation, our results indicate that reef areas developing outside this lagoonal system are not affected, so far, in their hydrographic characteristics.

Favorably, the reef systems along the Mexican Caribbean coast still thrive under low nutrient concentrations. However, the low concentrations of DIN in the coastal waters and the evident overgrowth of macroalgae on the reefs studied suggest the existence of diffuse nitrogen sources fueling their growth. Nitrogen fixation could be a major source for these reefs (see further evidences of this in the isotopic section),and if this nitrogen source dispersed through the water column, it would raise the DIN up to 0.3 μM day^{-1}[25]. This assumption is reasonable, especially when considering that the nitrogen isotope values ($\delta^{15}N$) in the tissues of macroalgae growing on these reefs (see below) are very close to the isotopic composition of atmospheric nitrogen ($\delta^{15}N_2$ = 0‰). This new nitrogen, however,may pass "undetected" in our monitoring sampling because it may be immediately assimilated by the macrophytes upon entering the coastal zone where the coral reefs develop. In this regard, the actual macrophyte biomass itself may be the best evidence of large nitrogen inputs into the otherwise oligotrophic environments that characterize coral reefs, where macrophytes' occurrence is commonly very scarce.

5. Isotope systematics of $\delta^{15}N$ in macroalgae

In order to differentiate potential sources of nitrogen to the reef zones we analyzed the nitrogen isotopic composition ($\delta^{15}N$) of the tissue of several species of macroalgae collected from reefs studied. The $\delta^{15}N$ of macroalgae has been a widely used as tracer of nutrient dynamics [27] This approach has been applied mainly in areas where nutrient sources are diffuse or little obvious, but also in areas where sources are very different, such as nutrient inputs from sewage. However, the spatial extent of its influence is not clear [28-29].

The $\delta^{15}N$ values of macroalgae from the different reefs of the three national marine parks are shown in Figure 8. The more common genus found in the study area were *Dyctiota* spp. and *Halimeda* spp., followed by *Penicillus pyriformis*, *Ulotrix* spp. and the seagrass *Thalassia testudinum*. We grouped all species by location and compared the average-$\delta^{15}N$ (± 1SD) of macroalgae between locations and sampling period (Figure 8a for winter-2006, and Figure 8b for summer-2007). For reference, we have included in this figure the average nitrogen isotopic composition of nitrate ($\delta^{15}NO_3$ = 4.37 ± 2.5 ‰) for the three parks (Carriquiry unpublished data). The validity of this reference comparison rests on the assumption that nitrate is a major source of nitrogen for macroalgae.

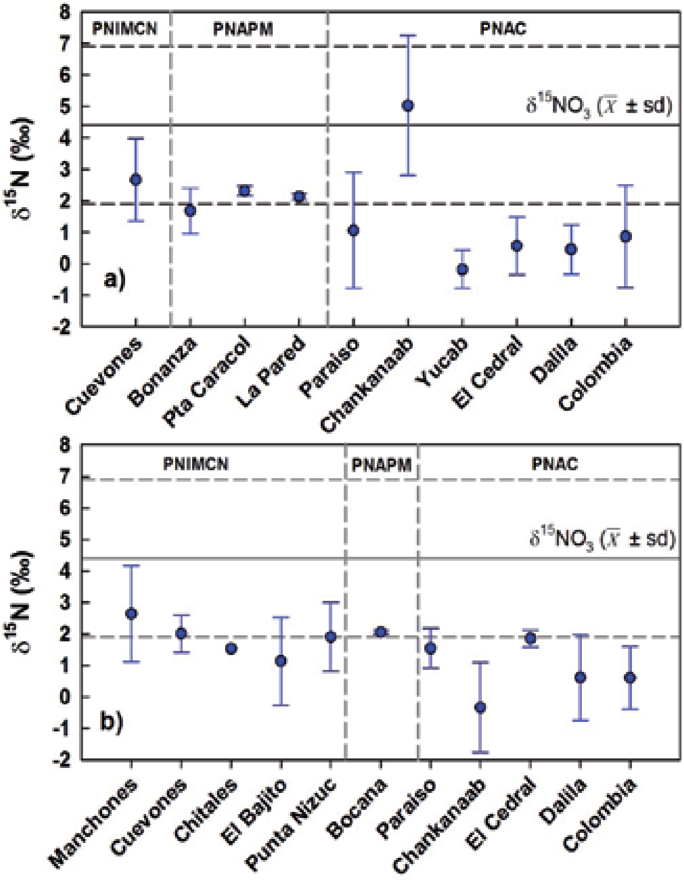

Figure 8. Average $\delta^{15}N$ composition (± 1SD) of macroalgae collected at each site during the winter of 2006 (a) and the summer of 2007 (b). The average isotopic composition of nitrate ($\delta^{15}NO_3$) in the coastal waters (Carriquiry, unpublished data) of the three coral reef national parks studied here is included as a thin horizontal line in each diagram.

A common feature for both collection periods is the low $\delta^{15}N$ values of macroalgae. During winter-2006, with the exception of Chankanaab reef at PNAC ($\delta^{15}N$ of 5.0 ± 2.2 ‰), the $\delta^{15}N$ of macroalgae is less than 3 ‰ and is markedly smaller than the isotopic value of nitrate ($\delta^{15}NO_3$) (Figure8a). As in the winter of 2006, the average $\delta^{15}N$ of macroalgae during the summer of 2007 varied from ~ 0.5 to 2.5 ‰, being always below the average $\delta^{15}NO_3$ (Figure 8b).

It is noteworthy to highlight the results obtained from Chankanaab reef (at PNAC) which shows the greatest contrast in the average $\delta^{15}N$ of macroalgae between sampling seasons: while the average $\delta^{15}N$ of macroalgae was the most positive of all sampling stations during the winter of 2006 (Figure 8a), during the summer of 2007 Chankanaab reef presented the most negative $\delta^{15}N$ values (-0.34 ± 1.43 ‰) of all the studied sites (Figure 8b). One factor that may explain this discrepancy is the difference in species composition between sampling sites. While in the winter of 2006 the $\delta^{15}N$ was measured in *Dyctiota* spp. and *Penicilluspyriformis*, during summer 2007 the species analyzed were *Lobophoravariegata*, *Dictyosphaera cavernous,Anadyomenestellata*and *Ulotrix* spp. The results for species indicates that the $\delta^{15}N$ of *Dyctiota* spp. and *P. pyriformis* were characterized by positive values in both sampling periods, while the species *L. variegata* always showed low $\delta^{15}N$ values, including *A. stellata* whose measured $\delta^{15}N$ was the most negative (-1.67 and -1.42 ‰ for Chankanaab and Dalila, respectively) in both sampling periods.

There are several alternatives to explain the low $\delta^{15}N$ values of macroalgae in this region. N_2 fixation in coral reefs is regarded as a major component of the nitrogen cycle that provides new nitrogen for these ecosystems. It has been estimated that fixed nitrogen can supply from one quarter to one half of the nitrogen requirements for the primary producers in these oligotrophic environments [30]. It has been shown in coral reef areas where nitrogen fixation is predominant that $\delta^{15}N$ value of macroalgae is close to 0 ‰, or even negative [31,32]. In agreement, the range of $\delta^{15}N$ values measured in the different species of macroalgae (<0 to <2.5 ‰) in our study, indicates that N_2 fixation may be playing an important role in fulfilling the macrophytes' nitrogen demand. This conclusion is also supported by [25] who found that the $\delta^{15}N$ values of 1.9 ‰ in the seagrass *Thalassia testudinum,* in Puerto Morelos lagoon, were the result of nitrogen fixation.

Alternatively, another possibility is the low concentration of dissolved inorganic nitrogen (DIN) in the studied reefs. Different studies have shown a positive relationship between the $\delta^{15}NO_3$ *versus* nitrate concentration [NO_3], both in temperate and tropical areas. It was found in a Massachusetts estuary that the $\delta^{15}NO_3$ values approach 0 ‰ when the nitrate concentration is reduced to levels <1 uM [33]. Similarly, other results obtained by [34]from the Mexican Caribbean reported that $\delta^{15}NO_3$ decreases linearly with the concentration of nitrate in the water column.Thus, consideringthe low DIN concentrations that characterizeour study area it would be expected that the $\delta^{15}N$-DIN available for macroalgae should be characterized by lower values.

Lastly, changes in the proportion of the different nitrogen species available for photosynthesis could explain the lower values in $\delta^{15}NO_3$. In our study, ammonia accounts for 60 to 76% of the DIN levels. This implies that ammonium, but not nitrate, could be the main source of nitrogen to seaweeds in the region. Hence, the $\delta^{15}N$ of macroalgae largely reflects the isotopic signature of ammonia. This hypothesis, although plausible, depends on the metabolic capacity of each species for using ammonium, depending on its availability in the environment.

6. The functional role of reef fish

Fishes are particularly recognized for their role as the main drivers of energy flow in coral reefs and can be separated into two major functional groups: the grazers or herbivores that regulate the abundance and community structure of algae; and corallivorous that selectively feed on coral tissue. Its importance, in addition to controlling the population of primary producers is that their feeding activity promotes biodiversity, since consumption of algae and coral leaves available space for colonization of new individuals or species [35]. Another important group are the predators as they play an important role in the ecosystem because they occupy the highest level in food webs, and from this position they regulate the organisms that are in the lower trophic levels. Additionally, they connect the dynamics of other communities and ecosystems that are apparently distinct as they often travel long distances. It has been suggested that the predator's ability to travel great distances in response to changes in prey abundance is important for maintaining stability of food webs [36]. Consequently, the loss of top predators could destabilize ecosystems through a chain reaction that eventually propagate down through the food web. With this in mind, the biomass of herbivorous and predatory fish have been calculated in order to determine whether there is spatial variability in these functional groups.

There is a close link between the fish community and benthic components, as any change in the structure of one of these communities has an effect on the structure of the other. [37] pointed out that in quantitative studies during the 80's reported high densities of predators, like sharks and groupers, associated with areas of high coral cover. Currently, the presence of large top predators is rare and is considered that the decrease in the abundance of this group has strongly affected the trophic flow patterns in reef communities [38]. In addition, the decrease in coral cover in coral reefs has been related to the decrease in the abundance and diversity of reef fishes [39].

In order to gain a better understanding of the role of fishes in our study area, we analyzed the community structure of reef fish sampled at PNAPM and PNAC; for PNIMCN we only had data for Manchones reef. By applying a similarity analysis (ANOSIM) to the abundance data, significant differences in the structure of the fish community were detected in these locations ($R = 0.442$, $p < 0.0001$). Paired tests showed significant differences between all locations, except Yucab and Paraiso Reefs ($p = 0.09$), and Yucab and Paso Cedral reefs ($p = 0.23$); also Dalila and Colombia do not show significant differences ($p = 0.20$). Using cluster analysis, based on a similarity matrix generated using the Bray-Curtis index, can be seen again the grouping of localities from each national park, leaving the Manchones reef alone as an isolated entity (Figure 9).

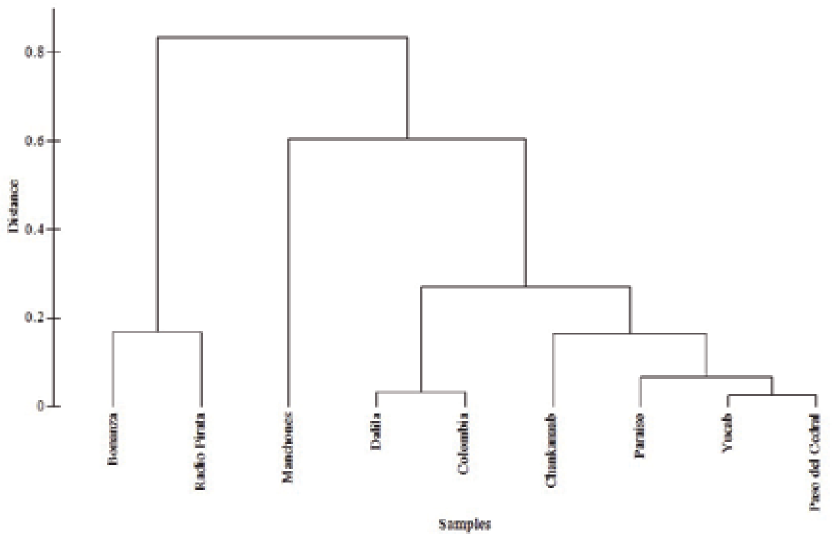

Figure 9. Cluster analysis of the reef fish community in northern Quintana Roo (2007 data).

The differences in the structure of the fish community, can be as well associated with structural differences in the benthic composition of the reefs, as the decline in coral cover reduces the structural complexity of the reef and therefore the space available for shelter and feeding [39] (Figure 10).

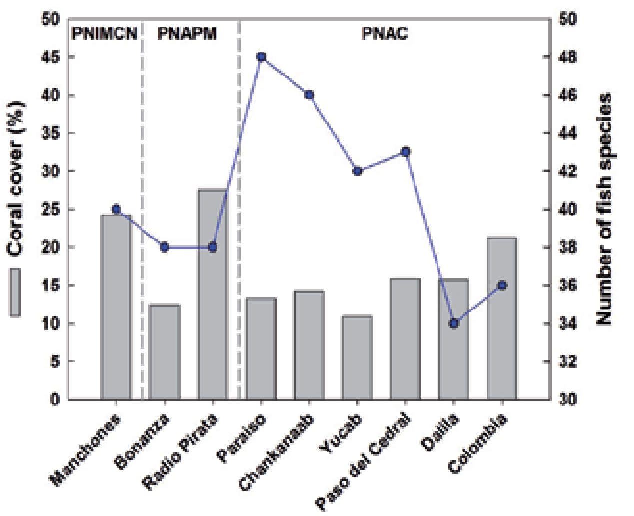

Figure 10. Trends in fish species richness and coral cover in the three national coral reef parks of Northern Quintana Roo, Mexico.

As to the relative abundance of trophic guilds, we can observe that higher predators generally have little relative abundance or simply not recorded during surveys, being Radio Pirate reef in Puerto Morelos, as well as Dalila and Colombia reefs in Cozumel were the only coral reefs where this trophic guild was recorded. The relative abundance of carnivores is up 50% Chankana'ab and Paso del Cedral reefs, however this trophic group also characterized by small fish whose dietary components include small invertebrates. Another group that has a high relative abundance of 60% and 50%, in Colombia and Dalila reefs respectively, are the herbivores (Figure 11).

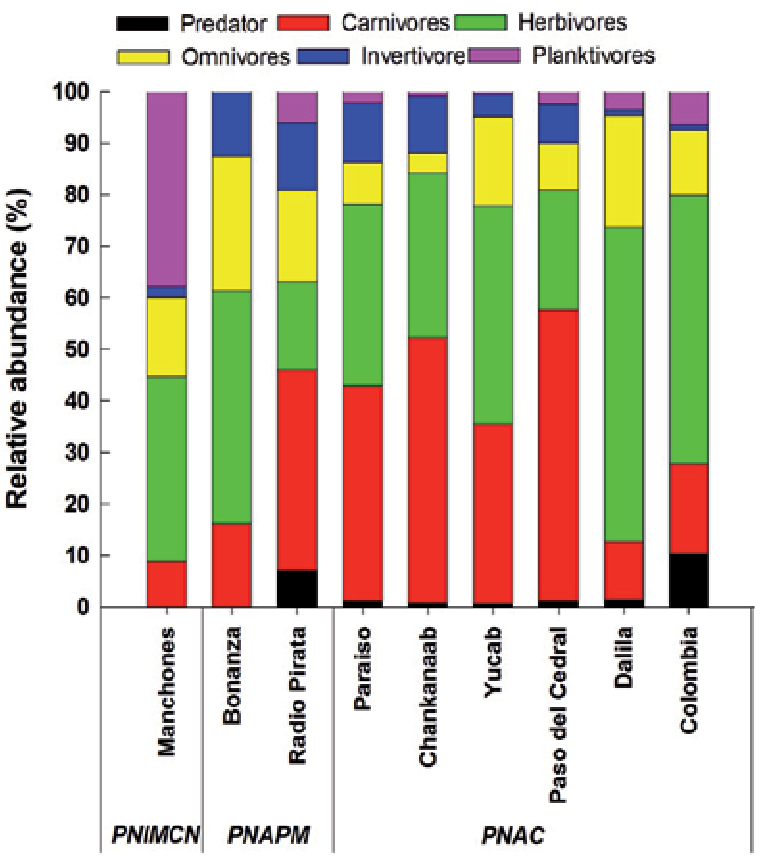

Figure 11. Relative abundance of the trophic guilds of the fish community associated with the coral reefs of northern Quintana Roo (2007 data).

Using the information of the size structure of three reefs (Manchones, Bonanza and Radio Pirata reefs) we calculated the relative biomass of the different trophic guilds using length – weight parameters for each species available at fish base [40]. This information allows assessing the degree of disturbance in the communities of each reef studied. In stable conditions or of low-disturbance, the dominant species of large size and longevity (K-strategists) are dominant in biomass and have low abundance. There are also present in the communities r-strategy species, opportunistic species with a short lifetime that are dominate in abundance but have low biomass contribution. When a community is disturbed, K-strategy species are usually not favored and opportunistic species increase in numbers and biomass [19].

For Radio Pirate and Bonanza reefs we can see that the relative biomass of carnivores is high (>50% of the biomass), however, the relative biomass of larger predators is virtually nonexistent. In the case of Manchones reefs, the herbivores contribute in greater proportion to the biomass (Figure 12). Such inverted biomass pyramids of fish have been reported in coral reefs characterized by low coral cover. To maintain these typesof biomass pyramids, however, a high primary production is required [37].

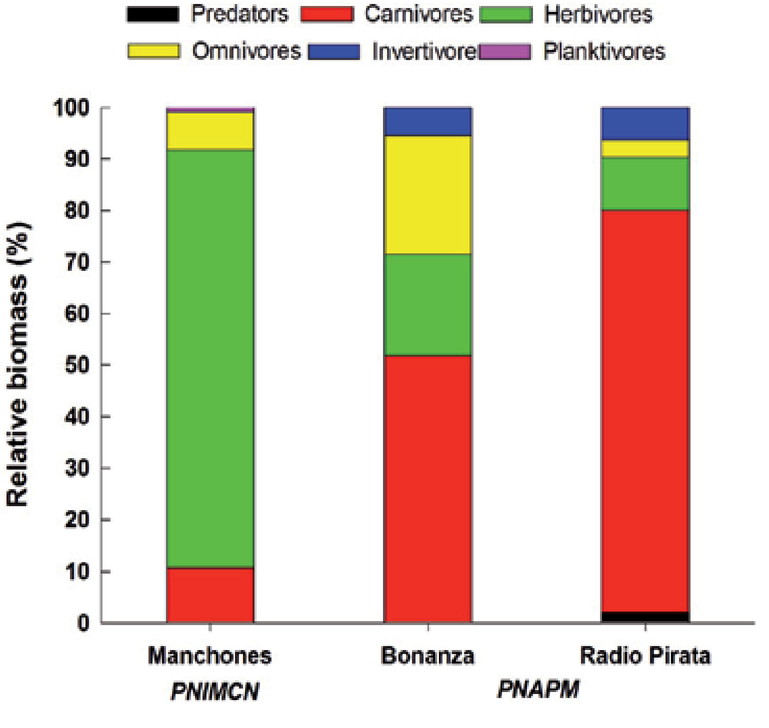

Figure 12. Relative biomass of trophic guilds in reef fish communities of northern Quintana Roo coral reefs (2007 data).

Additionally, a comparison analysis chart of abundance/biomass (Abundance / Biomass Comparison - ABC plots) was performed. This method presents a statistical test (W) that represents the abundance over biomass in a range of -1 to +1; if the statistical test generates a +1, biomass dominates over abundance and represents a system with no impact. On the contrary, when the result is -1, abundance dominates over biomass indicating that the system has been highly impacted. Values near zero indicate an intermediate disturbance [19].

In the case of reefs for which we had data on both, abundance and biomass, we obtained W = 0.146, indicating that the fish communities of these reefs are under a scenario of intermedi-

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ate disturbance (Figure 13) that may result either from the degradation of their habitat or the effect of fishing and poaching that take place in these reef locations [41-43]. This analysis allow us to conclude that It is essential to conduct a monitoring program of the fish community structure, and their biomass, to better assess their status and how they contribute to the functioning of these ecosystems.

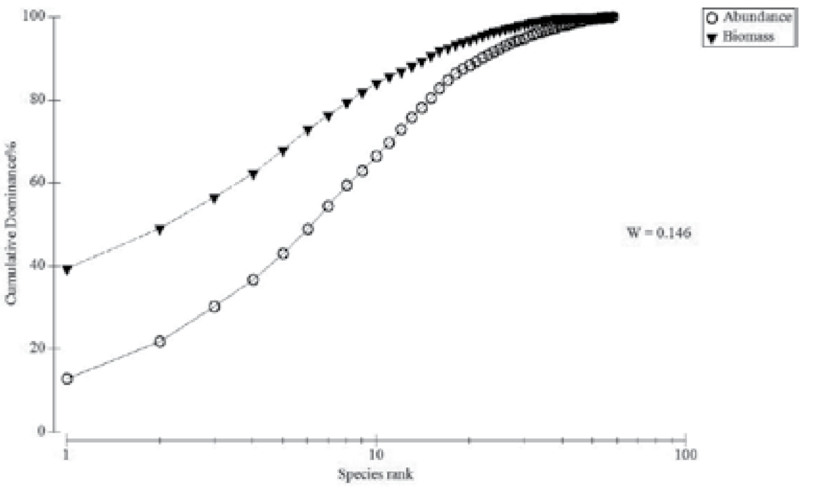

Figure 13. ABC-plot of reef fish for three coral reefs (Manchones, Bonanza and Pirate Radio) of northern Quintana Roo (2007 data).

7. Conclusion

The isotopic composition of algal tissue, along with the concentration of DIP and its various species, suggests that the low coral cover on reefs is caused by other factors rather than eutrophication of ecosystems. Plausibly, this may be an indication of reduced herbivorous-fish biomass, which is a key factor that regulates the abundance of macroalgae.

With regard to the fish community structure our results suggest an evident impact in the way biomass is distributed per trophic level, where large predators and consumers have significantly decreased. This type of inverted pyramids in fish biomass has been documented in other reef systems that show signs of anthropogenic disturbance, mainly by overfishing [37].

Fishing is the major environmental and economic problem facing most marine ecosystems, where pressure is exerted mainly on higher trophic levels in search of the largest fishes, and consecutively reducing the abundance and biomass of large predators, planktivorous and herbivorous fish, thus lowering the trophic level of the catches [2]. The ecological function of the fish is of great importance in the recovery and resilience of coral reefs and is likely to depend not only on food preferences of a trophic guild (e.g. herbivory), but also in the abundance and biomass of fish. Unfortunately, the limited information about fish populations prevent us to establish a reliable baseline for the coral reefs in the northern Mexican Caribbean describing an undisturbed ecosystem that can be used to compare with other coral reefs in the wider Caribbean. Most of fish studies mostly focus only on single fish taxon, which does not provide relevant information required to describe the conditions of the community. Thus, assessing the ecological effects of the loss of predators is difficult, but it is well documented that the decrease of fish diversity and of important functional groups (herbivores) brings significant structural impacts through food webs and benthic community, and ultimately in the functioning of coral reefs [8, 38].

The ecological symptoms of a coral reef with probabilities of collapsing (a phase-shift) are likely to include the loss of macro-fauna, reduced fish stocks, a change in the ecological role of herbivorous fish that are replaced by only one species of echinoid, destructive over-grazing and bioerosion due to food limitation suffered by sea urchins, and reduced coral recruitment. To be able to efficiently address the current global crisis of coral reefs, it is urgently needed to be able to generate information that allows us to assess the current status of these ecosystems. It is also required the active management of human activities that modify the essential ecological processes and functions of coral reef ecosystems.

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Chapter 3

Coping Mechanisms of Plants to Metal Contaminated Soil

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Additional information is available at the end of the chapter

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1. Introduction

Metals such as cobalt (Co), copper (Cu), iron (Fe) and nickel (Ni) are essential for normal plant growth and development since they contribute to the function of many enzymes and proteins. However, metals can potentially become toxic to plants when they are present at high levels in their bioavailable forms (Hall, 2002). Phytotoxic levels of one or more inorganic ions in soil can be found in various parts of the world. These toxic sites occurred through natural processes or by anthropogenic effects. Naturally toxic soils include saline, acidic and serpentine soils, while anthropogenic polluted soils occur through mining activities, aerial fallout, and the run-off from galvanized sources of electricity pylons or motorway verges polluted by vehicle exhaust fumes (Bradshaw, 1984). The biochemical effect of metals on plants varies and the excess metal usually results in oxidative damage which affects their phenotype (Kachout *et al.,* 2009)

Plants colonizing metal-contaminated soils are classified as resistant and have adapted to this stressed environment. Heavy metal resistance can be achieved by avoidance and/or tolerance. Avoiders are plants that are able to protect themselves by preventing metal ions from entering their cellular cytoplasm, while tolerant plants are able to detoxify metal ions that have crossed the plasma membrane or internal organelle biomembranes (Millaleo *et al.,* 2010). Based on strategies used by plants growing on metal-contaminated soils, Baker and Walker (1990) classified them into three categories; metal excluder, indicators and accumulators/hyperaccumulators. The excluder group includes the majority of plant species that limit the translocation of heavy metals and maintain low levels of contaminants in their aerial tissues over an extensive range of soil concentrations. Plants that are metal indicators accumulate metals in their harvestable biomass and these levels generally are reflective of the metal concentration in the soil. Metal accumulators/hyperaccumulators are plants that increase internal sequestration, translocation and accumulation of metals in their harvestable biomass to levels that far exceed those found in the soil (Mganga *et al.,* 2011; Baker and Walker 1990). Plants can accumulate and cope with the effects of high internal metal concentrations by the upregulation of the antioxidant defense system. This system is activated in order to respond to the deleterious effects caused by reactive oxygen species (Solanki and Dhankhar 2011).

Coping strategies allow the establishment of plant communities on metal contaminated soils. This is possible since some plants have adapted to these hostile sites by evolving mechanisms to deal with the toxic effects of metals in soil on plants. There is a need of identifying plants that are able to deal with excess metal in soil. Without these plants, the lands would remain barren and unsustainable.

The importance of plants in the remediation of heavy metal polluted soil is discussed in details in the present chapter. A review of the current knowledge on metal resistance mechanisms, as well as the potential genes and their role in metal homeostasis in plants will be examined. Finally, the coping mechanisms used by plants growing under metal contamination will be discussed.

2. Remediation of heavy metal contaminated sites

Soils that are heavily contaminated by metals may pose health risks to humans and to other living organisms in an ecosystem. Current techniques used to remediate metal contaminated soils include excavation, chemical stabilization, soil washing or soil flushing, but these methods are costly and impractical. There is a need to develop effective, low-cost and sustainable methods for soil bioremediation. The revegetation of these sites appears to be the most suitable method for long term land reclamation since plants can improve nutrient soil conditions. This can lead to the establishment of a self-sustaining vegetative cover, which in turn can prevent soil erosion (Wei *et al.,* 2005). Phytoremediation is an inexpensive and solar-driven approach that is performed *in situ*. It can be used to remove, stabilize and detoxify organic and inorganic pollutants including heavy metals from air, soil and liquid substrates (Salt *et al.,* 1998). An example of a reclaimed metal contaminated site in the mining region of Northern Ontario (Canada) is illustrated in figure 1. Plant species selected for land reclamation should grow and spread fast and be able to establish an effective soil cover. It is therefore important to search for plants that have spontaneously colonized these disturbed sites. Moreover, heavy metal contaminated mining sites exhibit physiochemical characteristics that are not suitable for the vast majority of plant species; hence the colonization of these sites is slow. However, plants that are resistant to this toxic environment can easily spread since there is a lack of competitors. It has been demonstrated that annual species have an extensive adaptive capacity compared to perennial genotypes due to their long-term natural selection (Wei *et al.,* 2005).

Phytoremediation is composed of five main subgroups: phytoextraction, phytovolatilisation phytostabilization, phytodegradation and rhizofiltration. Phytoextraction is a process by which plants extract metals from soil by accumulating them in their aerial biomass. These plants can be harvested and metals can be extracted from their tissues. Plants that accumulate metals in their aerial tissues have been involved in the phytoextraction of several metals including Cd, Cr, Cu, Hg, Pb, Ni Se and Zn (Yong and Ma 2002).

The accumulation of metals by plants is interesting from an environmental or agronomic point of view. In mining or industrial sites, as well as their surrounding areas, heavy metals are responsible for severe soil contamination. In these cases, accumulator plants could be used for phytoremediation as they are likely able to remove metals from soils (Salt *et al.,* 1998; Salt *et al.,* 1995). Since some heavy metals are also essential minerals that can be deficient in staple food crops, genetic determinants of hyperaccumulation could be utilized in biofortification to improve the nutritional value of these crops (Frérot *et al.,* 2010; Cakmak, 2008; Jeong and Guerinot 2008; Mayer *et al.,* 2008).

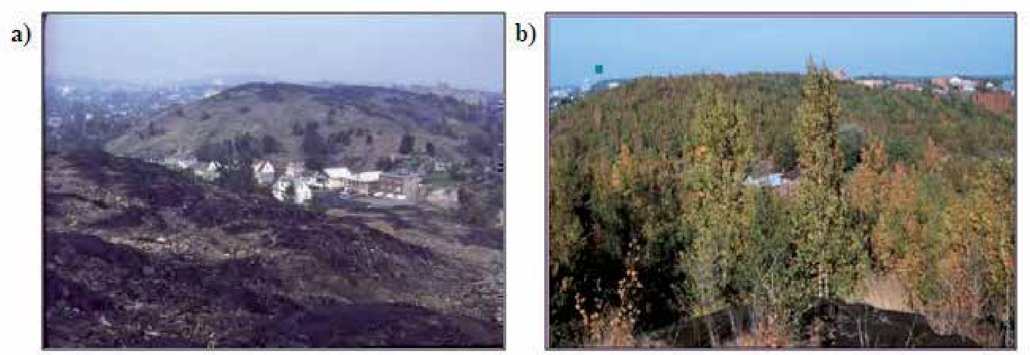

Figure 1. A metal contaminated site in Sudbury, Ontario, Canada; a) before remediation and b) after remediation (photos courtesy of Keith Winterhalder and David Pearson from Laurentian University).

These metal accumulator plants could also convert metals and release them in a volatile form. This process is known as phytovolatilization. Phytostabilization on the other hand, is a method that uses plants with a low ability for metal uptake to stabilize the contaminated soil thus preventing erosion. This limits the metals from entering the food chain. Plants can also be utilized for phytodegradation since they can in combination with microorganisms degrade organic pollutants. Finally, rhizofiltration is a process by which plant roots absorb metals from waste streams (Pulford and Watson 2003; Dushenkov *et al.,* 1995).

3. Resistance

Levitt (1980) stated that heavy metal contaminated environments act as stress factors on plants, which causes physiological reaction change that reduces or inhibits plant vigor and growth.

A plant showing injury or death due to metal stress is deemed sensitive to its environment. On the other hand, resistant plants can survive and reproduce under metal stress conditions (Ernst *et al.,* 2008). In general, plants can achieve resistance to heavy metals by avoidance or tolerance.

3.1. Avoidance

Avoidance occurs when plants restrict the uptake of metals within root tissue by several strategies. In environments where the soil metal contamination is heterogeneously distributed, plants can prevent metal uptake by exploring less contaminated soil. Another avoidance strategy involves mycorrhizal fungi, where they can extend their hyphae outside the plants rooting zone up to several tens of meters and transfer the necessary elements to the plant (Ernst, 2006; Baker, 1987). Also, these metal tolerant fungi can increase plant metal resistance by changing the metals speciation or by restricting the metal transfer into the plant (Ernst, 2006). Arines *et al.* (1989) found that mycorrhizal *Trifolium pratense* (red clover) plants growing in acid soils had lower levels of Mn in their roots and shoots as compared to the non-mycorrhizal plants. Plants can also restrict contaminant uptake in root tissues by immobilizing metals for example through root exudates in the rhizosphere. A role of root exudates is to chelate metals and stop their entry inside the cell. The cell wall has also been found to be involved in restricting metal uptake into the cell's cytoplasm (Mganga *et al.,* 2011).

3.2. Tolerance

In the absence of avoidance strategies, some plants can grow and survive in soil contaminated with toxic levels of heavy metals which are otherwise lethal or detrimental for growth and survival of others genotypes of the same or of different species (Maestri and Marmiroli 2012). Plants exhibiting tolerance are internally protected from the stress of metals that have entered the cell's cytoplasm (Baker, 1987). Metallophytes (metal tolerant plant) can function normally even in the presence of higher plant-internal metal levels. Plants adapt to their environments by developing heritable tolerance mechanisms. Tolerance to specific metals has evolved independently several times in different species from local non tolerant ancestral plant populations (Schat *et al.,* 2000). Plants can exhibit tolerance to metals that are present in surplus in the soil. Each metal is under control of specific genes.

According to Bradshaw (1991) most species are in a state of genostasis. It is the restriction of genetic variability which limits the evolution of the population/species. In the absence of avoidance pathways, metal contaminated soil acts as a selection force on a population, where only the plants with tolerant genotype can survive and reproduce. This leads to a bottleneck, where few individuals survive and reproduce. In turn, metal tolerant populations can evolve rapidly following a disturbance such as contamination of soil with heavy metals. Plant adaptation to these sites occurs in populations for which tolerance variability already exists prior to the contamination (Maestri and Marmiroli 2012; Baker, 1987). Genes for the tolerance of metals are pre-existing at a low frequency in non tolerant populations of certain plant species (Ernst, 2006; Macnair, 1987).

3.2.1. Variation in tolerance and accumulation characteristics

Variation occurs between species, populations and clones for tolerance and accumulation of metals. Assunçãno *et al.* (2003) found differences in the degree of chlorosis and concentration of metal for *Thlaspi caerulescens* (currently named *Noccaea caerulescens*) populations when grown in hydroponic solutions containing various Ni, Cd and Zn concentrations. Visioli *et al.* (2010) found differences in growth, morphology and Ni accumulation capacity when the Ni hyperaccumulator *T. caerulescens* and the non-metal adapted *T. caerluescens* were exposed to different Ni concentrations in hydroponic solutions. Besnard *et al.* (2009) used cleaved amplified polymorphic sites (CAPs) and microsatellites to determine the genetic variation for *T. caerulescens* populations from metalliferous and non-metalliferous sites from Switzerland. They found a correlation between the level of heavy metals in soil and the variation at the target loci for the genes involved in encoding metal transporters. Basic *et al.* (2006) found similar results when they analyzed the genetic variation of different *T. caerulescens* population sampled from different soil types with single nucleotide polymorphism (SNPs) in target and non target genes. These results were also observed in *Populus spp.* Marmiroli *et al.* (2011) compared *Populus* clones and found variation in their capacity to accumulate Cd. This variation in Cd accumulation between clones was correlated with SNPs at some target genes. These results imply that gene flow is limited between individuals found on metal contaminated and those from uncontaminated sites, at least for the loci that are involved in the fitness of the individuals (Visioli *et al.*, 2012). On metal-enriched soil, there is a strong selection of local offspring, which conserves the metal tolerant genotypes (Ernst, 2006).

3.2.2. Genetics of tolerance to metals

Identifying genes involved in a specific adaptation is challenging. Metal tolerance and accumulation in plants are complex genetic systems. Plants have to modify their physiological processes in order to be able to survive in the environment in which they have germinated. In turn, the survival of a population to the contaminated environment is dependent on the inheritance of favourable traits. Tolerance mechanisms are heritable and variable, resulting from genes and gene products (Maestri and Marmiroli 2012). Variation in the evolution of metal tolerance exists over species, populations and clones (Baker, 1987). Some species do not show variation in tolerance and accumulations. In order to determine genes involved in metal tolerance and accumulation, segregating analyses were used, where parents with contrasting phenotypes were crossed to produce progeny. Studies have determined that in many species, metal tolerance and accumulation are genetically independent (Assunçãno *et al.*, 2006). For example, in *Arabidopsis halleri*, Cd tolerance and accumulation segregated as independent traits while Cd and Zn tolerance and accumulation cosegretated. In this later species, two or more genes were proposed to be involved in Cd and Zn accumulation but only one gene for Cd and Zn tolerance (Bert *et al.*, 2003; Bert *et al.*, 2002). In *T. caerulescens*, no genes involved in Cd, Zn and Ni tolerance and accumulation cosegregated. This suggests that there is a high probability that the genetic and physiological mechanisms for these traits are distinct from each other (Yang *et al.*, 2005a; Maestri *et al.*, 2010; Richau and Schat 2009; Assunçãno *et al.*, 2006; Zha *et al.*, 2004). As a result, it is not possible to conclude that a plant with high levels of metals in aerial biomass is also metal tolerant. The concentration of metals in above ground tissue serves as an indication of the plant's potential metal tolerance (Frérot *et al.,* 2010).

Several techniques have been used to isolate and identify genes involved in heavy metal tolerance in plants, one of which is the quantitative trait loci (QTL) mapping. QTL mapping is a powerful tool in examining complex adaptive traits and in determining the number of genes involved in a trait as well as the genes effects and their interactions (Willems *et al.,* 2007). By mapping QTLs, it can be possible to identify or validate candidate genes involved in a complex trait such as metal tolerance and accumulation (Willems *et al.*, 2007). Other techniques used to identify genes for metal tolerance and accumulation are functional complementation in yeast mutants defective in metal homeostasis. These methods use plant cDNA expression libraries, as well as the identification of hypothesized pathways based on sequence similarities with plant cDNA libraries and genomic sequences (Lal, 2010). Transcriptome analyses have also been used to reveal genes involved in hyperaccumulation by analysing the differences in expression profiles or regulation-level of hyperaccumulator and non hyperaccumulator plants (Colzi *et al.*, 2011).

Few specific major genes have been found for Cd, Cu, Ni and Zn tolerance in *Silene vulgaris* by crossing plants from a metalliferous site with non tolerant plant from a nonmetalliferous site (Schat *et al.,* 1996; Schat *et al.,* 1993). Similar results were reported for Cu tolerance for *Mimulus guttatus* (Macnair, 1993) and Zn tolerance for *Arabidipsis halleri* (Bert *et al.,* 2003). In *S. vulgaris* and *M. guttatus*, modifier genes (minor genes) were involved in Cu tolerance, thus increasing tolerance and enhancing the effect of the major gene(s) (Smith and Macnair 1998). Only two QTL were involved in Ni accumulation and tolerance in *S. vulgaris* (Bratteler, 2005).

Studies aiming at identifying associations between molecular markers and metal tolerance and accumulation trait have been performed using interspecific and intraspecific crosses. When a high Zn accumulating *T. caerulescens* parent was crossed with a low Zn accumulating parent, two major QTLs were found to be involved in the increased of Zn accumulation in root (Assunçãno *et al.,* 2006). Deniau *et al.,* (2006) performed QTL mapping for the hyperaccumulation of Zn and Cd in *T. caerulescens*. They found two QTLs responsible for Cd and two for Zn accumulation in roots. In addition, one QTL for Cd and three QTLs for Zn accumulation in shoot were characterized. Macnair *et al.* (1999) reported a major gene involved in Zn tolerance from the analysis of F_2 progeny derived from a cross between *A. halleri* (tolerant parent) and *Arabidopsis lyrata* (sensitive parent). Willems *et al.* (2007) generated a backcross progeny from the interspecific cross between *A. halleri* (tolerant parent) and *A. lyrata (*sensitive parent) and identified three major additive QTLs involved in Zn tolerance in *A. halleri*. These QTLs were mapped to three different chromosomes (3, 4 and 6) and colocalized with genes that have been known to be involved in metal tolerance and accumulation. *HMA4* (*Heavy Metal ATPase 4)* encodes a P-type ATPase pump localized at the plasmamembrane involved in loading Zn and Cd into the xylem. *MTP1*-A and *MTP1-B* are Metal Tolerance Protein- vacuolar transporters that are involved in Zn tolerance) (Gustin *et al.,* 2009; Krämer, 2005). Three new QTLs were identified and mapped to chromosomes 4, 6 and 7 by Filatov *et al.* 2007, when F_2 progenies from a similar interspecific cross were analyzed. Frérot *et al.* (2010) also found Zn accumulation to be polygenic using *A. halleri* X *A. lyrata petraea* progenies. They determined that Zn accumulation is controlled by two QTLs in low Zn concentration and three QTLs in high Zn concentration. Four of the five QTLs mapped for Zn accumulation in their study were also reported in previous studies using *A. halleri* X *A. lyrata petraea* progenies (Frérot *et al.,* 2010; Filatov *et al.,* 2007; Filatov *et al.,* 2006).

Courbot *et al.* (2007), also using progeny from interspecific cross between *A. halleri* and *A. lyarata* determined three QTLs involved in Cd tolerance. A major QTL region was found to be common to Cd (Courbot et al 2007) and Zn (Willems et al 2007) tolerance and was colocalized with the *HMA4* gene. Hanikenne et al (2008) identified the role of *HMA4* using RNAi-mediated silencing. They reported that when the expression of *HMA4* was down-regulated, less Zn was translocated from the root to the shoot. When this gene was expressed in *A. thaliana*, an increase in Zn translocation to aerial tissue was observed. This increase in Zn translocation in *A. thaliana* plants resulted in signs of Zn hypersensitivity. Therefore, the expression of *AhHMA4* alone was not adequate for Zn detoxification. Additional genes are involved in the *A. halleri* Zn hyperaccumulation (Hanikenne and Nouet 2011; Frérot *et al.,* 2010).

Using segregating progeny resulting from intraspecific crosses between a high Cd accumulating parent and a low Cd accumulating parent for *Glycine max*, Benitez *et al.* (2010) identified a major QTL in seeds that was named cd1. This gene was mapped on chromosome 9. Jegadeesan *et al.* (2010) also identified a major QTL, *cda1*, associated with Cd accumulation in seeds of *G. max*. These two major QTLs were mapped to the same region of chromosome 9 which suggested that cd1 and *cda1* may be identical. Both QTLs were found to be a dominant major gene involved in the control of low Cd uptake. By analyzing the *G. max* genome, Benitez *et al.* (2010) revealed that the cd1 QTL is localized in the vicinity of the P_{1B}-ATPase gene (designated as *GmHMA1)* and proposed that this gene is involved in the transport of Cd. Benitez *et al.* (2012) found a single-base substitution between two cultivars, Harosoy (high Cd content in seed Cd) and Fukuyutaka (low Cd content in seed) in this P_{1B}–ATPase gene. This mutation resulted in an amino acid substitution (glycine in Fukuyutaka and glutamic acid in Harosoy) in GmHMA1a. Since the glycine residue at the amino acid substitution site was conserved in AtHMA3, AtHMA4, AtHMA6 and AtHMA7, it was suggested that the GmHMA1a from Fukuyutaka was the wild type, responsible for low Cd accumulation in seed (Benitez *et al.,* 2012). A dominant major gene involved in the control of Cd uptake was also observed in wheat (*Triticum aestivum*) (Clarke *et al.,* 1997) and oat (*Avena sativa* L.) (Tanhuanpää *et al.,* 2007). QTL analyses have also been performed in radish (*Raphanus sativus* L.). Xu *et al.* (2012) found a major QTL and three minor QTLs responsible for Cd accumulation in radish roots which were mapped on linkage groups 1, 4, 6 and 9. Induri *et al.* (2012) identified major QTLs for Cd response in *Populus* by performing a pseudo-backcross pedigree of *Populus trichocarpa* Torr. & Gray and *Populus deltoides* Bart. These QTLs were mapped to two different linkage groups. They performed a whole-genome microarray study and they were able to identify nine Cd responsive genes, which included a metal transporter, putative transcription factor and an NHL repeat membrane-spanning protein. Additional candidate genes located in the QTL intervals included a glutathione-S-transferase and putative homolog of a glutamine cysteine ligase.

Several QTL studies on rice (*Oryza sativa* L.) have been conducted to determine the number of genes involved in metal accumulation and tolerance. Three putative QTLs involved in Cd accumulation have been found on chromosomes 3, 6 and 8 (Ishikawa *et al.*, 2010; Ishikawa *et al.*, 2005). Ueno *et al.* (2009) also identified another major QTL for Cd accumulation in *O. sativa* that was mapped on the short arm of chromosome 7. QTLs for the translocation of Cd from roots to sink regions were reported in *O. sativa* (Xu *et al.*, 2012; Tezuka *et al.*, 2010). Tezuka *et al.* (2010) revealed a major QTL (*qCdT7*), mapped to chromosome 7, which controlled the translocation of Cd from roots to shoots. This QTL explained 88% of the phenotypic variation indicating that low Cd accumulation was a dominant trait. Dufey *et al.* (2009), using recombinant inbred lines, identified in *O. sativa* 24 putative QTLs involved in Fe tolerance which were mapped to chromosomes 1, 2, 3, 4, 7 and 11. In addition, two QTLs, located on chromosomes 2 and 3, were involved in As concentration in shoots and in roots respectively.

In durum wheat (*Triticum durum*, L.), Cd accumulation is controlled by a major gene named *Cdu1* and localized on chromosome 5BL (Knox *et al.*, 2009; Clarke *et al.*, 1997). Further, Ci *et al.* (2012) characterized 26 QTLs involved in Cd tolerance and accumulation in *T. aestivum*, where 16 were involved in Cd stress control, 8 for Cd tolerance and 2 for Cd accumulation in roots. In *A. sativa* L., a single QTL for Cd accumulation in grain has been reported (Tanhuanpää *et al.*, 2007).

In wheat (*T. aestivum* L.), Mayowa and Miller (1991) reported QTLs involved in Cu tolerance and accumulation that were mapped to chromosomes 5A, 4D, 7A, 7B, 7D. Ganeva *et al.* (2003) also characterized QTLs for *T. aestivum* on chromosomes 1A, 1D, 3A, 3B, 4A and 7D. Bálint *et al.* (2003) identified QTLs associated with Cu tolerance located on *T. aestivum* chromosomes 3D, 5A, 5B, 5D, 6B and 7D. In addition, Bálint *et al.* (2007) also determined QTLs for Cu tolerance in *T. aestivum*. They reported one major QTL for Cu tolerance on chromosome 5D and minor QTLs on chromosomes 1A, 2D, 4A, 5B and 7D. A QTL affecting shoot Cu content under Cu stress conditions was mapped on chromosome 1BL and an additional QTL for Cu accumulation was found on chromosome 5AL. The role of these genes located on various chromosomes in these different studies suggests that Cu tolerance is a polygenic character, as well as the possibility of different gene expressions against distinct toxic Cu concentrations in different populations. The accumulation of Cu in the shoots is affected by different QTLs, suggesting a strong metal-specific uptake and/or translocation. Bálint *et al.* (2007) reported a negative correlation between Cu tolerance and accumulation in the shoot indicating that the key tolerance mechanism in wheat could be the restriction of Cu uptake in the roots or the reduced translocation from root to shoot.

3.3. Categories of plants growing on metal contaminated soils

Baker and Walker (1990) categorized plants into three groups according to their strategy for coping with metal toxicity in soil; metal excluders, indicators and accumulators/ hyperaccumulators.

3.3.1. Excluders

The metal excluder strategy consist in limiting the amount of metals translocated from roots to shoots thus maintaining low levels of metal concentration in their aerial parts. Large amounts of metals in the roots of excluder species have been reported (Baker and Walker 1990). Examples of excluder species include *Oenothera biennis, Commelina communis, Silene maritime*, *Agrostis stolonifera* L., woody plants such as *Salix, Populus* and *Pinus radiata* (Maestri *et al.*, 2010; Wei *et al.*, 2005).

3.3.2. Accumulators/hyperaccumulators

Metal accumulators/hyperaccumulators are plants that can concentrate metals in their above-ground tissues to levels that exceed those in the soil or also to those in the non accumulating species found growing nearby with concentrations up to 100 times more than non hyperaccumulators (Salt *et al.,* 1998). Accumulators/hyperaccumulators growing on metal contaminated environments can naturally accumulate higher levels of heavy metals in their shoots than in their roots (Kachout *et al.,* 2009). Some plants can accumulate only a specific metal while others can accumulate multiple metals ((Mganga *et al.,* 2011; Almås *et al.,* 2009). Presently, at least 45 plant families comprising more than 400 species have been found to accumulate metals in their harvestable tissues, and the majority of them belong to the *Brassicaceae* family (Pal and Rai 2010). The best known genera from this family are *Alyssum* and *Thlaspi*. *Thlaspi* species can accumulate more than 3% of their shoots in Zn, 0.5% in Pb and 0.1% in Cd. *A. halleri* can also accumulate more than 1% of its above-ground biomass in Cd and Zn and *Alyssum* species can accumulate over 1% Ni in their harvestable parts (Di Baccio *et al.,* 2011). There are variations among family, species and populations in the ability to accumulate metals. For example, *Arabidipsis halleri* can accumulate Cd and Zn in their harvestable parts where as *A. thaliana* is known to be a metal excluder and restricts metals in the roots. *Betula spp.* can accumulate Zn, while other trees species of the same family (*Carpinus* and *Corylus*) are unable to do so (Ernst, 2006; Ernst, 2004).

3.3.3. Indicators

Like accumulators, metal indicators accumulate metals in their aerial tissue, but the metal levels in the above ground tissue of these plants usually reflect the metal concentration in the surrounding environment (Baker and Walker 1990). If these plants continue to uptake metals, they will eventually die-off. These plants are of biological and ecological importance since they are pollution indicators and also, like accumulators, they absorb pollutants (Mganga *et al.,* 2011).

3.3.4. Determination of excluders, indicators and hyperaccumulators plants

A plant is classified as a hyperaccumulator when it meets four criteria including; a) when the level of heavy metal in the shoot divided by level of heavy metal in the root is greater than 1 (shoot/root quotient > 1); b) when the level of heavy metal in the shoot divided by total level of heavy metal in the soil is greater than 1 (extraction coefficient > 1) (Rotkittikhun *et al.,* 2006; Harrison and Chirgawi 1989); c) when the plant takes up between 10 – 500 times more heavy metals than normal plants (uncontaminated plants - control plants) (Fifield and Haines 2000; Allen,1989); and d) more than 100mg/kg of cadmium, 1000g/kg of copper, lead, nickel, chromium; or more than 10000mg/kg of zinc (Mganga *et al.,* 2011; Ernst, 2006; Brooks, 1998). An excluder is a plant that has high levels of heavy metals in the roots but with shoot/root quotients less than 1 (Boularbah *et al.,* 2006). Finally, Baker and Walker (1990) classified a plant as an indicator when the levels of heavy metals within their tissues reflect those in the surrounding soil.

3.4. Physiological mechanisms of metal resistance

Resistant plants are able to grow on metal contaminated soil due to avoidance and/or tolerance strategies. Plant resistance to high levels of heavy metals in soils can result from either reduced uptake or once taken up, metals have to be transformed into a physiologically tolerable form.

3.4.1. Restriction of metal uptake

The plasma membrane is the first structure of living cells exposed to heavy metals. The membrane functions as a barrier for the movement of heavy metals into cytoplasm. The restriction of metals at the plasma membrane limits the uptake and accumulation of metals by preventing their entry into the cytoplasm. This can be done by changing the ion binding capacity of the cell wall and/or decreasing the uptake of metal ions through modified ion channels, and/or by removing metals from cells with active efflux pumps and/or with root with root exudates (Tong *et al.,* 2004).

3.4.1.1. The cell wall

The cell wall and membrane interface could be a site of metal tolerance since a significant amount of metals has been reported to be accumulated there. Divalent and trivalent metal cations can bind plant cell walls because of the presence of functional groups such as –COOH, -OH and –SH. Pectins are polymers that contain carboxyl groups which enable the binding of divalent and trivalent heavy metals ions. In enriched heavy metal environments, some plants will increase the capacity of their cell wall to bind metals by increasing polysaccharides, such as pectins (Colzi *et al.,* 2011; Pelloux *et al.,* 2007). Konno *et al.* (2010; 2005) showed that the pectin in root cell walls was important in binding Cu in the fern, *Lygodium japonicum,* and in the moss, *Scopelophila cataractae*. The cell wall of *Minuartia verna sp. hercynica* growing on heavy metal contaminated medieval mine dumps has been found to have high concentrations of Fe, Cu, Zn and Pb (Solanki and Dhankhar 2011; Neumann *et al.,* 1997). On the other hand, Colzi *et al.* (2012) found that a copper tolerant *Silene paradoxa* population restricted the accumulation of Cu in roots, when exposed to high Cu, by decreasing their pectin concentration in the cell wall and increasing pectin methylation thus preventing the binding of Cu.

3.4.1.2. Root exudates

Resistant plants can also restrict the entry of metals by immobilizing them in the rhizosphere with root exudates outside the plasma membrane (Colzi *et al.*, 2011). This has been reported in *T. aestivum* where the exudation of phytochelatins, citrate and malate may be responsible for Cu exclusion mechanisms in non accumulators (Yang *et al.*, 2005b; Bálint *et al.*, 2007). Hall (2002) also proposed a mechanism for Ni exclusion in plants involving Ni-chelating exudates which include histidine and citrate. In non hyperaccumulator plants, these Ni chelators accumulate in their root exudates which, in turn decreases Ni uptake. The copper exclusion could be due to its chelation with citrate and malate exudates in the rhizosphere of wheat roots. The restriction of Cu uptake in wheat by the efflux of these organic acids has been previously documented by Nian *et al.* (2002).

3.4.2. Chelation

The phytotoxic effect of free metal ions can be eliminated by their chelation by specific high-affinity ligands (Yong and Ma 2002). The chelation of metals allows for the restriction of metal uptake, the uptake of metal ions, sequestration and compartmentation, as well as xylem loading and transport within the plant. Baker *et al.* (2000) categorized these ligands according to the characteristic electron donor centers, which include sulfur donor ligands, oxygen donor ligands and nitrogen donor ligands.

3.4.2.1. Oxygen donor ligands

Organic acids such as malate, aconitate, malonate, oxalate, tartrate and citrate are involved in metal uptake restriction and dexotification in plants. These carboxylic acid anions form complexes with divalent and trivalent metal ions with high stability. They are involved in the restriction of metal entry into the cell, metal exclusion in the root cells, accumulation and transport within the plants. In wheat (*T. aestivum*), citrate and malate formed complexes with Cu in order to immobilize this metal in the rhizosphere thus preventing its entry into the cell (Yong and Ma 2002). Citrate was also involved in the hyperaccumulation of Ni in 17 New Caledonian plants and the amount of citrate produced was highly correlated with the accumulation of Ni (Lee *et al.*, 1977). The accumulation of Zn in some plants is facilitated by the transport of malate-Zn complexes. Upon the Zn ions uptake into the cytoplasm, they are bound to malate, which serves as a carrier to transport the Zn ions to the vacuole. Once there, the Zn ions are complexed by a terminal acceptor and released from malate. The malate is then able to return to the cytoplasm and transport additional Zn ions to the vacuole (Yong and Ma 2002). Still and Williams (1980) reported that the transport of free Ni ions to root cells via membrane is restricted. However, when Ni is bound to organic compounds such as citric and malic acids, it can be transported across the plasma membrane (Yong and Ma 2002). In *Zea mays*, the production of organic acid is influenced by external aluminium ion concentration (Pintro *et al.*, 1997). Also, in manganese tolerant *T. aestivum* cultivars, the production of malic, citric or aconitic acid was not induced when exposed to this metal but for the manganese sensitive cultivars, the organic acids concentration slightly increased (Burke *et al.*, 1990).

3.4.2.2. Nitrogen donor ligands

This group consists of amino acids and their derivatives which have relatively high affinity for specific metals. Krämer *et al.,* (1996) revealed histidine to be involved in the Ni tolerance and translocation of the hyperaccumulator plant *Alyssum lesbiacum.* The majority of Zn in roots of the Zn hyperaccumulator, *T. caerulescens*, was complexed with histidine (Salt *et al.,* 1999). Studies have also shown histidine to be involved in the restriction of metal uptake. For example, plants chelate Ni with histidine in the rhizosphere which prevents the uptake of this metal (Wenzel *et al.,* 2003).

3.4.2.3. Sulfur donor ligands

In plants, sulfur donor ligands are composed of two classes of metal chelating ligands which are phytochelatins (PCs) and metallothioneins (MTs). Phytochelatins are small metal binding peptides synthesized from the tripeptide glutathione (γ-Glu-Cys)$_{2\text{-}11}$-Gly) (Solanki and Dhankhar 2011; Hall, 2002). Since there is a γ-carboxamide linkage between glutamate and cysteine, PCs are not synthesized by translation of mRNA, but rather it is a product of an enzymatic reaction involving the enzyme PC synthase (Yong and Ma 2002). The production of PCs is positively correlated with metal accumulation in plant tissues (Pal and Rai 2010). PCs are produced in cells immediately after heavy metal exposure, including Cd, Pb, Zn, Ag, Hg, As and Cu as seen in *Rubia tinctorum* (Maitani *et al.,* 1996). PC production can be induced in roots, shoots, and leaves as observed in *Sedum alfredii* when exposed to Cd (Pal and Rai 2010).

Several research groups concurrently and independently cloned and characterized genes encoding PC synthase. These genes were isolated from *Arabidopsis thaliana*, *Schizosaccharomyces pombe*, and *T. aestivum*, and were designated *AtPSC1, SpPCS,* and *TaPCS1*, respectively. They encoded 50-55kDa sequences with 40-50% similarity. The polypeptides were found to be active in the synthesis of PCs from glutathione (GSH) (Yong and Ma 2002). In cultured *Silene cucubalis* cells, the presence of heavy metals, such as Cd, Cu, Zn, Ag, Hg and Pb, induce the synthesis of PCs by PC synthase from the GSH like substance (Pal and Rai 2010). Gaudet *et al.* (2011) did a comparative analysis of two *Populus nigra* genotypes from contrasting environments. They determined that both genotypes responded differently to Cd stress. The southern genotype (Poli) was more tolerant than the northern genotype (58-861). This variation was due to different adaptation strategies to Cd stress. The thiol and PC content, which was associated with the *glutathione S-transferase* gene, was higher in the southern genotype as compared to the northern genotype, which under Cd stress, revealed differences in the use of phytochelatin pathway that might be related to the variation in their Cd tolerance.

The second class of sulfur donor ligands are metallotioneins (MTs). They are low molecular weight (4-14kDa), cysteine-rich, metal-binding proteins found in a wide range of organisms (animals, plants, eukaryotic microorganisms, and prokaryotes) (Huang and Wang 2010). Unlike PCs, they are encoded by structural genes (Yong and Ma 2002). They play essential roles in a variety of organisms including Cu, Cd and Hg detoxification by sequestration (Palmiter, 1998; Ecker *et al.,* 1989), Zn homeostasis (Coyle *et al.,* 2002) and also scavenging of reactive oxygen species (Wong *et al.,* 2004). MTs have been divided into two classes based on their cysteine residue arrangements. Class I MTs are widespread in vertebrates and are composed of 20 highly conserved cysteine residues based on mammalian MTs. Class II MTs have slightly flexible cysteine arrangements and are found in plants, fungi and invertebrates. A third class includes phytochelatins (Chaturvedi *et al.,* 2012). Based on the position and allocation of cysteine residues, class II plant MTs are additionally divided into four types (Cobbett and Goldsbrough 2002). Type 1 plant MT genes have been more highly expressed in roots compared to leaves while the reverse is observed for the expression of type 2 plant MT genes. Type 3 MT genes are highly expressed in ripening fruits or in leaves while the expression of type 4 plant MT gene is restricted to developing seeds (Sekhar *et al.,* 2011; Cobbett and Goldsbrough 2002).

The expression of MT genes in plants subjected to metal stress has been studied. *AtMT1* and *AtMT2* genes showed increased expression levels when *Arabidopsis* plants were exposed to high levels of Cu and Cd (Sekhar *et al.,* 2011). Van Hoof *et al.* (2001) reported that the copper tolerant *S. vulgaris* individuals showed higher *SvMT2b* expression in roots and shoots when exposed to high concentrations of copper compared to the copper sensitive plants. Huang and Wang (2009) reported an increase in BgMT2 mRNA expression in large-leafed mangrove plants (*Bruguiera gymnorrhiza*) when exposed to Zn, Cu or Pb. Similar results were described by Gonzalez-Mendoza *et al.* (2007) in black mangrove *(Avicennia germinans*) seedlings exposed to Cd or Cu, showing a significant increase in AvMT2. High levels of the *CcMT1* transcripts were also observed in pigeon pea (*Cajanus cajan* L.) exposed to Cd and Cu (Sekhar *et al.,* 2011).

In general, there are variations between species in the expression of MTs to various metals. The up and down regulation of MTs in response to metal stress is largely unknown in plants. The MT gene expression was shown to be strongly induced by Cu, Cd, Pb and Zn (Huang and Wang 2009; Gonzalez-Mendoza *et al.,* 2007; van Hoof *et al.,* 2001). MT gene expression is also influenced by other abiotic stressors including absciscic acid (ABA), drought, salinity, heat, cold light, wounding and senescence (Sekhar *et al.,* 2011).

3.4.3. Mechanisms involved in internal metal tolerance

3.4.3.1. Metal uptake

The uptake of metal from soil into roots is dependent on the bioavailabilty of the metal, as well as its mobility in the rhizosphere (Maestri *et al.,* 2010). The bioavailability of various metals greatly varies. No correlation exists between the metal content in soils and in plants (Clemens, 2006). The bioavailability of metals in the rhizosphere is affected by the chemical environment. For example, in *T. caerulescens,* the chemical form of nitrogen influences the plants ability to uptake Cd and Zn (Maestri *et al.,* 2010; Xie *et al.,* 2009). Metals present in the rhizosphere of hyperaccumulators are more bioavailable than for those of non hyperaccumulators. Plants can render metals mobile in their rhizosphere by excreting root exudates, such as organic acids and phytosiderophores and by acidification with protons (Maestri *et al.,* 2010; Marschner, 1995). Bacteria in the soil also affect metal mobility and availability by lowering the pH, producing hormones, organic acids, antifungals, antibiotics and metal chelators which all enhance the root growth (Maestri *et al.,* 2010; Wenzel *et al.,* 2003). Higher amounts of bacteria were found in the rhizosphere of hyperaccumulators. Microorganisms found in the rhizosphere were linked to an increased uptake of Cd, Z, and Pb in *Sedum alfredii* and an enhanced root growth (Maestri *et al.,* 2010; Xiong *et al.,* 2008).

3.4.3.2. Metal uptake across the plasma membrane

The uptake of heavy metals in plants is mediated by a group of metal transporter families which consists of iron-responsive transport proteins (ZIP-IRT), the heavy metal-transporting P_{1B}-type subfamily of P-type ATPases, the natural resistance associated macrophage proteins (NRAMP) and the cation diffusion facilitators (CDF) (Baxter *et al.,* 2003). Transporters were originally identified for Fe^{2+} or Zn^{2+} homeostasis, but it was demonstrated that most transporters of essential metal ions can also carry non essential metals, such as Cd (Zhou *et al.,* 2012). The uptake of non essential metals may be the result of their close chemical characteristics or metal ion size to essential metals. Some metal transporters, present in the plasma membrane of root cells, exhibit low substrate specificity which can lead to the accumulation of other metals in plants (Schaaf *et al.,* 2006). For example, the non-functional metal Cd can be taken up via a Ca^{2+} transporter (Perfus-Barbeoch *et al.,* 2002) or also via the Fe^{2+} transporter IRT1 (Korshunova *et al.,* 1999). Plant tolerance to metal stress can be achieved with the modification of these transporter activities (Zhou *et al.,* 2012). Plants can prevent the uptake of certain metals by down-regulating the expression of such transporters, as observed in *S. vulgaris,* where the tolerant plants restrict the uptake of Cu by the down-regulation of Cu-transporters (Assunçãno *et al.,* 2003; Harmens *et al.,* 1993). Since Fe and Ni belong to the group of transient metals and have similar chemical properties, Fe deficiency may be the result of Ni phytotoxicity. Ni competes with Fe in physiological and biochemical processes, and in turn roots, can uptake Ni by Fe transporters (Pandey and Sharma 2002).

Increased Zn uptake is driven by an overexpression of members of the ZIP family of transporters. Under Zn deficiency conditions, many members of the ZIP transporter family are overexpressed in non hyperaccumulator species, while in hyperaccumulators, they are independently expressed regardless of Zn supply (Verbruggen *et al.,* 2009). Nishida *et al.* (2011) and Schaaf *et al.* (2006) showed that *A. thaliana* can increase the uptake of Ni in roots when Fe levels are low by the Iron-Regulated Transporter 1 (AtIRT1; member of Zrt/IRT-like *ZIP* family of transporters). AtIRT1 has a wide specificity for divalent heavy metals including Ni, Zn, Mg, Co and Cd and mediates the accumulation of such metals under Fe-deficient conditions. Nakanishi *et al.* (2006) reported that Cd was uptaken in yeast by two *O. sativa* Fe^{2+} transporters, *OsIRT1* (Iron-Regulated Transporter 1) and *OsIRT2.*

The uptake of Ni of some Ni hyperaccumulator accessions of *Thlaspi goesingense*, *Thlaspi japonicum* and *T. caerulescens* has been reported to be inhibited in the presence of Zn. This demonstrated that Ni entered the cell via Zn uptake transporters, specifically the TcZNT1 transporter (Assunçãno *et al.,* 2008). In Zn deficiency conditions, the expression of AtZIP4, the orthologue of TcZNT1 in *A. thaliana,* can be induced but when additional Ni was added, the expression was repressed. This suggested that Zn and Ni competed for their uptake via AtZIP4/TcZNT1 transporters (Hassan and Aarts 2011). In addition, in presence of high Zn concentration, the expression of *ZNT1* was higher in Zn hyperaccumulator *T. caerulescens* roots than in the non hyperaccumulator *Thlaspi arvense* suggesting its involvement in the hyperaccumulator phenotype (Hassinen *et al.*, 2007; Assunçãno *et al.*, 2001; Assunçãno *et al.*, 2001; Pence *et al.*, 2000). Milner *et al.* (2012) also determined that NcZNT1, isolated from *T. caerulescens*, played a role in Zn uptake from the soil which was based on its high expression in root.

Heavy metal-transporting P_{1B}-type transporters are also involved in metal-ion homeostasis and tolerance in plants by transporting essential and non essential heavy metals such as Cu, Zn, Cd, Pb across cell membrane. Transporters located at the plasma membrane function as efflux pumps by removing toxic metals form cytoplasm. They have also been found in membranes of intracellular organelles for compartmentalization of metals for sequestration in vacuoles, golgi or endoplasmic reticulum (Yang *et al.,* 2005b). These ion pumps transport ions across a membrane by hydrolysing ATP (Benitez *et al.,* 2012). Eight P_{1B}-ATPases, AtHMA1–AtHMA8, have been reported in *Arabidopsis* (Baxter *et al.,* 2003). AtHMA1, 2, 3, and 4 showed high similarity with Zn^{2+}/Co^{2+}/Cd^{2+}/Pb^{2+} ATPases previously characterized in prokaryotes (Axelsen and Palmgren 2001). The AtHMA4 was located at the plasma membrane. The ectopic expression of AtHMA4 improved the growth of roots in the presence of toxic Zn, Cd and Co concentrations (Yang *et al.,* 2005b). The heterologous expression of AtHMA4 enhanced Cd tolerance in yeast (Mills *et al.*, 2003).

In addition, the gene *Nramp* encodes for another divalent metal transporter located at the plasma membrane. This transporter also removes toxic metals from the cytosol by efflux pumping. It has been reported to be expressed in roots of *Arabidopsis* and *O. sativa* (*OsNramp1*- expressed in rice roots where as *OsNramp2* is expressed in leaves and *OsNramp3* is expressed in both tissues). The *OsNramp1* gene was found to be involved in the uptake of Mn, while the *Nramp* genes in *Arabidopsis* and rice were involved in the uptake of Cd, and other divalent metals (Yang *et al.,* 2005b). The AtNRAMP1, 3, and 4 showed uptake of Cd^{2+} when they were expressed in the yeast *Saccharomyces cerevisiae*. In addition, Cd^{2+} hypersensitivity was observed in *A. thaliana* when AtNRAMP3 was overexpressed. This transporter was located in the vacuolar membrane where it is involved in the mobilization of metals from the vacuole (Clemens, 2006).

In bacteria and in some eukaryotes, Zn, Co and Cd are transported by the CDF transport proteins. Within the *Arabidopsis* genome, there are 12 nucleotide sequences that are predicted to encode members of CDF transporter family. However, these transporters might be involved in cation efflux out of the cytoplasm, by pumping ions out of the cytoplasm to the exterior of the cell or into intracellular compartments such as the vacuole (Yang *et al.,* 2005b).

Plants can make metal ions more available for uptake by acidifying the rhizosphere and pumping protons via plasma membrane-localized proton pumps; and also by exuding low molecular weight (LMW) compounds that act as metal chelators (Clemens, 2006). The secretion of organic acids can render heavy metals mobile and enhance their absorption by plant roots. Krishnamurti *et al.* (1997) reported that when Cd was complexed with organic acids, it was readily available for transport across the membrane, while free Cd ions were restricted for uptake. Cieśliński *et al.* (1998) revealed a higher acetic acid and succinate in the rhizosphere of the *T aestivum* (Kyle) Cd accumulating genotype compared to the non accumulating (Arcola) wheat genotype. The Zn/Cd hyperaccumulating *Sedum alfredii* was able to extract high levels of Zn and Pb from its contaminated environment because of the release of root exudates (Li *et al.*, 2005). In *Alyssum*, the Ni transport and accumulation was enhanced by secretion of histidine in the rhizosphere (Krämer *et al.*, 1996).

3.4.3.3. Sequestration/compartmentation

Some metal tolerant plants can accumulate large amounts of metals within the cell without exhibiting toxicity symptoms (Entry *et al.*, 1999). These plants are able to store the surplus of accumulated metals where no sensitive metabolic activities occur such as organs or subcellular compartments (Ernst, 2006). This avoidance of metal poisoning involves the intracellular sequestration and apoplastic or vacuolar compartmentation of the toxic metal ions (Liu *et al.*, 2007). Compartmentation of metals can also be found in the cells central vacuole. This was observed in the Zn resistant *Deschampsia cespitosa* where the excess Zn ion was removed from the cytoplasm and actively pumped into the vacuoles of root cells where as Zn sensitive plants had a much lower capacity to do so (Brookes *et al.*, 1981).

Schaaf *et al.* (2006) determined that the transporter AtIREG2, located at the tonoplast, was involved in Ni detoxification in roots. AtREG2, confined to roots, prevents heavy metal translocation to shoots restricting metals to roots. This transporter counterbalances the low substrate specificity of transporter AtIRT1 and other iron transporters in iron deficient root cells. The AtIREG2 transporter, found in *A. thaliana*, was involved in the detoxification of Ni in roots under Fe deficiency conditions at pH 5 (Schaaf *et al.*, 2006). The *T. caerulescens ZTP1* gene was involved in the intracellular sequestration of Zn. The expression of the *ZTP1* gene was higher in the roots and shoots of the Zn tolerant *T. caerulescens* compared to the non tolerant plant (Assunçãno *et al.*, 2001).

Members of the CDF protein play a role in tolerance to various metals including Cd, Co, Mn, Ni and Zn by their sequestration into vacuoles (Montanini *et al.*, 2007). Increased Zn tolerance and accumulation was reported in non accumulator *A. thaliana* when *AtMTP1*, *PtdMTP1*, *AtMTP3* and *TgMTP1* (members of the CDF family) were ectopically or heterologously expressed. This suggested that the function of these proteins was the creation of a sink of Zn in the vacuole of plant cells in instances of high intracellular Zn levels or as buffer in Zn deficiency situations (Hassan and Aarts 2011).

Phytochelatins are also thought to be involved in the restriction of metals to the roots (Zenk, 1996). When *Nicotiana tubacum* seedlings were exposed to excess Cd, the level of phytochelatin increased (Vogelilange and Wagner 1990). The metal-phytochelatin complexes are formed when plants are exposed to high heavy metal concentrations. They are then sequestered into vacuoles for detoxification. A group of organic solute transporters actively transport phytochelatin-metal complexes into the plant's vacuole (Solanki and Dhankhar 2011; Salt and Rauser 1995). In the presence of excess Cu and Cd, phytochelatins form complexes with these metals in *Zea mays* and in turn reduce the root to shoot translocation (Galli *et al.*, 1996). The synthesis of phytochelatins is catalyzed by the enzyme phytochelatin synthase (PCS), a constitutive enzyme which requires post-translational activation by heavy metals and/or metalloids that include Cd, Ag, Pb, Cu, Hg, Zn, Sn, As and Au (Solanki and Dhankhar 2011). Martínez *et al.* (2006) reported that the expression of a PCS gene isolated from *T. aestivum* improved the accumulation of Cd, Pb and Cu in *Nicotiana glauca.* The elevation of phytochelatin concentration in roots might reduce the root to shoot transport required for accumulation in shoots.

3.4.3.4. Root to shoot translocation

The translocation of metals to the aerial biomass can be an important biochemical process used by plants to remediate polluted areas. In some plants, the mobilization of metals from their roots to their above aerial organs can minimize the damage that could be exerted by these heavy metals on the root physiology and biochemistry (Zacchini *et al.,* 2009). Excluders prevent or limit the translocation of toxic metals or essential metals from roots to shoots. On the other hand, accumulators/hyperaccumulators translocate metals from roots to shoots via the xylem with the transpiration stream. This is accomplished by increasing the uptake of metals in roots, and by reducing the sequestration of metals in the root.

The chelation of metals with ligands, such as organic acids, amino acids and thiols facilitates the movements of heavy metals from roots to shoots (Zacchini *et al.,* 2009). The xylem cell wall has a high cation exchange capability, thus the movement of metal cations is severely retarded when the metals are not chelated by ligands. Organic acids are involved in the translocation of Cd in the species *Brassica juncea* (Salt *et al.,* 1995).

The chelation of Ni to histidine is involved in the long distance translocation of Ni in the hyperaccumulator *A. lesbiacum*, where a 36-fold increase was reported in the histidine content of the xylem sap upon exposure to nickel (Solanki and Dhankhar 2011; Krämer *et al.,* 1996). Richau *et al.* (2009) found that the Ni hyperaccumulator, *T. caerulescens*, had a higher free histidine concentration in roots compared to the non Ni hyperaccumulator *T. arvense.* Also, *T. caerulescens* had less Ni in root vacuoles than *T. arvense* because the histidine-Ni complexes were much less taken up by vacuoles than free Ni ions. Therefore, an increase in free histidine in roots inhibited the vacuolar sequestration of His-Ni in *T. caerulescens* compared to free Ni in *T. arvense* and also had enhanced histidine-mediated Ni xylem loading. The elevated free histidine in root cells appears to be involved in reduced vacuolar sequestration and enhanced xylem loading of Ni (Richau and Schat 2009). This was also the case for Zn and Cd for this hyperaccumulating species (Hassan and Aarts 2011). An increase in Ni accumulation was also observed in the Ni hyperaccumulator *Sebertia acuminata* where, when chelated to citrate, Ni was able to translocate to the shoot. In the absence of citrate, Ni was no longer accumulated in the aerial tissues (Lee *et al.,* 1977).

The chelation of metals with nicotianamine (NA) also contributes to improved tolerance. Nicotianamine can chelate and transport divalent Ni, Cu and Zn (Takahashi *et al.,* 2003; Pich *et al.,* 2001; Ling *et al.,* 1999). The nicotianamine synthase (NAS) enzyme is responsible for the synthesis of NA by trimerization of S-adenosylmethionine (Shojima *et al.,* 1990). When exposed to high levels of Zn, Cd, and/or Ni, all four *NAS* genes were highly expressed in *T. caerulescens* compared to non hyperaccumulator *A. thaliana* (van de Mortel *et al.,* 2006). In the presence of elevated Mn, Zn, Fe and Cu concentrations, Kim *et al.* (2005) reported an increased expression of the *NAS* gene, as well as NA levels for *A. thaliana* and *N. tubacum*. In addition, Pianelli *et al.* (2005) showed that the over-expression of the *T. caerulescens NAS3* gene in the Ni excluder *A. thaliana* resulted in improved Ni tolerance and Ni accumulation in their aerial organs. An increase of Fe, Zn and Cu accumulation in *O. sativa* was associated with an overexpression of the *NAS3* gene (Hassan and Aarts 2011; Kawachi *et al.*, 2009).

Visioli *et al.* (2010) also showed that metallothioneins may be involved in the translocation of Ni in *T. caerulescens.* An increase in MT-1B in the individuals from the metal contaminated environment was observed when metallicolous *T. caerulescens* and non-metallicolous *T. caerulescens* individuals were grown in presence of high Ni concentrations, compared to non contaminated site. Additionally, Visioli *et al.* (2012) analyzed four *T. caerulescens* sub-population (MP1 to MP4) for their ability to accumulate and tolerate Ni. In four sub-populations analyzed, MP2p translocated the highest amount of Ni to the shoots. This sub-population also had the highest level of putative metallothionein protein (MT4C). Constitutively higher expressions of other MTs are also seen in the hyperaccumulators *A. halleri*, *S. paradoxa* and *S. vulgaris*.

Transporters are not only involved in the uptake of metals from the soil, but also in their transport out of the vacuole. These mobilized metals can then be translocated to aerial tissue. Visioli *et al*. (2012) subsequently found for sub-population MP2p, which exhibited the highest level of Ni translocation of the four sub-populations analyzed, significantly higher levels of the ABC27 transporter. This transporter is part of the ABC family of transporters which are involved in removing metals from the cytoplasm by pumping outside the cell wall, metals sequestered in vacuoles and other subcellular compartments (Visioli *et al.*, 2012; Martinoia *et al.*, 2002; Sanchez-Fernandez *et al.*, 2001). Hassinen *et al.* (2007) showed that the AtMRP10 homolog, also part of the ABC family of transporters, had different expression in roots of two *T. caerulescens* populations with contrasting Zn tolerance and accumulation. In addition, the AtNramp3 transporter was also involved in the mobilization of vacuolar Cd back into the cytosol. This was oberved when *AtNramp3* was overexpressed in *A. thaliana*. AtNramp3 was further hypothesized to play a role in the mobilization of Fe, Mn, and Zn in the vacuole (Clemens, 2006).

The passage of metal ions and/or metal ligand complexes from the cytosol of root cells into the vascular tissue requires their transport across the cell membrane. Transporters involved in this activity are the heavy metal transporting P-type ATPases (HMAs) (Clemens, 2006). The AtHMA2 and 4 are involved in translocation of Zn in *A. thaliana*. Stunted growth and chlorosis resulted in the *hma2hma4* double mutant from inadequate Zn supply to the leaves. The two genes were expressed in vascular tissue which indicates their hypothesized function in xylem loading (Hussain *et al.*, 2004). The AtHMA4 transporter was also involved in the transport of Cd^{2+} ions (Clemens, 2006). In *T. caerulescens*, the P-type ATPase, TcHMA4, was also involved in the translocation of Zn. When Zn and Cd levels were elevated or when Zn is deficient, the expression of *TcHMA4* was induced in the roots. This transporter was involved in the xylem loading of Zn in plant roots (Hassinen *et al.*, 2007; Papoyan and Kochian 2004). Milner *et al.* (2012) also determined that NcZNT1 in *T. caerulescens* was not only involved in Zn uptake from the soil but also could be involved in the long distance transport of Zn from root to shoot via the xylem.

3.4.3.5. Metal storage

Metals have to undergo a xylem unloading process prior to their distribution and their detoxification in the shoot and their redistribution via the phloem (Schmidke and Stephan

1995). Once unloaded, the metals are either taken up into surrounding cells and are symplastically transported through the leaf tissues or they are apoplastically distributed over the leaf (Hassan and Aarts 2011; Marschner, 1995). NA is important in the chelation of metals for their symplastic transport through the leaf. This occurs through the Yellow Stripe Like proteins (YLS) (Hassan and Aarts 2011; DiDonato *et al.,* 2004). In the hyperaccumulator *T. caerulescens*, three *YSL* genes (*TcYLS3*, *TcYSL5* and *TcYSL7*) were highly expressed in shoots around vascular tissues. This high level of expression was not observed in the excluder plant *A. thaliana* orthologues (Hassan and Aarts 2011; Gendre *et al.,* 2007). For the *TcYSL3*, it was suggested that its function was to unload Ni-NA complexes from the xylem into leaf cells and to distribute it to storage cells. Using yeast complementation and uptake measurement studies, it was determined that TcYSL3 was also a Fe/Ni-NA influx transporter. Considering that YSL proteins have a role in the transport of Fe-NA complexes, it was proposed that they might also be involved in the hyperaccumulation of Fe-NA in some plants (Hassan and Aarts 2011; Curie *et al.,* 2009).

The sequestration of excess essential and non essential metals is localized in various parts of the aerial tissue, such as trichomes, leaf epidermal cell vacuole and mesophyll vacuole. Broadhurst *et al.* (2004) grew five *Alyssum* hyperaccumulator species/ecotypes on Ni-enriched soil and determined that the majority of hyperaccumulated Ni was stored in either leaf epidermal cell vacuoles or in the basal section of stellate trichomes. They also found that the metal concentration in the basal part of the trichome was 15% to 20% of dry weight. This was among the highest metal concentrations reported in healthy vascular plant tissues. In *A. halleri*, the majority of Zn ions were stored in the vacuoles of mesophyll cells, while for *T. caerulescens*, most Zn ions were located in the vacuoles of epidermal cells (Verbruggen *et al.,* 2009). The transport of metals through the phloem sap is less documented. The sole molecule identified as a phloem metal transporter is nicotianamine which is involved in the transport of Fe, Cu, Zn and Mn (Stephan *et al.,* 1994).

3.4.4. Antioxidative defence involved in metal tolerance

In environments, where metals are present in toxic levels, the elevated activities of antioxidant enzymes and non-enzymatic constituents are important in the plant tolerance to stress. Metal tolerance may be enhanced by the plant's antioxidant resistant mechanisms. There is an indication that the alleviation of oxidative damage and increased resistance to stresses in the environment is often correlated with an effective antioxidative system. The minimization of damage due to oxidative stress is a universal feature of plants defense responses (Kachout *et al.,* 2009). The detrimental effect of heavy metals in plants is due to the production of ROS and induction of oxidative stress. Oxidative stress is expressed by the increase levels of reactive oxygen species such as singlet oxygen ($^1O_2$), superoxide radical (O^{-2}), hydrogen peroxide (H_2O_2) and hydroxyl radical (OH^-) (Salin, 1988). ROS are strong oxidizing agents that lead to oxidative damage to biomolecules, for instance lipids and proteins and can eventually result in cell death (Gunes *et al.,* 2006). It is shown that plant tolerance to metals is correlated with a rise in antioxidants and activity of radical scavenging enzymes (Kachout *et al.,* 2009). Plants respond to oxidative stress by activating antioxidative defence mechanisms which involve enzymatic and non-enzymatic antioxidants. The enzymatic components include superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX) and enzymes of ascorbate glutathione cycle whereas the non-enzymatic antioxidants include ascorbate and glutathione and atocoperol (Solanki and Dhankhar 2011; Kachout *et al.,* 2009). These antioxidants are responsible for elimination and destruction of the reactive oxygen species (Solanki and Dhankhar 2011).

Oxidative damage could result when the balance between the detoxification of the ROS products and the antioxidative system is altered (Kachout *et al.,* 2009). The tolerance of deleterious environmental stresses, such as heavy metals, is correlated with the increased capacity to scavenge or detoxify activated oxygen species (Kachout *et al.,* 2009). Boominathan and Doran (2003a,b) determined the role of antioxidative metabolism of heavy metal tolerance in *T. caerulescens*. They determined that superior antioxidant defenses, mainly catalase activity, may have an important role in the hyperaccumulator phenotype of *T. caerulescens*. Kachout et al (2010) determined the effects of Cu, Ni, Pb and Zn on the antioxidative defense systems of *Atriplex* plants. They found that when the plants were exposed to different levels of metals, their dry matter production and shoot height decreased. Of the antioxidant enzymes, metal toxicity only diminished the levels of superoxide dismutase (SOD) and probably ascorbate peroxidase (APX) but increased the activity of catalase (CAT) and glutathione reductase (GR). The plants showed an intermediate level of tolerance to the metal stress conditions imposed. The antioxidative activity may be of fundamental significance for the *Atriplex* plants in their response against environmental stress.

3.5. Problems associated with plant metal tolerance

Soils enriched with metals are demanding on tolerant and accumulator plants. The costs associated with their adaptation to these sites are related to energy and resources allocations. When a metal tolerant or accumulator plant is growing in a metal contaminated soil, there is an increase in cost because the organism has to spend energy to counter the effects of the metals (Maestri *et al.,* 2010). Slow growth and low reproduction are the main characteristics of plants growing on metal enriched soils (Ernst, 2006; Ernst *et al.,* 2000). Haldane (1954) stated that costs are associated with the natural selection of new alleles. More energy and resources are required for the maintenance of the tolerance mechanisms at the cellular level. It has been demonstrated that tolerant plants have increased synthesis of complexing molecules in the cytosol. For example, metallothioneins and phytochelatins for the detoxification of metals such as As, Cd, and Cu. ATP are also needed for the active transport of metals across the plasma membrane and tonoplast. The synthesis of these agents withdraws N, S and energy from the primary metabolism (Ernst, 2006; Verkleij *et al.,* 1998). Energy is also required for the translocation of metals from root to shoot as well as for their allocation to various tissues and cell types. The reduced biomass of metal tolerant plants compared to their non metal tolerant ancestors might also be the result of less than favourable environmental conditions such as low water and nutrient supply. The diminished biomass and seed production might be the result of all costs associated with their survival to these metal contaminated sites, such as adaptation and environmental constraints (Ernst, 2006). Plants have an advantages growing on metal contaminated soil. As previously mentioned, there is a lack of competitive species on these sites. With high metal accumulation of metals in their

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aerial tissues, the "elemental hypothesis" speculates that hyperaccumulators can deter predators such as herbivores from feeding on them (Maestri *et al.*, 2010; Vesk and Reichman 2009). However, some insects feed on hyperaccumulator plants and in turn accumulate the metals in their tissue which then aid in their defence against predators (Maestri *et al.*, 2010). This contradiction may explain why there is a mix of excluders, accumulator and hyperaccumulators growing on metal contaminated sites. Another advantage of hyperaccumulation is the elimination of competitive plants by further contaminating the surrounding soil by shedding their metal contaminated leaves (Maestri *et al.*, 2010).

3.6. Effects of metals on plant population diversity and structure

Elevated accumulations of metals in soil and vegetation have been documented within short distances of the smelters compared to control sites (Nkongolo *et al.*, 2008; Gratton *et al.*, 2000). Several authors have reported differences in genetic structure of plants growing in contaminated areas (Vandeligt *et al.*, 2011; Nkongolo *et al.*, 2008; Scholz and Bergmann 1984). Enzymatic studies of Norway spruce (*Picea abies*) revealed genetic differences between groups of sensitive trees in polluted areas (Scholz and Bergmann 1984). It has been demonstrated that the evolution of heavy metal tolerant ecotypes occurs at an unexpectedly rapid rate (Wu *et al.*, 1975) and that despite founder effect and selection, in several cases, the recently established tolerant populations maintain a high level of variation and appear to be at least as variable as non tolerant populations. Observations of higher heterozygosity in tolerant plants of European beech (*Fagus sylvatica*) in Germany (Muller and Starck 1985), scots pine (*Pinus* sylvestris) in Germany and Great Britain (Geburek *et al.*, 1987), trembling aspen (*Populus tremuloides*) and red maple (*Acer rubrum*) in the United States (Berrang *et al.*, 1986) have been reported. Several studies, however, have reported the detection of bottleneck effects (Nordal *et al.*, 1999; Vekemans and Lefebre 1997; Mejnartowicz, 1983). Mejnatowicz (1983) presented evidence of loss of genes and heterozygosity in tolerant Scots pines. The frequent lack of a bottleneck effect has been explained by different hypotheses: successive colonization events, a high number of tolerant plants in the primary populations, pollen flow from the neighboring populations, environmental heterogeneity and human disturbance (Nkongolo *et al.*, 2007).

Molecular analyses of several conifer and hardwood species clearly indicated that the exposure to metals for more than 30 years has no effect on genetic structure and diversity of early generations of *Picea mariana, P. glauca, Pinus banksiana, P. rubens, P. strobus*, and several hardwood populations in Northern Ontario (Narendrula *et al.*, 2012; Nkongolo *et al.*, 2012; Dobrzeniecka *et al.*, 2011; Vandeligt *et al.*, 2011). This lack of association between the level of genetic variation and metal content can be attributed to the long life span of these tree species. Table 1 shows similar level of genetic variabilities in pine populations growing in metal contaminated sites for more than 30 years compared to control in Northern Ontario, Canada. This is in contrast to data observed in herbaceous species such as *D. cespitosa* where a high level of metal accumulation reduced significantly the level of genetic variation (Table 2) (Nkongolo *et al.*, 2007). Metals impose severe stress on plants, especially in the rooting zone, which has led to the evolution of metal resistant ecotypes in several herbaceous species like *D. cespitosa* (Cox and Hutchinson 1980).

Populations	P (%)	h	I	Ne	Na
Vale site 1 (metal contaminated)	31.25	0.1120	0.1653	1.2035	1.3125
Vale site 2 (metal contaminated	31.25	0.1171	0.1727	1.2061	1.3125
Xtrata 2 (metal contaminated)	27.08	0.0995	0.1467	1.1758	1.2708
Xtrata 3 (metal contaminated)	20.83	0.0630	0.0982	1.1004	1.2083
Vale Tailing (metal contaminated)	35.42	0.0977	0.1552	1.1514	1.3542
Temagami site (control)	29.17	0.0818	0.1284	1.1310	1.2917
Low Water Lake (control)	31.25	0.0812	0.1297	1.1256	1.3125
Mean	31.63	0.1001	0.1528	1.1679	1.3163

Table 1. Genetic variability parameters of *Pinus banksiana* populations growing in the Sudbury, Ontario (Canada) area based on ISSR data.

P represents percentage of polymorphic loci; h, Nei's gene diversity; I, Shannon's information index; Ne, effective number of alleles; Na, observed number of alleles.

Region	Site	Polymorphism per site (%)	Mean polymorphism per region (%)
Sudbury	Coniston	72	74 (Sudbury)
(moderately contaminated)	Xtrata	92	
	Copper Cliff	67	
	Walden	65	
Cobalt	Cobalt-3	48	46 (Cobalt)
(highly contaminated)	Cobalt-4	46	
	Cobalt-5	44	
Manitoulin	Little Current	70	69 (Manitoulin)
(control)	Mississagi Lighthouse	68	

Table 2. Genetic variability within *Deschampsia cespitosa* populations from Northern Ontario generated with ISSR primers.

P represents percentage of polymorphic loci; Sudbury and Cobalt regions were moderately and highly contaminated with metals, respectively. Manitoulin Island region was not contaminated with metals and was used as a control region.

4. Conclusion

Plants play an essential role in the remediation of metal enriched soils. Coping mechanisms developed by some group of plants growing on metal contaminated soil facilitate the establishment of sustainable ecosystems in areas that would otherwise remain barren. A number of studies have been completed to explain the complex mechanisms involved in tolerance genotypes, and also the biological variability in their environmental adaptation. Depending on the circumstances, metal excluders or hyperaccumulators may be used to remediate polluted soil. Excluders may be useful for soil stabilization by preventing wind and water erosion and also by limiting the entry of heavy metals in the food chain. Metals can also be extracted by hyperaccumulators but since majority of these plants have low biomass, the extraction of metals from soil is very slow. The remediation of these sites using this technique may take up to hundreds of years. With genetic engineering, it may be possible to design the ideal plant prototype for the remediation of metal contamination in different environments. Many genes and mechanisms have been identified to have a role in tolerance and hyperaccumulation of metals. However, there is still a need for a better understanding of the mechanisms such as characterization of promoters of genes controlling metal tolerance and hyperaccumulation. This new knowledge would significantly contribute to a better understanding of the regulation and expression of different genes in hyperaccumulators. It is essential to mimic this regulation and expression of genes in high biomass non hyperaccumulators in order to obtain the hyperaccumulator phenotype.

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Chapter 4

Harnessing Earth Observation and Satellite Information for Monitoring Desertification, Drought and Agricultural Activities in Developing Countries

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Additional information is available at the end of the chapter

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1. Introduction

With the drastic advances in technology over the past decades, the availability, as well as the quantity, of large data sets for research in almost every scientific field has increased dramatically. More specifically, the availability of earth observation-based imagery data and satellite information for research purposes and practical applications has grown with many organizations such as the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the National Aeronautics Space Administration (NASA), the National Oceanic and Atmospheric administration (NOAA), the Flemish Institute for Technological Research (VITO), etc. for example, through GEONETCast, which is part of the core Global Earth Observation System of Systems (GEOSS), the users do not need to repeatedly build ground receiving stations for different satellites [1]. However, despite a wealth of remotely sensed data provided by GEONETCast, investments in science technology and innovations is often a low priority for decision and policy makers in most developing countries in Africa, Asia and global emerging economies like India and Brazil. Yet, most of these countries face serious environmental risks and development challenges which require reliable and timely access to accurate Earth Observation (EO) data and derived environmental information for their sustainable development. In particular, there is a clear need for research on the integration and utility of remote sensing data and products into the risk assessment cycle, scenario development and impact forecasting, in view of global (climate) change [2].

Climate alterations, although global in nature, may have different impacts in different regions of the world. Reports of Intergovernmental Panel on Climate Change (IPCC) showed that the global average surface temperature has increased over the 20th century by about 0.6ºC [3]. Global Circulation Models have projected that this rise in temperature may increase to a range of 1.5 – 5.8ºC by the end of the century. Results of crop growth modeling under climate change scenarios suggest that agriculture, and thus human well-being, will be negatively affected by climate change, especially in developing countries [4]. The vulnerability to drought and land degradation has increased in the past decades and this is especially true due to increased population pressure and limited livelihood options in drought-prone areas [5]. Significant gaps in observing systems exist, especially in developing countries, and timely access to both surface-based and space observations is still a challenge in many locations.

Global-scale population growth and economic development will have a large impact on water supply and demand, and it is necessary to understand the interactions between climate change and variability, hydrology and human systems, in order to have a view on future water vulnerabilities [6]. Since developing countries will become more susceptible to climate variability and drought, it is essential to develop climate (impact) monitoring services. A climate service involves broad partnerships of producer and user organizations, climate scientists, climate service providers, economists and social scientists. It provides an opportunity to interlink global, national and regional information systems; to provide essential information to policy makers, decision takers and to the public in general at regional and local scales, and a provide for a distributed decision-relevant research and development capability [7]. The climate service for the developing countries might focus on collaborative problem solving. Also capacity building and the improvement of infrastructure, related to the acquisition of advanced remote sensing technologies and the installation of satellite receiving stations by, is needed.

The gist of this chapter is therefore to strengthen the capacities of the regional scientific community to provide stakeholders from drought to agricultural activities with satellite information that is directly useful to improve decision-making in the context of the developing countries. The chapter is based on four case studies from Africa, South America, India and Europe to demonstrate the utility of satellite imagery data obtained from free or low cost platforms in providing information to address the above environmental issues, which are critical particularly in developing countries. Based on the expertise, experience and interest of a regional network of scientists from Uganda, Brazil, India, and Europe, the chapter focuses on harnessing satellite remote sensing resources and products for drought monitoring of areas subject to or in risk of land degradation processes, agricultural productivity and drought assessment. The following paragraphs include a series of example cases where time series of satellite imagery is used to monitor the impact of climate (change):

i. Degradation monitoring over South America

ii. Relation of NDVI with the moisture Index over the regions of different climatic types

iii. Sugarcane yield estimation and modelling based on NDVI data over Southeastern Brazil and

iv. Production and yield estimates of five major crops over Uganda

The importance of each of the above aspects in the context of assessing, monitoring and managing the natural hazards such as desertification, drought and risk management are discussed in detail in the individual sections.

All case studies make use of time series of Normalized Difference Vegetation index (NDVI), an index of vegetation activity that can be derived from broad band measurements in the visible and infrared channels onboard satellite instruments and which is directly related to the photosynthetic capacity of plants [8]., Satellite sensors such as NOAA Advanced Very High Resolution Radiometer (AVHRR), Moderate Imaging Spectroradiometer (MODIS), Système Pour l'Observation de la Terre (SPOT) Vegetation etc. provide NDVI data on different intervals (8-day, 10-day, monthly and seasonal). NDVI value varies minus one (-1) to plus one (+1), whereby low NDVI values (< 0.2) reflect sparse vegetation, and higher NDVI values (> 0.4) reflect high vegetation densities. Several studies looked into the interannual variability and trends of NDVI in relation to meteorological parameters such as rainfall, temperature etc [9-11].The long time series of NOAA AVHRR has been widely used to relate the synoptic meteorology/climatology to understand the vegetation dynamics, vegetation response to climate and climate vegetation feedback mechanism [5, 12-14]. The studies of [9, 15-17] concluded that AVHRR NDVI is a valuable tool to monitor and asses large scale agricultural droughts. Other studies use NDVI time series derived from MODIS [18-20] or SPOT-Vegetation [21, 22].

In this work, the authors made use of NDVI imagery datasets derived from different satellites to relate the respective crop and climatic parameters to understand the sensitivity of NDVI with these parameters and further to use them for vegetation monitoring over large areas which contributes to risk management.

2. Time series analysis for desertification monitoring

In the last decades, remote sensing technologies started to contribute enormously in documenting changes in land cover and monitoring desertification, drought and agricultural activities on regional and global spatial scales. Although desertification is highlighted as one of the most important global environmental issues, both desertification and greening processes have been reported on global scale [23-26]. These processes are related in many ways with other environmental issues, such as climate change and the carbon cycle, loss of biodiversity and sustainability of agriculture [27]. Also in South America environmental change is an important concern. In the last decades, South American ecosystems underwent important functional modifications due to climate alterations and direct human interventions on land use and land cover [28]. In South America, the main forest conversion process in the humid tropics in the period 1990-1997 was the clear-cutting of closed, open, or fragmented forest to make room for agriculture at a rate of approximately 1.7 million ha per year [29]. Apart from deforestation, also forest degradation occurs, a process leading to a temporary or permanent deterioration in the density or structure of vegetation cover or its species composition. Land degradation in arid, semi-arid and dry sub-humid areas is called desertification, and is the result of various factors, including climatic variations and human activities [30].

To determine desertification conditions, this case study focuses on vegetation dynamics in South America over a long time period based on a time series of low spatial resolution, high temporal resolution NDVI derived from SPOT-Vegetation, and to recognize to which extent this variability can be attributed to variability in rainfall, since rainfall is one of the most determinant factors of vegetation growth. In general, and especially in semi-arid regions, strong correlations between precipitation and the NDVI can be found. Therefore, the NDVI can be used as an indicator for vegetation status and vegetation response to precipitation variability. This study expands the analysis, as was performed on the Andes region [31] to South American continental level. In the first phase, trends of vegetation and precipitation indices are analyzed. In a next step, through correlation of NDVI and precipitation dynamics, these areas where the evolution of vegetation is not related to climate only and human induced impacts play an imperative role can be identified.

The time series of SPOT-Vegetation 10-daily composite NDVI data (April 1998 – March 2012) at 1 km resolution (http://www.vgt.vito.be/) was smoothed [32] and consequently synthesized to monthly images using the maximum value composite technique. Also 10-daily rainfall estimates at 0.25° resolution, available from the European Centre for Medium-Range Weather Forecasts (ECMWF) through MeteoConsult and the Monitoring Agricultural ResourceS (MARS) unit, were combined to retrieve monthly composites. The spatial resolution of the NDVI time series was degraded in order to fit the rainfall estimates using a weighted average approach. Many authors remove seasonality by integrating the data into annual values (e.g. [25, 28, 33]). In this study, in order to remove seasonal vegetation changes and thus facilitate the interpretation through the historical record, deviations from the 'average' situation were calculated for the NDVI time series using the Standardized Difference Vegetation Index (SDVI) [34] and for the precipitation time series using the Standardized Precipitation Index (SPI) [35]. In a next step, for each pixel a correlation analysis is performed on the monthly NDVI and SPI datasets, in order to identify the temporal scale at which the environment is most sensitive to precipitation anomalies (the so-called 'best lag').

The results of the correlation analysis between NDVI and SPI are shown in Figure 1. Positively correlated (blue) areas suggest precipitation-vegetation coupling. In general, high positive correlation with best lags between 3 – 6 months are found in the semi-arid regions of South America, while weak (or even negative) correlation at all time scales was found in both the hot and humid zones and the deserts and high mountainous areas. These positive relationships between vegetation greenness and rainfall in drylands, where biomass production is determined by the amount of rainfall, and the opposite in humid and cold regions, where rainfall is not the limiting factor for vegetation growth, and deserts, where there is no rainfall at all, is consistent with findings of other authors, such as [33, 36].

In order to identify if a pixel is greening or degrading, and after identifying the best lag for each pixel, linear least squares trend analyses were performed on the SDVI time series and the SPI time series, taking into account the accumulated rainfall over the respective best lag. Only trends with Pearson correlation coefficients significantly different from zero (at significance level $p < 0.05$) are considered significant trends. Figure 2 shows the slope of the significant linear trends of vegetation greenness and precipitation anomalies, SDVI and SPI respectively.

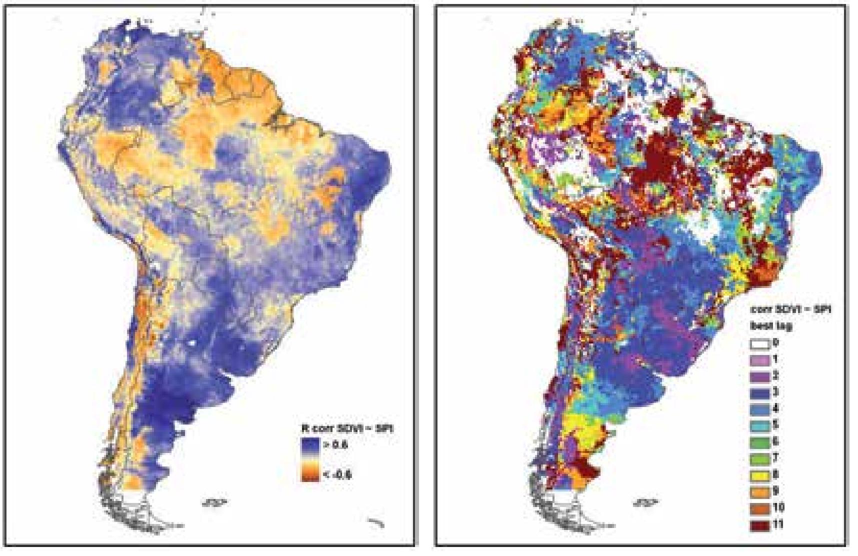

Figure 1. Correlation analysis between NDVI and SPI. Best lag expressed in months.

SDVI show slight but significant (P<0.05) positive trends in large areas in the northern part of South America, but significant negative trends in Argentina and the Peruvian coast. The results are comparable, but far more pronounced than results from annual series trend analysis, such as from [25, 28]. Also the SPI shows positive trends in the north-west of South America and the centre of Brazil. Negative precipitation trends are found in Argentina, the Peruvian coast and north-east of Brazil.

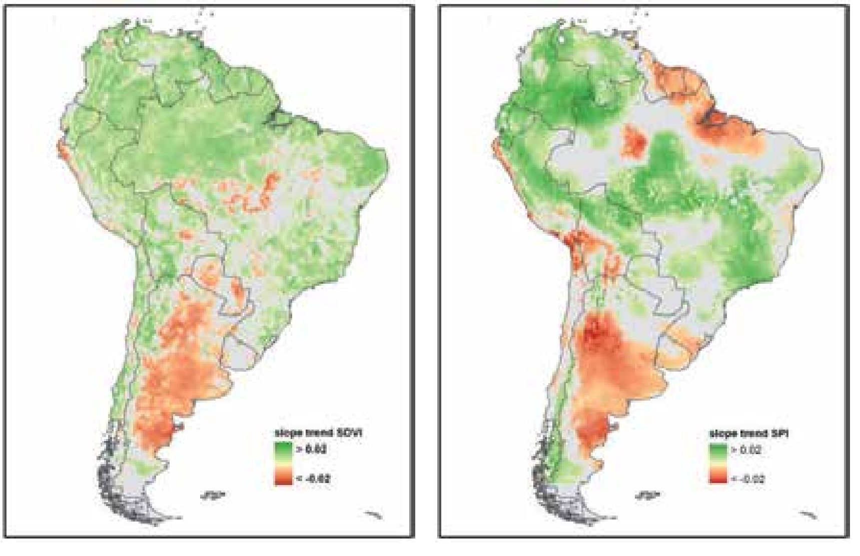

Figure 2. Slope of the trend analysis of SDVI (left) and SPI (right). Non significant trends are masked in grey.

Following the trend analyses, a decision tree approach is adopted in order to interpret the results. Five queries are stipulated: (1) Does the time series of SDVI show a significant trend? (2) Are significant trends in SDVI coupled to significant correlations between NDVI and SPI? (3) Are significant trends in SDVI linked to significant trends in SPI? (4) Does the SDVI show a positive trend? (5) Do trends in SDVI correspond to trends in SPI?

The first question is meant to identify the focus area, i.e. pixels where the de-seasoned vegetation index (i.e. SDVI) shows a significant linear trend over time. The second and third queries are used to identify areas that differ in their relationship between vegetation and precipitation trends, respectively, while queries 4 and 5 are meant to distinguish positive and negative trends that are linked to trends in precipitation. On the other hand, it is possible to identify regions where positive or negative trends in vegetation are not linked to changes in precipitation and other climate variables or human impact play an imperative role. In step 4, pixels are divided in greening or degrading pixels. In the last step, both the trends in SDVI and SPI are evaluated.

The results of the decision tree analysis are shown in Figure 3. Green classes show a significant positive trend in SDVI coupled to an increase in SPI. Red classes show a coupling between a decrease in SDVI and SPI. The yellow and orange classes are classes where SDVI and SPI show an opposite trend. Argentina is clearly suffering from vegetation degradation linked to a decline in precipitation, which confirms the findings of [35]. The opposite is going on in Colombia and some parts of Brazil, where a process of greening seems to be linked to an increase in precipitation. Nevertheless, Brazil shows a patchy result, with some areas showing an increase in SDVI, although the precipitation decreases (yellow areas in Figure 3), and other areas showing a decline in vegetation, although precipitation increases (orange area in Figure 3), probably related to deforestation or forest degradation.

The resulting map can be used to estimate the coupling between vegetation (SDVI) and precipitation (SPI), shown in Figure 4. Three estimations are made: (A) a large estimation where significant trends in SDVI are coupled with trends in precipitation when SPI shows the same trend (significant or not); (B) an average estimation where significant trends in SDVI are linked to trends in precipitation when SPI shows a significant trend; and (C) a conservative estimation where significant trends in SDVI are linked to trends in precipitation when the SPI shows a significant trend and the correlation between NDVI and SPI is significant.

In estimation A, also weak trends in SPI are taken into account. These non-significant trends in precipitation are most probably not by itself responsible for significant trends in SDVI. Together with other variables like temperature change or human impact, these weak changes in precipitation might however give an extra impulse to greening or degradation processes. It is also possible that an increase in precipitation does not result in higher vegetation cover because the area is covered with climax vegetation or, the other way round, a decrease in precipitation does not result in further degradation because the area is already covered with minimal vegetation growth. Estimations A and B show little difference. The difference between estimation B and C is based on the significance of the correlation between NDVI and SPI, and shows larger differences, mainly in the greening pixels. In many pixels that show a positive

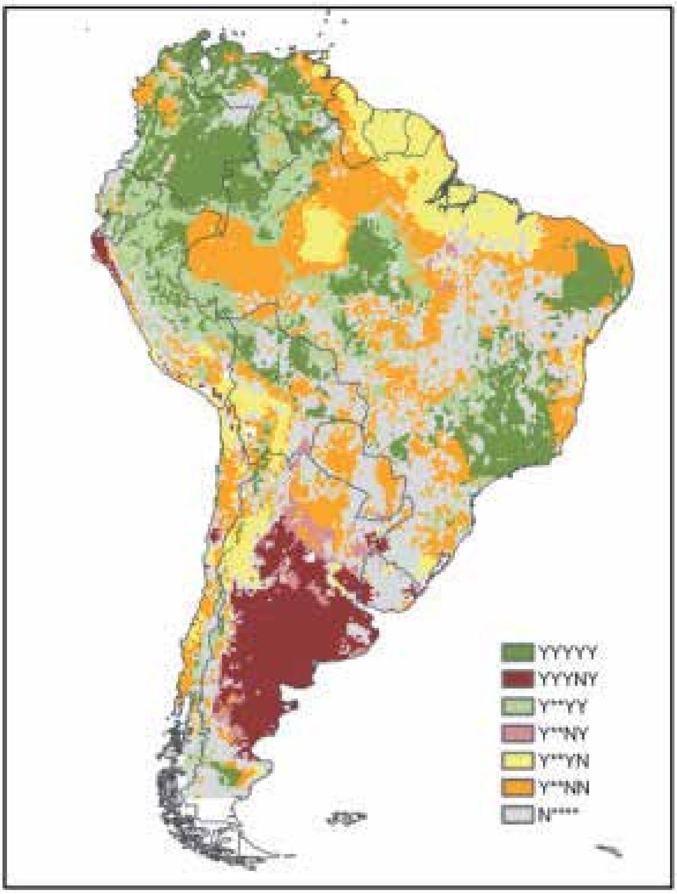

Figure 3. Result of the decision tree approach. Pixels are classified according to the 5 queries described in the text (where Y and N refer to a 'yes' or 'no' answer to the query, and * to either Y or N): green areas show an increase in SDVI, coupled to a significant positive trend in SPI (dark green) or not (light green); red areas show a decrease in SDVI, coupled to a significant negative trend in SPI (dark red) or not (light red); yellow areas show a positive trend in SDVI, but a negative trend in SPI; orange areas show a negative trend in SDVI, but a positive trend in SPI. Pixels without a significant trend in SDVI are masked in grey.

trend in SDVI, vegetation greenness is not significantly correlated to SPI. It is therefore not certain that in these areas the increase in SDVI is coupled to an increase in precipitation.

From the conservative estimation, we can conclude that in 8% of South America, vegetation degradation is coupled to a significant decrease in the amount of precipitation in the last 14 years. Our results corroborate with the findings of [37]. In contrast, in 18% of the subcontinent, vegetation greenness has significantly increased over the last 14 years, coupled to an increase in precipitation. For 46% of the study area, significant degradation or greening processes could not be linked to changes in precipitation over time, indicating human impact or the influence of other climatic factors, such as temperature. Finally, and without taking into account the link with trends in precipitation, 40% of the subcontinent is showing an increase in photosynthetic activity over time, while desertification is taking place in 32% of the area.

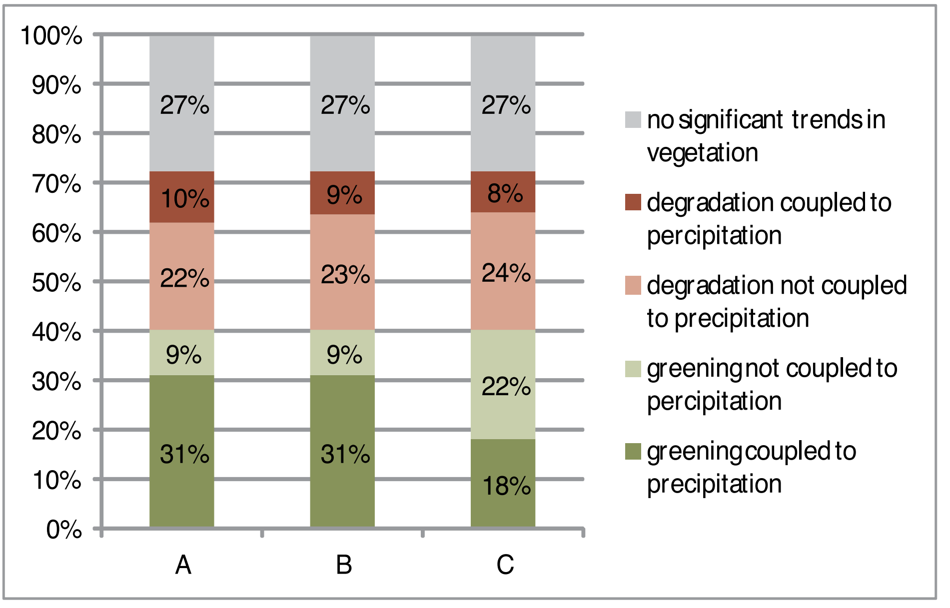

Figure 4. Large (A), average (B) and conservative (C) estimation of the linkage of greening and degradation to changes in precipitation over time. In case of estimation B and C, the yellow areas in Figure 3 are included in the light green fraction, while the orange areas in Figure 3 are included in the light red fraction.

3. Time series analysis for drought monitoring

Drought is a recurrent feature of the Indian climate and usually begins at any season and can prolong for many years. The study of drought characteristics is to ascertain the spatial and temporal distribution of droughts, synoptic meteorological conditions associated. The definition of drought mainly depends on the precipitation deficiency. Studies on droughts in India have been reported by many scientists based on the rainfall anomalies over a particular region [38-40]. According to India Meteorological Department (IMD) guidelines, drought is defined as the consequent rainfall deficiency (below 19% of normal) for a period of 2 consecutive weeks. However, this criterion varies from country to country, based on the meteorological/climatological conditions such as percentage of moisture present, land topography etc.

Drought is of different types including meteorological droughts, agricultural droughts, hydrological drought and socioeconomic droughts. These are based on the variations of rainfall, crop water, surface water and economic conditions respectively. These droughts show variation with respect to the climatology which prevails of that region. The climatology of a region is a replica of the severity of drought. The climatology can be derived from the Thoronthwaite Climate System by taking the inputs of rainfall and water need. The model gives the amount of moisture (annual/seasonal) from which the classification of climate can be studied.

In view of the above, the present study focuses in obtaining the climates in different parts of Karnataka state which is located at the western half of the Deccan Palateau of India. The Moisture Index values which are the basis for delineating climatic type were compared with the AVHRR NDVI to understand the drought climatology in different test regions of Karnataka, India (Figure 5).

Figure 5. Study area of the present investigation

The rainfall (P) and potential evapotranspiration (PE) data for the period 1982 to 2000 was downloaded from [41]. This data is based on the global rainfall and temperature (PE can be calculated from temperature) data sets of Climate Research Unit, University of East Anglia, United Kingdom. This was averaged for all the districts of Karnataka state till the year 2000 and uploaded website.

Taking the inputs of P and PE, we run awater balance model and derived the monthly Aridity Index (I_A) and Humidity Index (I_H). Moisture Index (I_M) which is the basis to tell the climatology of a region can be obtained by subtracting I_A from I_{H}. Table 1 below shows the infered climate types based on I_M as per Thoronthwaite Climate Approach [42, 43].

Moisture Index(IM)	Climatic Type	Notation
100 & above	Perhumid	A
80 to 100	Humid	B4
60 to 80	Humid	B3
40 to 60	Humid	B2
20 to 40	Humid	B1
0 to 20	Moist Subhumid	C2
-20 to 0	Dry Subhumid	C1
-40 to -20	Semiarid	D
-60 to -40	Arid	E

Table 1. Classification of climatic types based on Thoronthwaite Approach

The selected districts for the study are Chikkamagaluru, Belgaum, Chamrajnagar and Gulbarga of which climates are Humid, Dry subhumid, Semiarid and Arid. A comparative study was made with the seasonal values of IM and NDVI using time series and correlation analysis.

Table 2 shows the climatology of the four selected test sites during the period of 1982 to 2000. The overall climate of the test regions for the study period represented the humid, dry subhumid, semi arid and arid for Chikkamagaluru, Belgaum, Chamrajanagar and Gulbarga districts respectively.

Year	Climate Type			
	Chikkamagaluru	Belgaum	Chamarajanagar	Gulbarga
1982	C1	C1	D	E
1983	B1	C2	D	E
1984	C2	D	D	E
1985	C1	D	D	E
1986	C2	D	D	E
1987	C1	D	D	E
1988	B2	C1	D	E
1989	C2	D	D	E
1990	C1	D	D	E
1991	B1	C1	D	E
1992	B2	C2	D	E
1993	B1	B1	C1	E
1994	B2	C2	D	E
1995	C2	C1	D	E
1996	B1	D	D	E
1997	B1	C1	C1	E
1998	B2	C2	C2	E
1999	B1	B1	C1	E
2000	B1	C2	D	E

Table 2. Climatic types of test regions from 1982 to 2000

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3.1. Chikkamagaluru (Humid region)

The climatic types of Chikkamagaluru were dominated by humid type which is followed by the dry sub humid type. Chikmagalore (Humid region) recorded a maximum I_M of 450 during the year 1994 (Figure 6). The variation of I_M shows that it has increased from June to August in all years and recorded a comparative less value in the month of September. In a similar way, the NDVI progressed from June to September in all years with a maximum value of 0.55 for September, 1992. It is conspicuous that the variability in NDVI is more than I_M and the trends of I_M and NDVI were increasing. The correlation coefficient of these two indices is +0.08 which is very poor. The studies of [38, 39] also suggested that understanding the relation of NDVI with rainfall and its by-products is a very difficult task in humid regions. Since the plenty of moisture is already available in the soil, the vegetation can utilize the moisture for its growth and in such case it may not directly/immediately dependant on rainfall derived indices in humid regions.

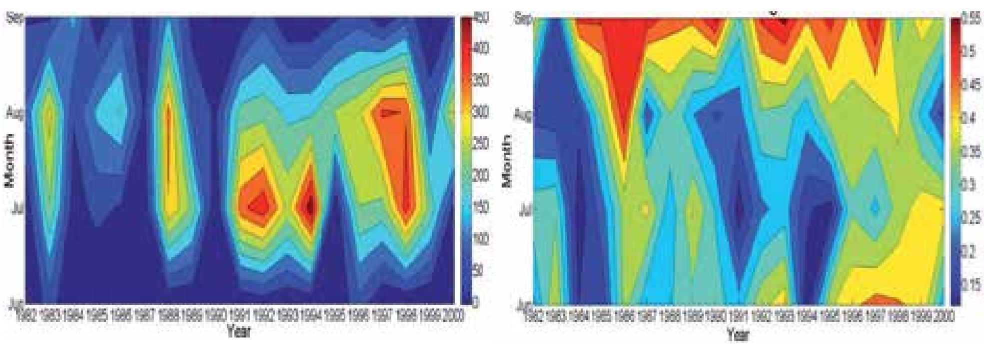

Figure 6. Variation of IM and NDVI – Chikkamagaluru

3.2. Belgaum (Dry subhumid)

The climate of Belgaum varied from semi arid to 1st humid type during the study period. 10 years of the study period show the subhumid climates followed by semi arid in 7 years. The variation of I_M with NDVI over Belgaum unraveled the low variability of I_M associated with high variations of NDVI (Figure 7). The maximum NDVI is 0.55 that is during September of 1984 and 1992 linked with the very low values of I_M. The I_M values were around zero during all the years of study period in June and July months countered by the low values of NDVI. There is no sea – saw relation found between I_M and NDVI over this region. The correlation in this case was also found to be very poor and insignificant.

3.3. Chamrajnagar (Semiarid)

From Table 2, it is noticed that Chamrajanagar shows the arid climate category in 15 years of the study period. The years such as 1993, 1997, 1998 and 1999 displayed subhumid climates. The climatic types of this region are the good representative of climatic features over the study

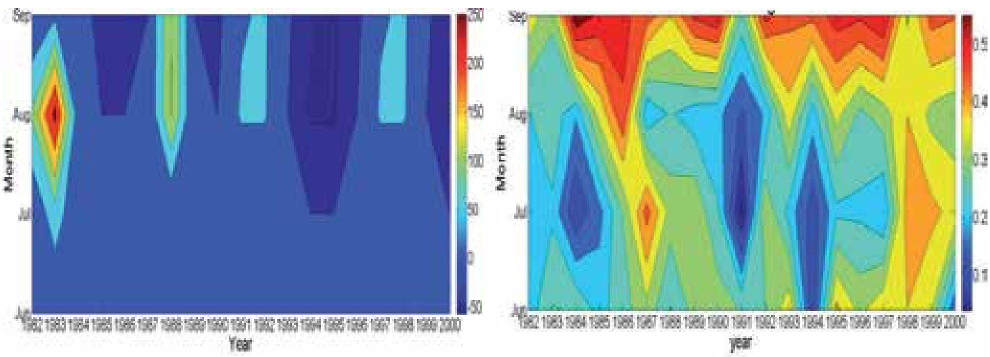

Figure 7. Variation of I_M and NDVI – Belgaum

period. In the case of semi arid region of Chamrajnagar, the variability of I_M and NDVI is better as compared with the humid and dry subhumid regions (Figure 8). The overall I_M is varied from -10% in the year 1984 to a maximum of 44% during the year 1998 for the south west monsoon season. Accordingly NDVI, also varied from 0.26 to a high value of 0.42 in the year 1996. The values of NDVI are less in this region than previously mentioned areas but the trends of I_M are NDVI were positive with slopes of 0.824 and 0.002 for I_M and NDVI respectively along with the standard deviations of 11.5 and 0.05. The correlation of these two data sets is 0.42 at 0.05 level of significance which infers the good agreement of I_M and NDVI. From this analysis, it can be noticed that the deficiency of moisture which is represented by I_M in this study was well reflected by low NDVI values and adequate moisture conditions are supported by the moderate vegetation conditions.

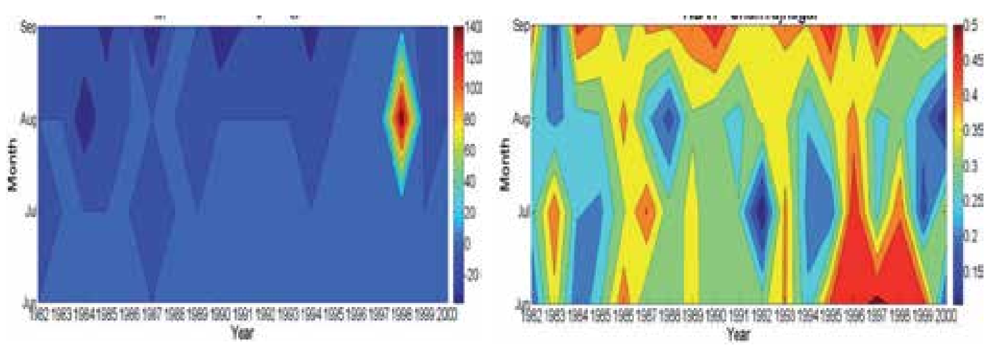

Figure 8. Variation of I_M and NDVI – Chamrajanagar

3.4. Gulbarga (Arid)

All the years of study period are dominated by the arid category for this region. The comparison of I_M and NDVI yielded good results in the arid region of selected test sites (Figure 9). The interannual variability was found to be very high both in I_M and NDVI where as I_M varied from -77% during August of 1982 to zero value during September month in the years 1983 and 1992 with the corresponding NDVI values of 0.055 and 0.127 respectively. The time series plot for I_M and NDVI for the total south west monsoon season display the one to one linear agreement where the trends of both were highly increasing than other test regions (Figure 8). The slopes of the trends were 1.68 and 0.007 respectively. The standard deviations of 14 and 0.05 infer that the interannual variability of I_M is more than NDVI from which it can be noticed that the vegetation over a region may not respond immediately to the rainfall/available moisture despite there is a dependence of vegetation on rainfall/available moisture. The time series plot of I_M and NDVI (Figure 10) shows that the maximum of amount of moisture of-12% have seen in the year of 1998 with the NDVI value of maximum NDVI of 0.269 that is recorded during the entire study period. The correlation in this case is +0.64 which is at 0.01 level of significance which shows the strong agreement between I_M and NDVI.

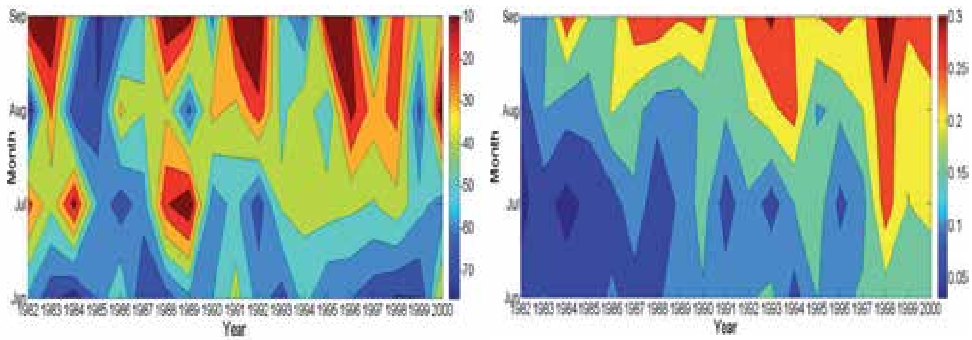

Figure 9. Variation of I_M and NDVI – Gulbarga

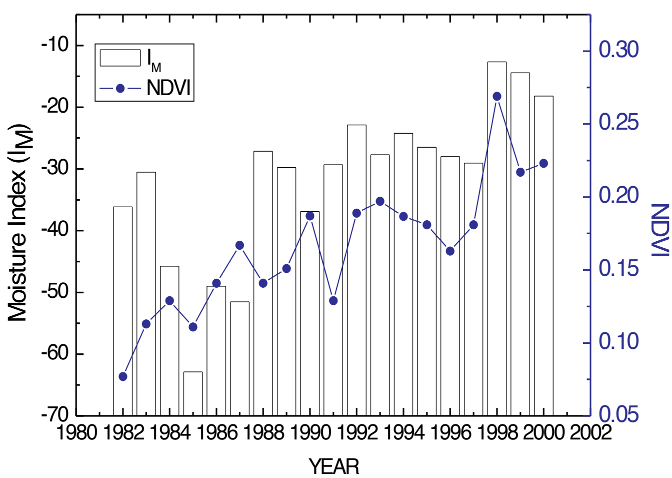

Figure 10. Time series of I_M and NDVI for southwest monsoon

The study commenced with the retrieval of I_M values from the water balance model on monthly basis over different selected test regions those represent the various climatic types such as humid, dry sub humid, semi arid and arid. The knowledge of different climatic types enables us to understand the climatology of the test regions during the study period. Since these climates were derived from the I_M values, they replicate the status of the moisture content available which is very essential input to decide the crops fate. The comparison study of I_M with the satellite derived NDVI shown very interesting features of sensitivity of NDVI with I_M over different climatic types. The study inferred the poor correlation such that no linear and significant relation of I_M with NDVI over humid and dry subhumid regions. The reason for this could be the plenty of available moisture over these regions and even temporary perturbations of land surface conditions may not affect the crops/agriculture. The relation grown up to strong when the comparison closes from semi arid to arid regions. Especially, Gulbarga, arid region displayed very strong relation of I_M with NDVI which unraveled the poor/good vegetative conditions associated with low/high values of I_M. The correlation of +0.65 is a good supporting factor to say that the relation is substantial. The overall analysis of the present study suggested that the relation of I_M with NDVI is very strong and it is of immense use for the studies of drought monitoring in the arid areas as compared with the other climatic types.

4. Quantification of sugarcane crop productivity: A study case in Southeastern Brazil

Agriculture represents an important segment of the economy of Brazil. Over the past 30 years, Brazilian agricultural growth and development has been guided by policies and technologies based on research for development. Remote sensed imagery plays an important role in agricultural crop production over large area, quantitatively and non-destructively, because agricultural crops are often difficult to access, and the cost of ground estimating productivity can be high. The recent development of GEONETCast–EUMETCast data has allowed us to obtain frequent and accurate measurements of a number of basic agrometeorological parameters (e.g. evapotranspiration, surface albedo, surface temperature, solar radiation, rainfall etc.). The GEONETCast–EUMETCast real-time and on-line data dissemination systems represent global network of satellite-based data dissemination systems designed to distribute space-based, air-borne and in situ data, metadata and products to diverse communities.

To determine agriculture productivity, this case study aimed to develop a GEONETCast-EUMETCast product-based method of estimating the productivity of sugarcane using an agrometeorological spectral model. The study was carried out in the Municipalities of Barretos and Morro Agudo, located in the state of São Paulo, Southeastern Brazil (Figure 11). The analysis was performed for 2009/2010 and 2010/2011 year's crop.

The values of sugarcane parameters used such as Respiration Factor (RF) (0.5 for temp. ≥ 20°C and 0.6 for temp <20°C); Agricultural Productivity Factor (APF) (2.9), Yield Response Factor (Ky) and Crop Co-efficient (Kc) were taken from [44-46]. The EUMETCast service is installed at Laboratory of Analysis and Processing of Satellite Images (LAPIS) at Federal University of

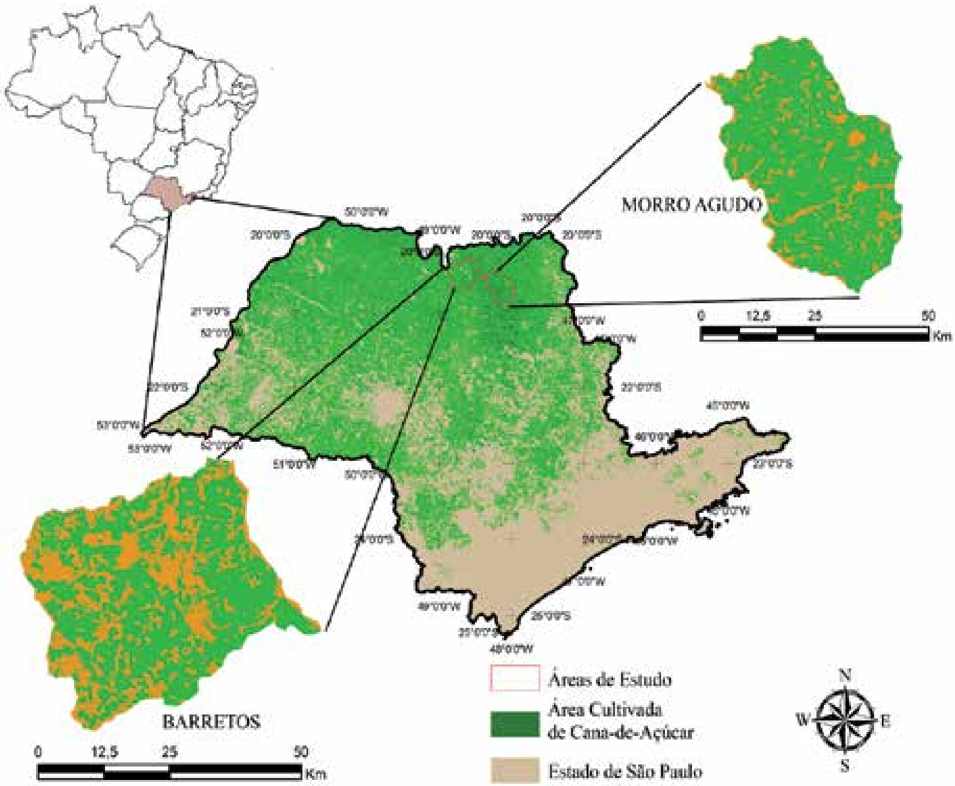

Figure 11. Spatial variability of crop yields (2010/2011) of Barretos and Morro Agudo in Sao Paulo, Brazil.

Alagoas (UFAL). The remote sensing data of NDVI S10, Production of Dry Matter (DMP) are available at the website http://www.lapismet.com and SPOT Vegetation indices of VITO were collected form http://free.vgt.vito.be/.

This application proposes to test a remote sensing approach to quantify estimates of sugarcane productivity over the Coruripe municipality with the Integrated Land and Water Information System, (ILWIS, 3.7.1) GIS software. ILWIS was used to compute sugarcane crop estimates for each pixel in NDVI DMP and ETp images by applying radiative, aerodynamic and energy balance physics in 7 computational steps. These images are currently provided over both daily and 10 day composites at about a 3km and 1km spatial resolution, by EUMETSAT and VITO respectively.

Step 1: Input NDVI and DMP databases using algorithm adapted from GEONETCast Toolbox

To implement a methodology for the ingestion of both the NDVI and DMP databases (raster) into ILWIS, specific routines of GEONETCast–toobox are adapted to import the datsets. For the ingestion procedure, based on a GIS approach using open source components, it requires additional work on corrections using overlays (Status map and LOG–file) to mask all appropriate areas of sugarcane crops over the Coruripe municipality.

Step 2: Computation of Fractional Vegetation Cover (FVC) from NDVI

For each pixel, the NDVI is converted to Fractional Vegetation Cover (FVC) by means of the the formula of [47]. The FVC is the one biophysical parameter that determines the contribution partitioning between bare soil and vegetation for surface evapotranspiration, photosynthesis, albedo, and other fluxes crucial to land–atmosphere interactions.

FVC= 1.1101*NDVI – 0.0857.

Step 3: Computation of Leaf Area Index (LAI) from FVC

For each pixel, the FVC is converted to Leaf Area Index (LAI) by means of the formula of [48]. The LAI, defined, as the total one-sided leaf area per unit ground area, is one of the most important parameters characterizing a canopy. Because LAI most directly quantifies the plant canopy structure, it is highly related to a variety of canopy processes, such as evapotranspiration, interception, photosynthesis and respiration.

LAI= –2Ln (1 – FVC).

Step 4: Computation of growth factor from LAI

[49] developed a simple approach for deriving growth rate equation from LAI. Experimental evidence indicated that the growth rate of several agricultural crop species increases linearly with increasing amounts of LAI, when soil water nutrients are not limiting [46]. The following equation is used:

$CGF = 0.515 - e^{[-0.667 - (0.515*LAI)]}$

where *CGF* = Corrected Growth Factor. Experimental evidence indicated that the growth rate of several agricultural crop species increases linearly with increasing amounts of LAI, when soil water nutrients are not limiting.

Step 5: Computation of maximum yield potential (Yp)

The final equation that was used to derive maximum yield potential (Yp) includes evaporative fraction corrected growth factor (CGF), respiration factor (BF), agricultural productivity factor (APF) and production of dry matter (DMP) product.

Y_p=CGF*BF*APF*DMP

where Yp is the maximum yield potential (kg ha^{-1}).

Step 6: Retrieval of evapotranspiration (ET_p) via Land Surface Analysis –Satellite Application Facility (LSA SAF) ET_p product

The crop coefficient is defined as the ratio of crop evapotranspiration, ET_r, to reference evapotranspiration, ET_p. K_c is crop specific and ranges from zero to over unity, depending on the crop growth stage. Crop evapotranspiration at any time during the growing season is the product of reference evapotranspiration and the crop coefficient.

$ET_r = ET_p * K_c$

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Crop coefficients was developed for nearly all crops by measuring crop water use with lysimeters and dividing the crop water use by reference evapotranspiration for each day during the growing season of 2009/2010 [50].

The recent development of LSA–SAF products has allowed us to obtain frequent and accurate measurements of a number of basic agrometeorological parameters (e.g. surface albedo, surface temperature, evapotranspiration). The satellite estimated agrometeorological parameters have several advantages compared to conventional measurements of agrometeorological data in ground meteorological network.

Step 7: Estimation of sugarcane productivity

The sugarcane yield estimation model over the growing season, on a biweekly basis, is accomplished by using an agrometeorological model integrated to ILWIS according to [46]:

$$Y_e = Y_p[1 - ky(1 - ET_r/ET_p)]$$

where Y_e is the estimated yield (kg ha^{-1}), Y_p the maximum yield (kg ha^{-1}), k_y the yield response factor; ET_r the actual evapotranspiration (mm) and ET_p the maximum evapotranspiration (mm). Maximum yield (Y_p) is established by the genetic characteristics of the crop and by the degree of crop adaptation to the environment.

The resulting map of the estimated yield (Y_e) is clipped to mask the Coruripe municipality boundaries in the State of Alagoas, Brazil. To establish correct coordinates, Map calculation within the ILWIS is used to implement this procedure. Flow diagram of methodology of quantifying sugarcane productivity via satellite products is shown in Figure 12.

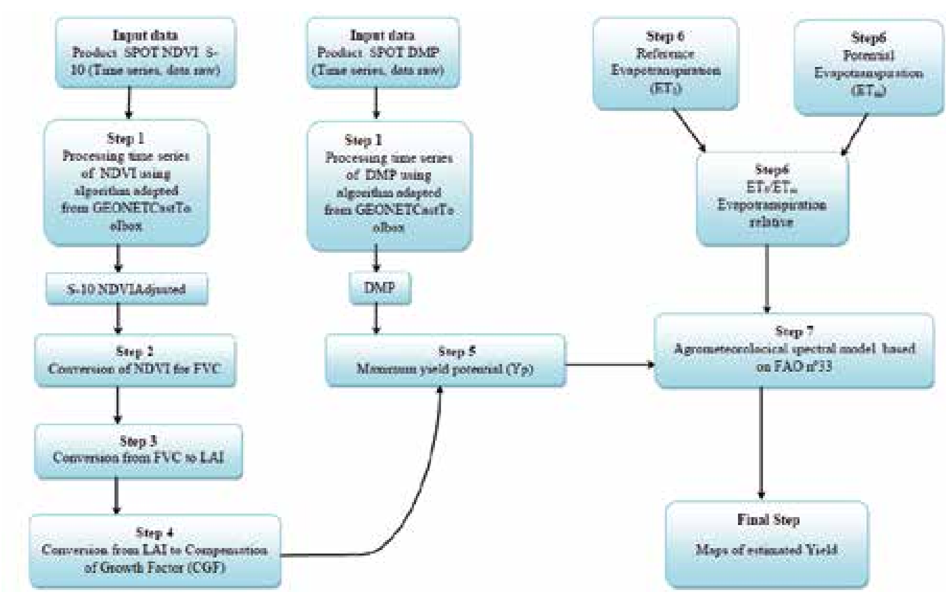


Figure 12. Flow diagram of methodology of quantifying sugarcane productivity via satellite products.

Figure 12 shows the spatial variations in sugarcane production over the Barretos and Morro Agudo municipalities for 2009/2010 and 2010/2011. The figure clearly indicates high spatial patterns in yield variability. This could be due to the mixing of significant fraction of observed pixels for the “arable pixel” and “non-arable pixel” within the municipalities. The quantified results give sugarcane yield mean range of 50 to 135 Ton ha^{-1}.The results obtained here represents a first step towards an operational use of ILWIS tools in Brazil using NDVI S-10, DMP SPOT and ETo for operational estimating of sugarcane productivity. Overall, the model was able to identify (Figure 12) and quantify (Table 3) the spatial variability of agricultural production over the municipalities analysed. Therefore, the methodology is useful for developing estimates of operational support for the sugarcane productivity [51].

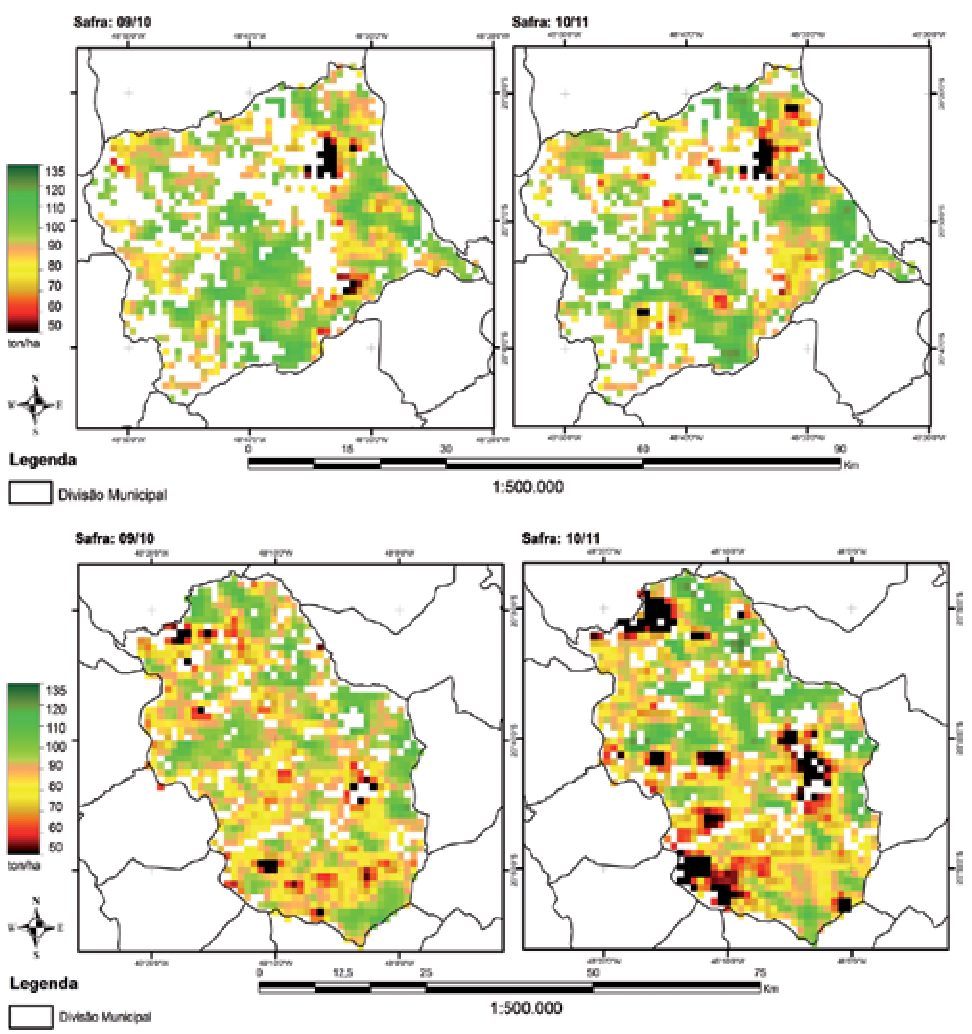


Figure 13. Spatial variability of crop yields over the Barretos and Morro Agudo municipalities for 2009/2010 and 2010/2011.

Mean Productivity (t/ha)		
Barretos	**Crop**	
	2009/2010	**2010/2011**
Agrometeorological model	93,15	93,31
CONAB	96,21	93,29
Mean Productivity (t/ha)		
Morro Agudo	**Crop**	
	2009/2010	**2010/2011**
Agrometeorological model	87,96	84,10
CONAB	93,60	87,25

Table 3. Comparison between the productivity of sugarcane using an agrometeorological spectral model and harvested crop yield from National Food Supply Company (CONAB).

5. Time series analysis for agriculture monitoring: Uganda

The economy of Uganda and its development goals are heavily premised on agriculture. Over 79% of the households are engaged in agriculture while 73% are directly or indirectly employed in the agricultural sector. Uganda's agriculture is however almost entirely rain-fed and very susceptible to climate risks. Studies indicate that Uganda's agricultural sector will be adversely affected by climate variability and projected climatic changes making real time monitoring of crop growth and crop productivity very important for better adaptation to climate variability and climate change. Quantitative analyzes reveal that the agricultural sector in Uganda needs to grow at an annual rate of 7% to effectively contribute to national development. Currently, the rate of agricultural growth in Uganda is below the population growth. With the threats of climate change and variability, Uganda needs to among other things harness geo-information technologies (remote sensing and geographical information systems) to improve agricultural productivity.

Remotely sensed images are powerful tools in monitoring crop productivity and yields. In most developed countries and emerging developing countries like Brazil and India, remote sensing has been greatly harnessed to plan for agriculture production, monitor crop growth and estimate yields. This is paramount in the sense that timely interventions can be taken and obviates possibilities of famine and food insecurity. Although there have been strides taken to improve the utility of remote sensing in the agriculture some developing countries, a lot remains to be done to make it more efficient, relevant and more productive. An investigation of the causative factors of the low utility and uptake of remote sensing in the agricultural sector in Uganda implicates a number of factors ranging from low capacities to expensive images. Recent developments have however extended numerous opportunities in utilizing remote sensing in the agricultural sector.

The onset of utilization of remotely sensed techniques in Uganda was in the early 1990s spearheaded by the National Biomass Project and focused largely on land use and land cover mapping. The activities of the National Biomass Project were later taken on by the National Forestry Authority (NFA) but the domains and scope remained largely the same with more focus on land use, land cover and related aspects being given priority. Apart from the NFA, academic institutions of higher learning and to some extent some research institutions like the National Agriculture Research Laboratory Kawanda (NARL) and the National Environment Management Authority (NEMA) have some remote sensing application either for teaching or research. In general, the remote sensing applications in Uganda in the agricultural field are scattered and more project based. This is partly due to the fact that there is lack of a government agency with a clear mandate to spearhead and propel the utility of remote sensing application in the country. Nevertheless, some efforts through the government cooperation with UN agencies such as the FAO regularly provide some information analyzed at the regional level for early warning in the agricultural sector. Some of the historical constraints to efficiently harnessing remote sensing in natural resource management in Uganda are generally those also experienced in other developing countries in Africa including the high costs of imagery data, processing software, coarse resolution of images, inadequate physical and human capacities and weak institutions. To-date, most of the issues to do with data costs and software have been significantly resolved with many freely available images, open source versatile software or special low for developing countries on commercial software. The contemporary challenge now is more of institutional/agency capacities, human capacities and policy environment for enhancing the utilization of remote sensing in the country.

A range of great opportunities, hitherto unavailable exist now for effectively using remote sensing in agriculture and natural resource management, notably through; (a) datasets disseminated through the Geonetcast Platform (b) freely available and downloadable datasets (c) open source softwares and low cost commercial softwares. Details of the Geonetcast is fully described in various sources (e.g. [48-50]). In brief, its a low cost facility which enables dissemination of near real time satellite imagery data. It is part of the emerging Global Earth Observation system of Systems (GEOSS), led by the Group on Earth Observation (GEO), for environmental analysis [54]. The Geonetcast does not require internet connectivity which is always a major constrain in developing countries and the data is disseminated at a very high temporal resolution through a ground recieving station, making monitoring easy. The facility streams diverse datasets which can broadly be used in environmental monitoring covering agriculture, water, soils, fire forestry etc. The data can be processed using the ILWIS software, where a specific toolbox has been developed.

In this case study, we demonstrate the utility of relatively low spatial but high temporal resolution satellite images from earth observation systems in monitoring and assessment of agricultural productivity in Uganda. There are two main inputs i.e. production data and remotely sensed data. Production data was obtained online from the FAOSTAT [55]. We extracted the annual yield, production and harvested area of the top five crops produced in Uganda according to FAOSTAT; (1) plantain/banana (2) cassava (3) sweet potatoes (4) sugarcane and (5) maize for 10 years spanning from 2001 to 2010. Bananas/plantain (*Musa spp*) are largely grown in central, western and eastern (highland areas) parts of Uganda. As perennial crops, banana are year round crops. Cassava (*Manihot esculenta*) is an important food security crop in Uganda with the largest production coming from eastern and northern Uganda. Cassava accounts for approximately 13% of the daily caloric intake in Uganda. Cassava is commonly planted in the first season which is around February-march in most parts of the country and its also a perennial crop. Sweet potatoes (*Ipomoea batatas*) are also a food security crop in Uganda grown largely in the mid to high altitude regions of the country

(1000-3000 meters above sea level). They are annual crops grown twice a year with the first season between February and June, while the second season stretches from September to November. They thrive well in the deep volcanic soils of Southwesten Uganda and Eastern Uganda. Sugarcane (*Saccharum officinarum*) in Uganda is largely grown on large plantations mainly in the near east and western Uganda. There are also a couple of out growers who are supported by sugar companies. It is mainly an income generating perennial crop. Maize (*Zea mays L.*) is grown in almost every part of the country and is a major staple food crop. It is an annual crop grown twice a year (March to June and September to November) in areas of the country where biophysical conditions are supportive. To ease the analysis, the production and yields for the five crops were compounded into one annual value.

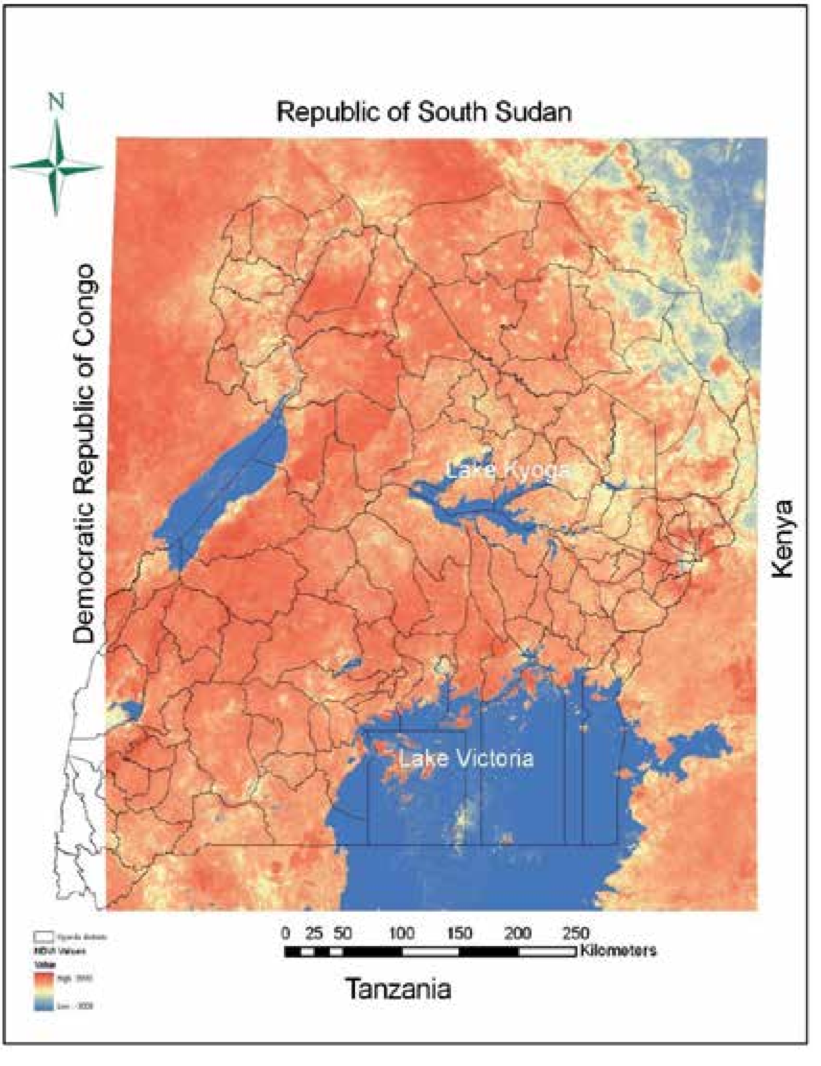
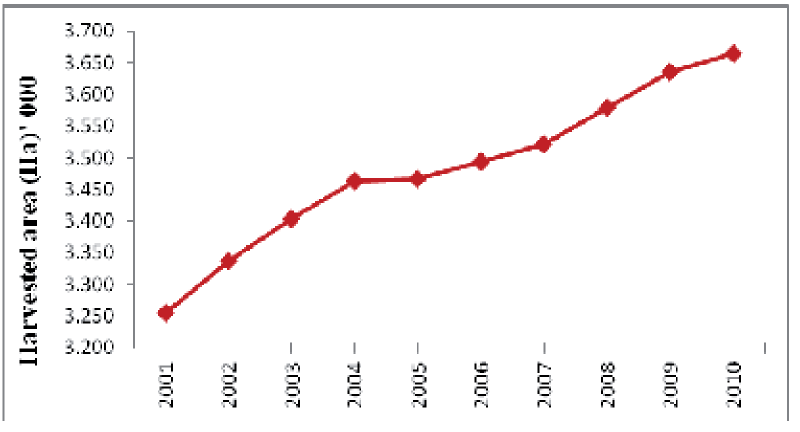


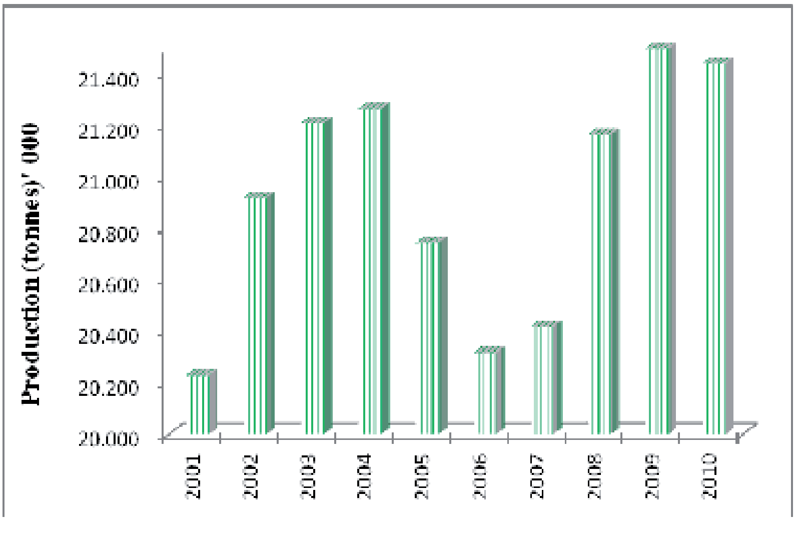
Figure 14. Scope of study

The results on harvested area, production and yields are shown in Figures 15, 16 and 17 respectively.



Data obtained from FAOSTAT

Figure 15. Harvested area of five crops between 2001 and 2010.



Data obtained from FAOSTAT

Figure 16. Production (compunded) trends of five selected crops between 2001 and 2010 compounded

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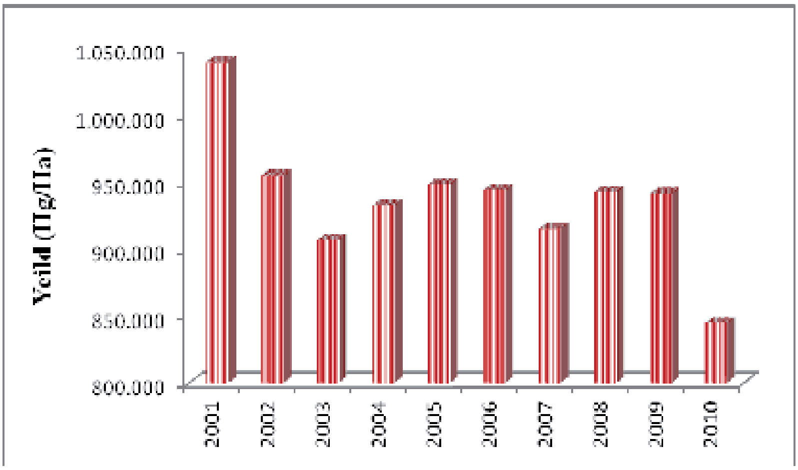

Data obtained from FAOSTAT

Figure 17. Yields (compounded) of five major crops between 2001 and 2010

The results based on the three factors i.e. area harvested, production and yields do not depict a definitive trend. In terms of harvested area, there is an increasing trend, implying that more areas are being converted for cultivation of the specified crops (Figure 15). Production between 2001 and 2010 has modestly increased. Yields per hectare are however more variable and actually show and generally declining trend. Bearing in mind that production is increasing, it becomes explicit that the increments in production are related to extensification rather than intensification. In most cases, extensification entails conversion of ecologically sensitive and fragile areas such as wetlands or reclamation of forest area which has its environmental implications. Subjected to a statistical analysis, the results revealed a strong and positive correlation between the yields and production area (r^2=0.52, $p<0.05$).

Remote sensing analysis was on the MODIS NDVI data, which has a spatial and temporal resolution of 250 m and 16 days respectively. For each year 23 images are available in a decal arrangement. For the 10 year period, we downloaded a total of 230 images in HDI format and processed them in ERDAS Imagine where file format conversions were undertaken and later ILWIS for arithmetic analysis. Individual images (23 decades) for each year were stacked to generate a single profile for each year. Relevant statistics such as the mean, standard deviation, coefficient of variation were late extracted. The spatial distributions of average NDVI for selected years are shown in Figure 18, while Figure 19 gives the temporal average NDVI dynamics for the 10 years. Mean average NDVI value is 0.56. In spatial terms, the southern part of the country registers higher NDVI values than the northern part. This is not surprising in light of the coverage in terms of natural cover and the crops grown which significantly entail banana and a range of annual crops grown in two seasons. The North Eastern part is particularly poorest in terms of annual average NDVI values. Understandably it is a semi arid region and generally more tailored to livestock enterprises than cropping enterprises. Annual NDVI values for the whole country were subjected to a correlation analysis with production and yield data, resulting into poor and insignificant correlations (r^2=0.19 to 0.2.1). The low coefficient are partly explained by the fact that some crops like sugarcane are eother irrigated or are grown in areas almost permanently under water (wetlands). However when the data was collapsed into the growing seasons and the water bodies excluded from the analysis, better and significant correlations were obtained (r^2 0.46 to 0.61, $P<0.05$) demonstrating the efficacy of using NDVI for crop monitoring and yield prediction. In light of the expected variability and changes in climate, coupled with the availability of data in real time, the NDVI analysis represents a great potential in sustainable adaptation where from both a policy perspective and direct intervention. This has positive implications in timely provisioning of information to farmers, adaptation to climate change and variability as well as enabling science based policy options for appropriate interventions. Specific prediction coefficients for different crops and regionalized to the climatic conditions can be helpful to local governments where timely interventions can obviate social instability related to crop failures. On the other hand, predictions of higher yields can also enable relevant agencies to solicit for markets for the produce, improving the welfare and livelihood of the farmers, who in the context of Uganda are largely small holder farmers. All these can only be realized if there is a good policy framework that ties all the relevant pieces in the chain i.e. science, production, markets and institutions.

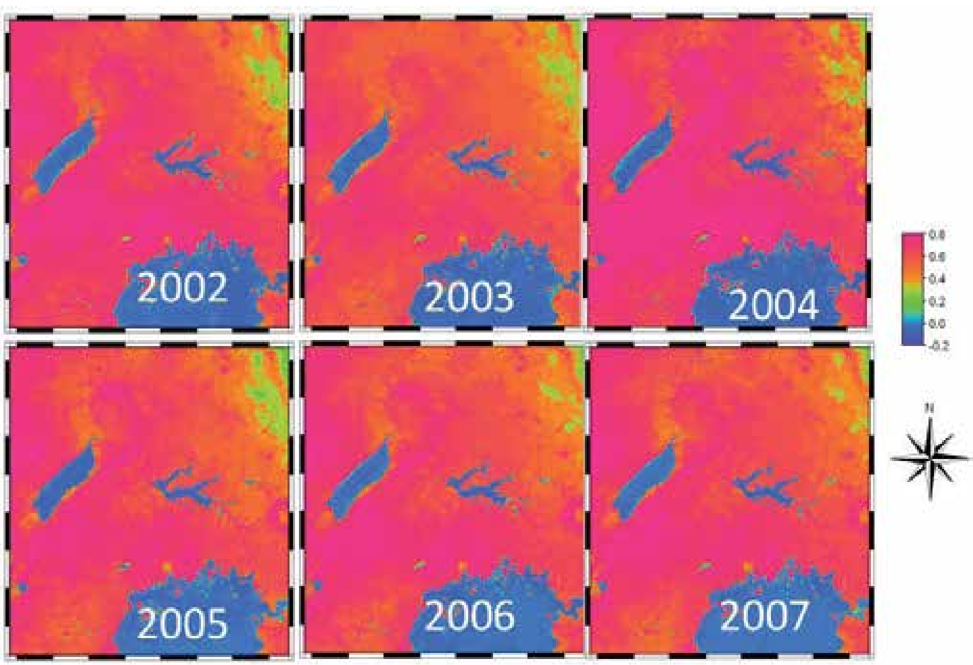

Figure 18. Average annual NDVI for selected years

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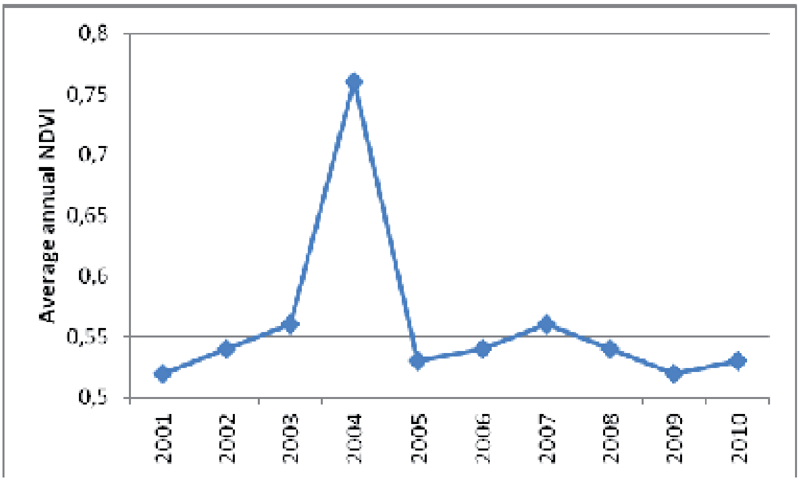

Figure 19. Variation of annual NDVI values between 2001 and 2010

6. Outlook and conclusions

We have provided four multi-disciplinary case studies on the power of using remote sensing technologies, and more specifically time series analysis of low resolution satellite derived indicators, for monitoring and analysing land cover changes, desertification, drought and agricultural activities on different spatio-temporal scales. Generating this information at finer temporal resolutions is crucial for reducing risks to disaster, preparedness and formulation of strategies for better adaptation to climate change particularly the increasing dramatic hydro-meteorological events in developing and emerging countries.

This chapter provides a variety of methodologies of processing chains over satellite data, allowing the monitoring of areas subject to or in risk of desertification and land degradation processes. This chapter provides new insights related on the use of remote sensing data for climate (change) impact monitoring, which will contribute to the advance of warning systems and adaptation measures in developing and emerging countries. The focus of future activities should however focus on institutional support and capacity building for impact assessments for Africa, South America and India. The importance of training and joint cooperation with local providers and users cannot be overestimated.

One of the most robust, multi-purpose and yet simple remote sensing index is the NDVI. NDVI imagery data is widely available for immediate use at almost no cost. This has been given emphasis in this chapter through demonstration of its utility in various environmental and production domains. The section 2 of the chapter mainly emphasizes the relation between trends of vegetation greenness and rainfall over a long term period, taking into account the time lag between rainfall and vegetation response. As a result, areas of greening or degradation can be identified, and the process can be linked or not to changes in precipitation.

The section 3 of the chapter tells the mode of relation between NDVI and moisture index over different climatic regions. The relation was found to be poor over humid and dry subhumid regions where as it is improving in semi arid and arid regions. The relation of above cannot be taken as granted in the humid regions though it is implicitly understood that NDVI maintains positive relation with IM. The study infers that the NDVI and IM relations cannot be used to characterize the drought over humid regions but can be taken as an indicator in arid and semi arid regions. This is particularly relevant for adaptation purposes in semi arid regions which cover big chunks in Africa, India and some parts of Southern America.

Section 4 of the chapter mainly focuses on the estimation of sugar cane yields in Southeastern Brazil by using spatial tools which have been integrated in ILWIS 3.7.1, open source software. This study underpins that the NDVI data along with the other meteorological data is of immense use for the estimation of crop yields. This gives a business orientation on the utility of spatial tools, but also has a livelihood implication where small scale farmers or out growers are involved in sugarcane production. Interestingly, sugarcane is a major crop in all the case study countries in this chapter.

The last section of the chapter also gives more emphasis on yield estimates of five major crops in Uganda. The results of the study showed that the production between 2001 and 2010 has modestly increased with the variability in yields. Also, this analysis showed that the extensification of crops is dominated by intensification and it is implied that the increments in production are related to extensification.

In a nutshell, the chapter demonstrates how remotely sensed data available in the public domain freely or at very low cost can be harnessed to address critical challenges in developing countries pertaining to environment, agricultural productivity, drought, desertification and ultimately climate change adaptation. The chapter shows that relating the satellite derived vegetation indices with existing models and parameters can be useful proxies to understand the various phenomena of the crops. However, despite the availability of the technology, full benefits from available remotely sensed imagery resources for developing countries can only be realized when enabling policies are formulated and implemented and concerted capacity development is undertaken to establish a critical human resource base. This will enable the policy makers to go for the risk managing practices such as agricultural crop reinsurance schemes, drought defining criteria etc.

In light of the resource constraints in developing countries, cooperation and collaboration is important to develop a nucleus of future demand and contributing to new scientific insights related to projected changes in drought drawing information from satellite data, which will contribute to the improvement of warning systems and adaptation measures in developing and emerging countries.

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Section 2

Management, Policy and Concepts

The Way We Think Shapes Our Future: On the Importance of Fruitful Concepts, Well-Founded Attitudes, and Powerful Rhetoric

Sigmund Hågvar

Additional information is available at the end of the chapter

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1. Introduction

”Business as usual” will not lead us into a sustainable future. Therefore, we need visions about alternative routes to follow. We have to think along new lines, both collectively and personally, in order to make other choices and to reconsider what is really important. Such alternative, sustainable thinking is already underway, and when we analyse it, we discover that a gradual creation of new concepts is important. New concepts open new perspectives and allow for fruitful discussions. However, new concepts have to be precise enough. Twenty-five years ago, the concept of “sustainable development” achieved global consensus [1], and initiated waves of new thinking. As we shall see, there was also a great need to discuss the concept itself, and to refine purpose and aims through a number of sub-concepts. This process is still going on. For instance, it is not yet clear what should be meant by “green economy”. In the following, we shall also illustrate how conceptual progress in certain academic disciplines has fuelled our thinking about environmental questions.

A significant element in sustainable thinking is our personal attitudes. Good concepts help us in the process of developing well-founded attitudes. We shall consider the development of attitudes as a process of systematic thinking. Our perseverance in environmental work depends highly on the quality and strength of personal attitudes.

Given a good conceptual framework and well-founded attitudes, we should probably be well armed to fight for a sustainable future? In addition, rhetoric, or the way you communicate, should not be underestimated. We are reminded by the famous Roman speaker Cicero (106-43 BC), that the way you present and formulate your message is crucial; also in environmental questions, rhetoric matters. In fact, concepts and rhetoric are not always clearly separated. The formulation “Think globally and act locally” is both good rhetoric and contains a conceptual core about how we all can participate to solve common challenges. In a separate section, examples of well-formulated statements from various authors will be cited.

After having illustrated the importance of concepts, attitudes and rhetoric in order to shape environmental action, the problem of mental barriers will be discussed. We have all an ability to suppress, or deny, environmental threats. This psychological mechanism supports “business as usual”. The book “Collapse – how societies choose to fail or succeed” warns us about this psychological trap [2].

An important product of sustainable thinking should be to create hope. Concepts, attitudes and rhetoric are helpful not only to describe problems, but also to show possibilities. This will be discussed in a final section.

2. Material and methods

Except for Introduction, Discussion and Conclusions, this is a review paper based on relevant scientific literature, as well as a number of books and articles which illustrate the debate about sustainability. The review part has been structured into four topics:

Development of concepts. Here, the gradual refinement of the sustainability concept has been summarized. Since its “foggy” presentation in 1987 [1], the concept has been vividly discussed, and a number of new concepts have evolved in order to analyse and implement it. We shall also study the rise of applied ecological thinking, how global warming has triggered new concepts, and the difficulty of expressing the value of nature as a source of life quality.

Development of attitudes. While concepts can be adopted, attitudes have to be personally developed. The process of developing attitudes is exemplified.

Rhetoric matters. Here, selected citations are presented to illustrate the power of language.

Our ability to deny or suppress environmental threats. This is a summing up from Jared Diamond’s book “Collapse – How societies choose to fail or succeed” [2].

In the Discussion, we are reminded that concepts, attitudes and rhetoric must have the necessary quality. In debates, we must be ready to argue against misuse of concepts, unsustainable attitudes, “greenwashing” of unsustainable activity, and a “counter-rhetoric” which defends “business as usual”.

3. Development of concepts

A new step in science is often tied to the development of a new concept. A good example is Darwin’s “natural selection” from 1859 [3]. This concept soon became basic for our way of thinking within biology and opened doors for progress in a number of biological disciplines.

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In 1973, the evolutionary biologist Theodosius Dobzhansky formulated the famous statement that "Nothing in biology makes sense except in the light of evolution" [4]. The term "evolution" is a term which today we accept as a given. Within the discipline of ecology, the great progress during the last hundred years has been fuelled by a continuous development of new concepts. In order to study, understand, and discuss how processes in nature are working and connected, concepts like food chains, food webs, trophic levels and energy budgets are basic. The 1965 version of Odum's classic textbook "Fundamentals of Ecology" [5] was structured upon a systematic presentation of such concepts. At that time, also terms like succession, niche, mutualism, commensalism, and others were in use. Later, ecological insight has grown strongly due to a number of other fruitful concepts like island biogeography, socio-biology, conservation biology, metapopulations, key species, cascade effects and many others. A university exam in ecology today could well be to define a number of central ecological concepts.

This example illustrates how fruitful the evolution of concepts is, and our dependence on them. But it also illustrates that a lack of concepts limits our insight, and also our ability to talk about a topic. Today's environmental change cries for insight, discussions and action – collective action. The following presentation will illustrate how a gradual development of new concepts has been fruitful within sustainable thinking, but also that a further conceptual development is necessary.

3.1. Sustainable development: A concept that triggered a breed of new concepts

3.1.1. Global concensus about a foggy concept

In 1987, the Brundtland Commission's report *Our Common Future* [1] presented the concept of "sustainable development". It was defined as a development that "meets the needs of the present without compromising the ability of future generations to meet their own needs". However, this well-meant concept rapidly turned out to be problematic [6-9].

Firstly, the commission had argued for strong and continuous economic growth in order to reach sustainable aims, and even today, many politicians talk about "sustainable growth". However, economic growth was soon identified as a major cause behind environmental problems. Consequently, some observers called sustainable development an *oxymoron*: fundamentally contradictory and irreconcilable. Secondly, the term is so "creatively ambiguous" that anyone can redefine and reapply the term to fit their purposes and proceed with business as usual. For instance, companies with an environmentally harmful activity could make small, cosmetic adjustments and then characterize themselves as "green" or "environmentally friendly". Such "greenwashing" of environmentally destructive activities became a problem. Clearly, the well-meant concept needed to be problematized: What should be sustained, what are the ultimate aims in a sustainable community, and which conflicts have to be solved – for instance between economic activity and other aims?

After eight years of debate, a clarification of terms was given [6]. A kind of concensus had been reached that we should distinguish between three parallel, but interconnected, aims of sustainability: Environmental, economic, and social sustainability. In addition, within each of these concepts, there was a need for subconcepts [6], as explained below.

3.1.2. Environmental sustainability

The basic aim of environmental sustainability is to maintain healthy, productive, and species rich ecosystems. Such “supporting ecosystems” deliver “environmental services”. They have a certain tolerance to disturbance, and a certain “carrying capacity” regarding production of goods as wildlife, fish, various forest products, clean water, fertile soil, etc. Healthy ecosystems also have a certain “assimilative capacity” for our pollution and wastes. Many prefer to use the concept of “natural capital” for nature’s ability to serve us, and this capital has to be maintained. Furthermore, the term “sources” is often used for raw materials extracted from nature, and “sink” for wastes. A “sustainable production” and a “sustainable consumption” implies to live within the limitations of the biophysical environment, while “overconsumption” gradually liquidates nature’s ability to deliver environmental services. Loss of nature also implies loss of other “services” like recreation, various cultural values, and nature as a source of fascinating science.

As long as nature was “in excess”, nature’s productivity and assimilative capacity was enormous compared to man’s needs and activities. Today, healthy ecosystems have become a scarce resource, like intact forests, species-rich coral reefs, productive oceans, clean rivers, or fertile soils. During the last sixty years, ecological thinking and ecological concepts have become a cornerstone in defining the limits – but also the options – for man in a sustainable future. The conceptual development within the rise of applied ecological thinking is presented in chapter 3.2.

3.1.3. Economic sustainability

Since economic development is one of the primary drivers behind environmental degradation, economic activity should be kept within strong limits. For instance, to eradicate one resource after the other (e.g. whales, tropical forest, oil wells and fish stocks) may be good economics in terms of income, but totally unsustainable. Environmental costs have to be included in economic activity. A “sustainable economy” can be regarded as a human economy subsystem which does not harm the ecosystems and their ecological services on which we depend. Economics has rarely been concerned with natural capital, because until recently, these resources had not been scarce. The new scarcity of natural capital arose because the *scale* of the human economic subsystem had grown large relative to its supporting ecosystem. The “scale criterion” would constrain the so-called “throughput growth” – the flow of material and energy (natural capital) from environmental sources to sinks (pollution and waste), via the human economic subsystem. However, due to our limited knowledge about nature’s resilience and the danger of irreversible damage to ecosystems and their services, economists need to use the precautionary principle routinely. Also in economics, ecological thinking and concepts have become relevant.

At the UN conference in Rio de Janeiro 2012 (Rio + 20), "green economy" was identified as a pivotal concept in order to create a sustainable development [10]. The intention was to define an economy which is positive for both environment, climate and poverty problems. However, economic growth is still a silent premise in the new "green economy". In Rio, both OECD, The World Bank, large companies and national leaders in several of the richest countries encouraged further economic growth. This request was discussed and criticized in a Norwegian newspaper article [11]. For instance, the authors argued that the northern "brown oil economy" has to be changed into a green direction, which implies reduced overconsumption and more focus on intellectual resources. Furthermore, many ecological services cannot – and should not – be capitalized, as the optional value of biodiversity, nature's production of clean water, air and soil, or the recreational value for man. The article also presented the concept of "brown-green new colonialism", which was exemplified by the oil-nation Norway which pays for forest protection and climate quotas in the south, rather than on a national level within Norway.

3.1.4. Social sustainability

This concept points to a peaceful and tolerant community kept together by cooperation, but also by laws and discipline. Also here, the concept of capital is used. "Human capital" is created by investment in education, health and nutrition of individuals. "Social capital" points to the importance of social stability, and "moral capital" indicates shared values and equal rights. All three types of capital are threatened by the underlying problem of unchecked population growth. There is much debate about how many people the globe can support, but too little about how far we are above a "population optimum". The Norwegian professor in social economy, Ragnar Frisch, who in 1969 received the Nobel price in economy, tried already in 1940 to define a "population optimum". He argued that because natural resources in each country are limited, there is an optimum population size which gives the best quality of life for people within a specific area of land [12]. The concept of population optimum deserves to be used in visions about a sustainable future.

3.1.5. Alternative thinking about sustainability

An alternative model for sustainable development within a "sustainable hierarchy" has been presented [8]. This focuses on unsustainable activities which should be avoided and lists the most serious problems at the bottom. Level 1 actions endanger the survival of humans, Level 2 actions significantly reduce health and life expectancy, and Level 3 actions may cause species extinctions or violate human rights. The fourth and last level contains actions that reduce quality of life or are inconsistent with other values, beliefs or aesthetic preferences. The authors argued that this level should not be considered to be within the sustainability concept, since these topics to a high degree depend on subjective criteria. As shown in chapter 3.4., this viewpoint is not shared by the present writer.

Twenty years after the Brundtland Commission, it was suggested to "reopen" the concept of sustainable development [9]. This paper relies heavily upon a science-based approach to sustainability known as "The Natural Step Framework" after the organisation promoting it.

They focus on the way we extract resources, use them and produce wastes, but also on other ways in which we destroy nature's carrying capacity. In a nutshell, nature should not be subject to systematically increasing…

1. concentrations of substances extracted from the Earth's crust.
2. concentrations of substances produced by society.
3. degradation by physical means, and..
4. people should not be subject to conditions that systematically undermine their capacity to meet their needs.

Regarding "economic ethics", the article stresses that "hidden costs of unsustainability" must be shown, and no economy should exceed nature's carrying capacity [9].

Another thorough review [7] was critical to economic growth and pointed out various misuses of the sustainability concept. Still, they saw a hope for a further "creative global dialogue". In fact, since sustainable development is an imprecise concept – but still with intuitive aims – it contains a "creative tension", and the debate is still active. Sustainable development can be viewed as a social movement: a group of people with a common ideology who try together to achieve certain general goals. The authors point, for instance, to the vision of "voluntary simplicity" and a need to define life quality by other criteria than by economy and consumption. Today, it has been a serious matter to explore various indexes of "well-being" or "level of happiness", see [13].

3.1.6. Perspective

We can conclude that during the twenty-five years since 1987, the vague vision of the Brundtland Commission has undergone a considerable conceptual refinement. Although we find different "schools" that vary in their way of thinking, they all strive to enlighten the way into a harmonious future. Ecosystem thinking has become a fruitful common approach, illustrating ecological services and nature's vulnerability to overconsumption. A further conceptual development will certainly occur, both in order to clarify ideals and principles, to describe conflicts, and to implement concensuses in law and in personal lifestyle.

There is a special need to clarify the conflict between environmental and economic sustainability. Even in 2012, world leaders include economic growth in the concept of "green economy". This concept is accepted and could be fruitful, but is unsustainable until it is defined as a sub-system which is in harmony with the biophysical limits of ecosystems. Also, what are the guidelines for an "economic ethic" that implies a moral aspect in addition to income? Economic thinkers have a challenging task, and interdisciplinary research is needed to describe a sustainable "green economy".

3.2. The rise of applied ecological thinking: From basic science to politics

This topic has already been mentioned when discussing environmental sustainability but here, the use of ecological thinking will be followed in a more chronological way.

3.2.1. The awakening 1960's

Until 1960, ecology was regarded as a narrow and rather anonymous science of little public interest. However, persons working with nature conservation became increasingly interested in ecology, which revealed insight in nature's structure and function. The first edition of Odum's textbook in ecology in 1959 [5] became an eye-opener for many persons and inspired "green" organisations. Here they found a scientific basis for discussing nature's vulnerability and the importance of taking care of nature's production and diversity.

A main focus in the 1960's environmental debate was the danger of pollution, which included the harmful concentration of agricultural pesticides in food chains. Rachel Carson's book "Silent Spring" in 1962 [14] created a global focus on these dangers. After a great rise in ecological awareness in Europe during the late 1960's, the Nordic Council of Ministers decided that 1970 should be the "European Year of Nature Conservation". The concept of "Natural heritage", which signalises both values and duties attached to nature, became established in several countries at that time. While the "Cultural heritage" focuses on historical documents which are made by people, the natural heritage points to "nature documents" as a part of a nation's identity.

3.2.2. Nature as an ideal — Early "ecopolitical" thinkers

Even though ecology as a science is purely descriptive and not normative, healthy ecosystems were gradually regarded as an ideal: Humankind has to cooperate with nature instead of conquering it. In 1971, two young Norwegian biologists published an article titled *Ecopolitics – the new dimension in nature conservation* [15]. Instead of a society based on continuous growth, they pointed to "a society in balance" as a political alternative. In the international arena, the American biologist Barry Commoner achieved much attention in the same year for his book *The Closing Circle* [16]. Here he presented his "four laws of ecology", as a basis for a new politics:

1. Everything is Connected to Everything Else. There is one ecosphere for all living organisms and what affects one, affects all.

2. Everything Must Go Somewhere. There is no "waste" in nature and there is no "away" to which things can be thrown.

3. Nature Knows Best. Humankind has fashioned technology to improve upon nature, but such change in a natural system is, says Commoner, "likely to be detrimental to that system."

4. There Is No Such Thing as a Free Lunch. Exploitation of nature will inevitably involve the conversion of resources from useful to useless forms.

3.2.3. A new discipline: Conservation biology

The practical application of ecological knowledge in nature conservation took a big step with the new discipline of "conservation biology". A textbook with this title from 1986 illustrates this well [17]. The aim of conservation biology is to find practical ways to preserve ecosystem functions, and to avoid extinction of species, based on scientific knowledge. Ecological concepts which describe nature's vulnerability were now used in an applied perspective. "Resilience" was used for the ability of ecosystems to withstand stress, or to retain stability after disturbance. Certain species which have a pivotal role in ecosystems because many other species depend on them, were "key species" or "drivers". An extensive discussion arose whether some species could be lost without harming the ecosystem because they were "ecologically redundant". Does it matter that humans drive certain species to extinction? Such questions also stimulated the pure science of ecology. Today we know that even "anonymous" species may have important functions, for instance in pollination, decomposition, or degradation of human wastes. Microscopic fungi cooperate with the roots of trees in a symbiosis called mycorrhiza, on which many tree species fully depend.

An important section within conservation biology is the vulnerability of small populations to become extinct. Concepts like "minimum viable population", "extinction risk" and "extinction vortex" appeared in combination with mathematical models. "Fragmented populations" are vulnerable, but less if the various fragments can exchange individuals, as in so-called "metapopulations". Also, there was a growing understanding that extinction may take time. An early sign of extinction may be that the distribution area of a given species is shrinking, and the populations are also often gradually fragmented and isolated. Species depending on old forest in Finland illustrate this process. The gradual loss of old forest in Finland has already led to extinction of more than 100 species. Furthermore, approximately one thousand other old-forest species are on their way to extinction if the loss of old forest proceeds. The pre-destinated extinction, which is not yet realized, is called "extinction debt" [18]. This is a powerful concept which can be easily comprehended by non-biologists like politicians.

The concept of "umbrella species" is also helpful in practical conservation work. Certain species need very large areas to survive. If we set aside sufficient areas to protect these, a number of other species will automatically be saved under their "umbrella". Examples are reindeer on the tundra, elephants on the plains, or large forest predators. In order to catch the interest of people or politicians for conservation measures, certain beautiful or spectacular species have been fronted. These are the "flagship species". Examples are the WWF symbol, the Giant Panda, the tiger, or paradise birds.

In close cooperation with conservation biology, also the discipline *restoration ecology* appeared in the 1980's. Since ecosystems are so often harmed by human activity, an important part of nature conservation work is to repair and restore damaged or destroyed ecosystems. This scientific study has its own journal "Restoration Ecology", and there is a "Society for Ecological Restoration". Within this discipline, there has been a special conceptual framework developed [19].

The fruitful cooperation between basic ecology, conservation biology and restoration ecology led to an improved understanding about nature's structure and function. Even "anonymous" species may have important functions, so we should be very careful to address a species as "ecologically redundant". The world needed a concept which covered the total variation in nature, and also an international agreement for preserving it. A breakthrough came with E. O. Wilson's book *Biodiversity* in 1988 [20]. Four years later, in 1992, the international *Convention*

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on Biological Diversity (often shortened to Convention on biodiversity) was signed by a large number of countries in Rio de Janeiro. The biodiversity concept rapidly swept around the globe. It covers not only the diversity of species, but also the genetic variation within species, as well as the diversity of habitats and landscape types. Between the lines in the convention, the inherent, or intrinsic, value of biodiversity is acknowledged: Conservation measures shall not depend on argumentation of applied value or possible redundancy. As a natural consequence, countries are currently producing updated "red lists" of threatened species as a focus for their efforts. Also "black lists" are produced, listing problematic, introduced species which are ecologically harmful and should be combatted. Sweden and Norway have each established a "Biodiversity Information Centre", often called "the species data bank", which produces updated information on the biodiversity status, including red and black species lists. Based on such knowledge, politicians can decide practical measures to preserve biodiversity, and also initiate research on lesser known groups of organisms.

Box
Edward Osborne Wilson: A concept producer.

E. O. Wilson, born in 1929, is a famous American biologist and author. His biological specialty is myrmecology, the study of ants, on which he is considered to be the world's leading authority. Through several cross-disciplinary books, he has opened doors to new scientific fields and new recognition. Some of his famous and fruitful concepts are listed below.

Concept	Explanation	Reference: Book
Sociobiology (1975)	The extension of population biology and evolutionary theory to social organization.	*Sociobiology: The New Synthesis* [21]
Biophilia (1984)	Man's unconscious interest and fascination for other life forms.	*Biophilia. The human bond with other species* [22]
Biodiversity (1988)	The diversity of nature types, species and genetic variation within species.	*Biodiversity* [20]
Eremozoikum (1994)	"The age of loneliness", when man has lost many of the surrounding species.	*The diversity of life* [23]

3.2.4. Ecological service: The new mantra

Early warnings about environmental challenges were typically pollution problems, because they were visible locally, for instance in the 1960's. The next decade focused as much on the limitation of resources like minerals, wood, oil, etc., often in combination with population growth. *The Limits of Growth* from 1972 [24] was a book about the computer modelling of unchecked economic and population growth with finite resource supplies. None of these topics have lost their importance. But today, we have also developed an ecosystem way of thinking, realising that nature is servicing us through a number of vital "ecological services". Species diversity represents a large potential for new ways of producing food, medicines or other products, and these options imply that species diversity represent a "gene bank". Healthy ecosystems perform several functions - or services - on which we depend. They enable pollination of agricultural crops, provide clean water, air and soil, allow for decomposition of our wastes and neutralize pollution. The concept of ecological service is to an increasing degree used in national and international fora to promote nature conservation, and to implement the Biodiversity Convention. In order to illustrate the more or less hidden values of ecosystem services, some have tried to transform them into their economical value, including the astronomical costs of manual pollination of agricultural crops, for example, see [25]. The term ecological service is strongly "anthropocentric", which means that we focus on humankind's egoistic interests: *What is in it for me?* A broader perspective is the "biocentric" view: Life in general is in focus, respecting the intrinsic value of all life forms. Wilson [22] used both perspectives, but waiting for the intrinsic value to be seriously respected, he strongly argued for the anthropocentric motivation in nature conservation. Here, we find many duty-based arguments versus future generations.

3.2.5. Ecology in our mind: Eco-concepts matter

The vision of an "eco-policy" in which the society is in harmony with nature, has led to several new eco-concepts. The prefix "eco-" is often used in the sustainability debate: eco-friendly products, eco-food, eco-tourism, eco-efficiency practices designed to reduce waste, energy consumption, and resource use, etc. Within eco-effectiveness, the concept "cradle-to-cradle" is creative. Earlier, "cradle-to-grave" was a paradigm illustrating the linear use of resources resulting in waste, while "cradle-to-cradle" regards waste as a resource that can be recycled.

Sometimes, the term "green" is used as a substitute: an environmentally friendly economy may be called green economy. The term "ecological footprint" has also become universal: It represents the amount of biologically productive land and sea area necessary to supply the resources a human population consumes, and to assimilate associated waste, see [26].

Perhaps we should use, more often, the strong moral force in the eco-prefix to *warn*. Political decisions of today are often "eco-unfriendly". The term "ecological crime" is already in use, often shortened as "eco- crime". In Norway, eco-crime is in fact used for both ecological and economical crime, and an official body termed "ecocrime" was erected in 1989. On our journey towards a sustainable future we should probably have a stronger focus on environmentally unfriendly activities.

Literature has already produced a number of "eco-thrillers", describing how nature strikes back when ecological limitations are crossed. Recently, the term "eco-angst", or "eco-fear", was presented in a Norwegian magazine [27]. Originating from the USA, the concept describes a new mental anguish which seems to be spreading: Bad forecasts for the future, for instance due to climate change, cause depression [28,29]. This is a serious signal to us all, both to politicians and consumers. Eco-fear is due to our eco-crimes. Overconsuming societies led by short-sighted economical profit are not only ecologically unsustainable, but also *mentally unsustainable.*

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3.2.6. Ecological and precautional thinking in law: Examples from Norway

Until 1981, most wildlife species in Norway could be hunted without restriction, and hunting of various predators was often encouraged by payment for killing. However, as a better understanding of ecological knowledge showed, predators play an important role in nature and several of these became endagered. Therefore, the Wildlife Act of 1981 (implemented in 1982) stated that all wildlife species should be protected. Hunting became allowed only during specific periods for selected species. This turnover of practice was called "the mirror principle". Wildlife in this connection encompassed all mammals, birds, reptiles and amphibians.

In 2009, a new act was adopted in order to protect biological, geological and landscape diversity and ecological processes through conservation and sustainable use: *Act of 19 June 2009 No. 100 Relating to the Management of Biological, Geological and Landscape Diversity (Nature Diversity Act).* The act reflected an ecological and precautional thinking, as exemplified by the following principles:

Section 8 (knowledge base): Official decisions that affect biological, geological and landscape diversity shall, as far as is reasonable, be based on scientific knowledge of the population status of species, the range and ecological status of habitat types, and the impacts of environmental pressures.

*Section 9 (precautionary principle):*If there is a risk of serious or irreversible damage to biological, geological or landscape diversity, lack of knowledge shall not be used as a reason for post-poning or not introducing management measures.

Section 10 (ecosystem approach and cumulative environmental effects): Any pressure on an ecosys-tem shall be assessed on the basis of the cumulative environmental effects on the ecosystem now or in the future.

Section 11 (user-pays principle): The costs associated with preventing or limiting any damage caused by a project to biological, geological and landscape diversity shall be borne by the project owner, unless this is unreasonable in the light of the nature of the project and of the damage.

Finally, the act introduced the concepts of *priority species* and *selected habitat types*. These are threatened species or nature types which will be given special concern through specific conservation programs.

In order to implement these various intensions, increased ecological knowledge is often needed about species and habitats, cumulative effects, and risks. We see how ecology feeds politics, and how political intentions again ask for more ecology to be able to practice ecological intentions.

3.3. Global warming: A test on long-term thinking

Already around 1970, specialists in atmospheric physics warned about a gradual global warming, due to increased concentration of CO_2 caused by humans. A "greenhouse effect" due to "climate gases" was gradually considered as a dangerous threat both to man and biodiversity, and in 1992 the Convention on Climate Change was born in Rio de Janeiro to reduce emissions. A much used concept is "climate quota", which means that one country can pay another country for reducing their emissions, instead of reducing its own. Unfortunately, global CO_2-concentrations have continued to rise, and at the Rio + 20 meeting in 2012, the international hope was to limit temperature increase to 2°C. The ghost in this situation is the concept of "tipping point" [30]. At a certain temperature, which is unknown, natural mechanisms may take over and rapidly push temperature still higher by feedback mechanisms, out of human control. For instance, more open water at the poles means that more solar radiation is absorbed, and if the permafrost of the tundra starts to melt, the strong greenhouse gas methan (CH_4) will be released to an increasing degree. Besides a massive extinction of species, large groups of people will suffer due to unstable weather with drought, floods, strong cyclones, and rise in sea level. The concept of "climate refugees" is already on the lips.

Our hope is that temperature stabilises below the tipping point. Realistic visions about "carbon-neutral communities" based on "renewable energy" or "carbon-catching and storing" exist, but such options are followed up only slowly. Until now, extra "climate taxes" on CO_2 emissions have had little effect. It is still cheap and comfortable to do business as usual. Also, there is a conflict between the two Rio aims: biodiversity and climate. In Norway, for instance, there is a great potential to save energy through better design in buildings etc. Also, existing hydroelectric power stations can be upgraded to become more efficient. Nature conservation organisations want to give energy saving priority, and argue that the "greenest energy is the energy which is not used". However, politicians are thinking along other lines, and the official energy politics in 2012-Norway is to increase the total use of energy. To achieve this, large plans exist for wind parks and new hydroelectric power stations. These plans are marketed as "green", "clean" or "environmentally friendly", although they may destroy nature of international value. Furthermore, this extra energy is not needed at present, and it does not substitute a corresponding reduction in the use of fossil energy. This is an example of tensions between possibilities and practice, between NGOs and politicians, which raises temperature also in energy debates. Such debates are to a large degree rhetoric, and "greenwashing" of increased energy use is often a problem.

Solar energy is an interesting option for the future, and some people have the vision of a "solar age". No one owns the solar energy, and it can be downloaded by anyone anywhere. Seen from above, places where people live contain large areas of roofs on which this energy can be collected free.

3.4. Nature as a source of life quality: How to express it?

Many people claim that contact with nature has a strong recreational effect, and that loss of nature would reduce their life quality (Figure 1). The conceptual framework for these values is still limited, but we shall present some fruitful studies, that have appeared during the past decades. The mental value of nature contact is still undercommunicated and deserves both more concern and further research.

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Figure 1. Nature, with beauty and silence, is a rich source for mental recreation. For many people, nature is an arena for the quality of life. From Jotunheimen mountains, Norway. Photo: S. Hågvar.

Callicott [31] listed the various values of biodiversity, pointing to both *intrinsic values* (diversity for its own sake) and *instrumental values* like various goods, ecological services, and information. Finally, he added the *psycho-spiritual* values, which include aesthetic beauty, religious awe, scientific knowledge, etc. The present author followed up the concept of psycho-spiritual values and pointed at nature as an *arena for the quality of life* [32]. He addressed these values as important among the "third generation" of environmental problems. While pollution problems were the main focus at the first UN conference in Stockholm in 1972, a "second generation" of environmental problems including climate change and biodiversity loss were discussed in the UN conference in Rio, 1992. He argued that it is due time to address the psycho-spiritual values in an international context as a "third generation" environmental challenge, broadening the perspective of nature loss to include our mental health.

Edward O. Wilson is a famous biologist who has coined several biological terms, but he has also contributed with an important concept regarding our mental relation to nature. He argues that humankind has a subconscious interest and fascination for other life forms (Figure 2), and calls this "biophilia". The term literally means "love of life or living systems." In his book *Biophilia. The human bond with other species* [22] he reminds us that we have evolved in nature, just like all other species. Genetically, we have not changed significantly since we lived completely surrounded by nature. Since nature is our original home, it may not be surprising that our brain – maybe unconsciously – enjoys contact with nature. Wilson argues strongly for rescuing the species richness of our planet – not only because species have an inherent value, an ecological value, and an applied value – but also because the wonders of life fascinates us and elevates our life quality. Nature presents us for both beauty and mystery, which appeals to our brain. Biodiversity may thus be regarded as an important basis for the human spirit.

Figure 2. Wilson's "biophilia" concept indicates that man has a basic interest in, and is fascinated by other life forms. Larva of the Privet Hawk-moth, *Sphinx ligustri.* Photo: S. Hågvar.

Many studies have shown that contact with nature is good for our mental health. A classic book in this context is *The Experience of Nature* by Kaplan & Kaplan [33]. They documented that contact with nature – from gardening and urban parks to the experience of wilderness – increased people's life quality. Regarding nearby nature they concluded:

People feel more satisfied with their homes, with their jobs, and with their lives when they have sufficient access to nature in the urban environment. People value natural settings for the diverse opportunities they provide – to walk, to see, to think. They are not necessarily aware of the many forms of encounter they have with nature or the variety of benefits that accrue.

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The modern, busy life often makes us feel worn out, and in need for a break or a recovery period. This worn-out state is generally not physical. Rather, these situations involve what we are calling “mental fatigue”. A mentally fatigued person finds it burdersome to concentrate, and to pay attention to something uninteresting. Kaplan & Kaplan found that we have two types of attention: An active and voluntary “directed attention” which we use when we concentrate upon a task, and a passive, “involuntary attention” which requires no effort. When we become mentally fatigued so that we need recreation, it is the directed attention which is exhausted. A key issue here involves the concept of “inhibition”. In order to maintain one’s focus on a particular thought, you have to inhibit the stimuli around you that compete for your attention. To resist the attractions of what you hear, see (or mental associations you get), for instance if you work in a room together with other people, demands mental effort. In short, continuous distraction breaks down your valuable, directed attention. For such “burned-out-people”, nature is a good arena for mental recreation. The directed attention is resting and recovering, at the same time as we can enjoy nature’s “soft fascination” by our passive, involuntary attention. Such psychological insight, based upon fruitful concepts, documents the value of having access to nature, as a mental source for recreation and life quality.

In the best-seller book *Last child in the woods: Saving our children from nature-deficit disorder* [34], Richard Louv worried about American children growing up without contact with nature. Not only is nature gradually lost where children grow up, but today’s access to electronic media results in sedentary children who often prefer to stay indoors. Access to electrical outlets may be more attractive than access to nature! The author concluded that this lifestyle was both mentally and physically negative for children and coined the concept of “nature-deficit disorder”. The book and the concept have inspired city planners to include green areas, especially remnants of real nature, as an important element in long-term city planning. For instance, in the author’s home city, San Diego, “undeveloped areas” like canyons with a rich plant and animal life were earlier regarded as a problem since they were difficult to urbanize. Instead, a process was started to preserve this varied near-nature by creating “San Diego Urban Canyonlands Park”. A new view on nearby nature had been triggered – but someone had to trigger it! There is now a growing understanding in the USA that protection of nearby nature has not only to do with biodiversity conservation, but also with the conservation of people’s physical and mental health.

In his book *The big connection. How modern Swedes consider man’s place in nature* [35], psychiatrist Nils Uddenberg studied how important contact with nature is for Swedish people. Both large studies with many people, and in-depth-interviews with fewer persons from different social groups documented that contact with nature was important for their life quality. In a large study covering one thousand people, 94 percent agreed with the following statement: “Strolling in the forest and fields makes me relaxed and harmonious”. However, when people were asked to explain why nature mattered, they had problems finding words to explain their statement. They lacked concepts and formulations for this purpose. People often ended up with religious concepts like holy, cathedral, or divinity to try to communicate their experiences, even if they were not religious. In my opinion, here is a field where a further development of concepts should be welcomed. Emotions are valuable for us, but difficult to communicate. The situation might be paralleled by the difficulties of explaining a deep musical experience.

Nature's health-promoting effect in the Nordic countries Norway, Sweden and Denmark, came into focus three years ago by a report from Nordic Council of Ministers [36]. While epidemic diseases represented the main health problem in earlier times, the health of today's people is mainly threatened by *non-epidemic life style diseases*. There are two of them: Overweight due to inactivity, and a depressed mental state, maybe due to a strong materialistic focus. Physical activity is good for both diagnoses, but the effect is best if the physical activity occurs in nature. Nature greets us with the absence of stress, combined with beauty, silence, and other positive experiences. Furthermore, physical and mental improvements support each other through so-called "effect-chains", resulting in improved life quality. In Sweden, and to a certain degree also in Norway, doctors have begun to order outdoor activity as a "green prescription" instead of tablets. Rather than heading to the chemist, people are heading to nature. This is cheap medicine, since nature is free and always open. The new trend reminds us of the importance of having access to near-nature, a resource which is shrinking in many Nordic cities and other densely populated areas. Areal planners are increasingly aware that to preserve green areas and greenbelts are good health politics. Health improvements by green prescription is, of course, also economically favourable for the society by shortening the hospital queues.

Concepts like threatened nature types and threatened species are now universally used. Sometimes we also see the term "threatened nature phenomenons". The Monarch butterfly is famous for its long, yearly migrations between Canada in north and Mexico and California in south. Although the Monarch is not an endangered species the annual migration is considered a threatened phenomenon by IUCN. Since there are very few overwintering sites where the adults aggregate, their populations become vulnerable. These sites are threatened by human activities, mainly logging, development, and agriculture. In 1984, the Monarch Project was created in order to save these sites. The Mexican conservation organization, Monarca, works closely with governmental agencies and local people to establish land protection and enhance alternative economic development in the region.

Also the spectacular, yearly migration of wildebeest and zebras over long distances through Tanzania and Kenya is a threatened nature phenomenon. Plans about a highway through the Serengeti national park, which would halt the necessary migrations, has till now been stopped, due to international protests.

The concept of threatened nature phenomenons deserves to be used more actively. People are not only fascinated by the teeming diversity of other life forms, but perhaps even more about what they are doing: What kind of processes nature reveals for us, and how it all functions. And least of all: Nature's secrets and mystery, about which we like to wonder. In light of the psychological value of nature experiences we should also use the concept of "threatened nature experiences". And furthermore, we should regard nature as a "resource of positive experiences". My favourite concept, trying to include nature's various contributions to our mental health, is *nature-dependent life quality*.

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4. Development of attitudes

The human mind seems to have a strong need for consistency, so we all develop attitudes [37]. Attitudes reflect our evaluation in various fields, and always have a focus (a person, nation, product, etc.). The attitude may be negative (unfavourable), neutral or positive (favourable). If we receive new information, attitudes can change since we want to eliminate mental inconsistency. Attitudes can be more or less conscious, depending on the amount of information and reflection, and they may be weak or strong.

Within the discipline of conservation biology, several authors have pointed to the development of attitudes as important in order to save biodiversity. Ehrlich [38] said that "a revolution in attitudes" is needed, and that "a quasi-religious transformation leading to the appreciation of diversity for its own sake, apart from the obvious direct benefits to humanity, may be required to save the organisms and ourselves". Wilson [20] concluded: "In the end, I suspect it will all come down to a decision of ethics – how we value the natural worlds in which we evolved and now, increasingly, how we regard our status as individuals". He also stressed that these questions include the "protection of the human spirit".

Box

The power of "intrinsic value"

Many species do not have any apparent practical value for man, nor any clear ecological function. They may only have "intrinsic value" – an ethical right to exist. However, acceptance of intrinsic value may have great power. The endangered Northern Spotted Owl in the USA, which depends on very old forest, may serve as an example. In the conflict between conservationists and the timber industry, the strategy of the timber industry was to put the burden on the scientists to prove an adverse effect of timber harvest on Spotted Owl persistence. However, this strategy failed because the court found it sufficient that scientists could document a risk to the species – a decision which reflects an intrinsic value of Spotted Owl. This is in accordance with The U.S. Endangered Species Act of 1973, which claims that habitats on which any endangered species depend should be protected. Due to intrinsic value of the owl, the burden of proof shifted from conservationists to developers: Now the forest industry would have to prove that the advised measures to save the owl had a significant negative effect on their business. In this case, we also see the application of the "precautionary principle": Doubt about a negative effect on the owl went in favour of the owl, and not in favour of the forest industry. Conclusively, intrinsic value has power both because it may shift the burden of proof from conservationists to developers, and because it may trigger the application of the precautionary principle.

For further reading about the Spotted Owl case, see [39].

The Norwegian philosopher Arne Næss is known for his "deep ecology", which includes respecting the intrinsic value of all life forms [40,41]. This also implies respecting people's spontaneous appreciation of species and nature.

The development of attitudes as a process of systematic thinking has been described by the present author [42]. His focus was the natural heritage, with biodiversity and pristine nature as the main elements. In the box, with permission from the Royal Swedish Academy of Sciences, four levels of insight are presented. The first level is to achieve good *knowledge* about the threats to the natural heritage. Step two is to discuss the *values* which are connected to biodiversity and pristine nature. The combination allows us to formulate *attitudes*, which represent the third level. Attitudes built on such stepwise thinking are clear and easy to explain. They form the motivation for *action*, or practical conservation work, the fourth level.

BOX

A gradual development of attitudes through various "levels of insight". Attitudes create actions which preserve natural heritage.

Levels of insight	Contact with prehistoric times	Today's situation	Perspective for the future
1. Descriptive knowledge	Our planet is very old. The richness of species and biota is a product of several thousand million years' evolution.	Biodiversity and pristine nature disappear rapidly, due to uncontrolled human activities. Many species depend on pristine nature.	It takes millions of years to develop new species or biota. Biodiversity in the future depends on today's plundering or conservation.
2. Values	Pristine nature is an important part of our planet's identity, and brings us in contact with prehistoric times. Natural communities help us to reconstruct the evolution, and to document our biological roots.	The loss of biodiversity and pristine nature implies a loss of qualities and values. A number of ecological, egoistical and ethical values are connected to biodiversity.	Pristine nature has all potential uses intact. The diversity of species represents valuable "gene banks" for future generations. All life forms have an inherent (specific) value. Preservation of species is beneficial for evolution.
3. Attitudes	Respect for the planet's history, its pristine habitats and species richness (the planet's own products through evolution).	Constant care for biodiversity, pristine nature, and habitats for threatened organisms. All doubt should go in favor of nature (the precautionary principle).	Respect the democratic plurality of future generations. Do not destroy their possibilities by reducing biodiversity. Allow evolution to proceed on the basis of genetic diversity.
4. Action	Priority for preservation of pristine nature.	Mapping and preservation of threatened species and their habitats. General care of biodiversity in forestry, agriculture, industry, areal planning, etc.	An empty chair in important meetings, for the imaginary representative for future generations.

Because today's situation is a result of earlier evolution and history, and also represents the options for future biodiversity, each level of insight contains a time factor. As well as having focus on today's situation, we are invited to consider "contact with prehistoric times" and "perspective for the future". At the first level, we are reminded that the planet is very old, and that today's biodiversity is a product of a very long evolution. Correspondingly, evolution will

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need millions of years to develop new species, and future biodiversity depends on our plundering or conservation. At the second level, pristine nature is considered to be an important part of our planet's identity. Intact nature also brings us in contact with prehistoric times, and helps us to understand and reconstruct evolution. In a futuristic perspective, pristine nature has all potential uses intact and can be regarded as a "gene bank". Besides this selfish aspect, the inherent value of all life forms is pointed at. Also, preservation of species is beneficial for further evolution, while termination of evolutionary lines in our time represents irreversible losses. The third level formulates attitudes in a condensed way, where words like "respect for" and "care for" are useful in expressing a feeling of responsibility and duty. The precautionary principle is central here, meaning that all doubt should go in favour of nature. In a prehistoric perspective, it is a matter of respecting the planet's own production through evolution. Likewise, it is considered morally right to allow evolution to proceed on the basis of genetic diversity.

At the attitude level, a futuristic perspective also must consider our duties for future generations. We should not destroy their possibilities by reducing biodiversity. They also might find quite new ways of using or appreciating both species and nature types – including cultural and recreational purposes. Furthermore, there is a democratic challenge here: Later generations will consist of a much higher number of persons together, than the population living today. In that perspective, we have an ethical duty to respect their democratic plurality.

Finally, we reach the fourth level of action, which is our everyday fight to preserve nature qualities. It consists of mapping, preservation, and a general care of biodiversity in forestry, agriculture, industry, areal planning, etc. It is no secret that personal attitudes mean a lot in this work, which is often a fight against several strong, and often short-sighted forces. Even within a ministry of environment, it is possible to do both a bad and good job; even within schools or in your own local community. At all levels, it is often so that certain "resource persons" may be driving forces, and also inspire others. Furthermore, both the prehistoric and the futuristic perspective may be relevant for the way we think and act. An evolutionary perspective helps to motivate preserving pristine nature as nature documents. And what about placing an empty chair at important meetings, for the imaginary representative for future generations?

In our everyday work, we might need a "short version" attitude to guide our priorities and decisions. In a condensed form, a basic attitude could be formulated in the following way: "Respect for the planet's natural heritage, for future generations, and for future evolution" [42]. Perhaps this attitude may even help us to preserve our respect for ourselves.

Who shall teach us to develop sound environmental attitudes? A good beginning is to get people into contact with nature, the younger the better. If you love nature, you may be prepared to defend it. If you have not "tasted" enough nature to miss the savour when it is gone, you may not be concerned about nature loss. Today, more than half of the world's population lives in cities. Therefore, there is a danger of "less nature – less concern" [43].

5. Rhetoric matters

5.1. Some examples and citations

Former vice president of the USA and winner of Nobel Peace Prize, Al Gore, fought strongly for solving the climate crisis through the documentary film *An Inconvenient Truth* (2006). His creative rhetoric was probably as important as the data he presented. Another case of forceful rhetoric was seen in the Time Magazine of 13 September 2007. Here, Nancy Gibbs treated global warming under the heading GLOBAL WARNING, with these words:

In a week when cable screens were split among solemn ceremonies, falling governments, the first serious congressional debate over a war now in its fourth year and an economy with a nervous twitch, it was even harder than usual to catch the sirens in the distance – to hear the sounds of ice melting, species vanishing and cities choking the people who live in them. You can't really cover a story that hasn't happened yet, but sometimes the news about the future is the biggest story of all.

This was a week for warnings. U.S. government scientists announced that the Arctic ice cap is melting even more rapidly than they had feared; by 2050, 40% of the ice cover in the Arctic Ocean could be gone, a loss that wasn't supposed to happen for 100 years. One scientist called the news "astounding." Since greenhouse gases linger for decades, even drastic reductions in emissions won't be enough to prevent further decline.

Do we hear "the sirens in the distance"? Are we able to realise that "the news about the future is the biggest story of all"? The climate problem is not only a matter of collecting scientific data, but also a massive pedagogic challenge. Our motivation for action depends highly on a mental empathy for future consequences. We need concepts for debate, but sometimes even more powerful rhetoric for motivation – for mental change.

The American biologist Edward O. Wilson is known for several well-formed statements. His main concern is to preserve biological diversity. In 1980, professors within different disciplines at Harward University were asked to identify the most serious threats of the nearest future. Wilson answered:

The worst thing that can happen during the 1980s is not energy depletion, economic collapse, limited nuclear war, or conquest by a totalitarian government. As terrible as these catastrophes would be for us, they can be repaired within a few generations. The one process ongoing in the 1980s that will take millions of years to correct is the loss of genetic and species diversity by the destruction of natural habitats. This is the folly that our descendents are least likely to forgive us [44].

In his book "The Diversity of Life" [23], Wilson stated:

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In the United States and Canada more people visit zoos and aquariums than attend all professional athletic events combined. They crowd the national parks to view natural landscapes, looking from the tops of prominences out across rugged terrain for glimpses of tumbling water and animals living free. They travel long distances to stroll along the seashore, for reasons they can't put into words.

In the same book, Wilson coined the concept "eremozoic age", or "eremozoikum", – the age of loneliness – to which we may be heading. If ecosystems collapse and the diversity of species disappear around us, humankind is getting more and more lonely on the planet. In this context, it is a paradox the some of the most threatened species are our closest relatives, the gorilla, chimpanzee and orangutang.

Wilson is a reputated synthesizer, and has come up with several basic hypotheses and concepts. The following statement is relevant for sustainable thinking, where information should be transformed to wisdom:

We are drowning in information, while starving for wisdom. The world henceforth will be run by synthesizers, people able to put together the right information at the right time, think critically about it, and make important choices wisely. [45].

Norton [46] presented the following formulation about the mental value of contact with nature:

To be moved by the beauty of organisms and whole, healthy ecosystems, to experience a sense of wonder and awe in the face of nature's inexhaustible marvels, is to become a better person.

The conservation biologist Soulé asked for a stronger engagement among biologists about attitudes and ethics [47]. He refuses the viewpoint that we should leave speeches to the politicians, morality to the priests, and ethics to the philosophers: *Few of them can speak with authority and familiarity about the exquisite detail and amazing diversity of life.* He concludes: *Who are more capable than biologists to spread the word that it is wrong to terminate evolutionary lines, and that it is wrong to wipe out entire communities?* He also touches the human pain from the destruction of biodiversity: *The planetary tragedy is also a personal tragedy to those scientists who feel compelled to devote themselves to the rescue effort. It is painful to witness so much termination.* This is powerful rhetoric, where Soulé manages to communicate both the duties biologists have to fight for biodiversity, and also his personal pain in witnessing biodiversity loss.

The rhetoric of the American expert in atmospheric physics, James E. Hansen, is also well worth to listen to [30]:

It is worth imagining how our grandchildren will look back on us. The picture that I fear has the polluters, the utilities, and automakers standing in court demanding the right to continue to emit carbon dioxide for the sake of short-term profits. The disturbing part is that we, through our national government, are *standing alongside the polluters, officially as a hulking amicus curiae (friend of the court), arguing against limitations on emissions. Is this the picture of our generation that we want to be remembered by? We live in a democracy, and policies represent our collective will. If we allow the planet to pass tipping points, it will be hard to defend our role. The state of the wild is in our hands, and we can still preserve creation and serve humanity worldwide. A drive for energy efficiency and clean energy sources will produce high-tech jobs. Restoration of clean air will be universally beneficial. Rural life and the planet can benefit from intelligent development of biofuels and renewable energy. At the front lines, observing the changes in the wild, conservationists serve as a voice for the plants and animals that have already started reacting to climate warming. To conserve as much biodiversity as we can, conservationists must unite with many others to push for a far more radical reduction in carbon dioxide emissions than has hitherto been considered practical. Otherwise, alpine and polar species, coral reefs, and species living in areas that become arid will be lost over the next century.*

In Norway, the biologist, Magnar Norderhaug (1939-2006) was well-known for his formulations in a number of books, articles and speeches about nature conservation. One formulation he used in order to wake up an audience was: *The future is no longer what it used to be*. Another formulation which was meant as a final inspiration was: *We must make the necessary possible*. The environmentalist and eminent speaker, Øystein Dahle, presented the following formulation about the need to deviate from "business as usual" on our journey into the future: *Our destination should not be where we are heading.*

Even the graffiti genre may deliver forceful formulations. The statement: *The future is cancelled* is strongly negative and illustrates that rhetoric is a weapon that can be used in many ways. A more constructive formulation is: *Good planets are hard to find.* This is true, and could motivate us to rescue the one we have.

5.2. Creating hope and action with words: "If you are a part of the problem, you are a part of the solution"

This formulation illustrates constructive, sustainable thinking [9]. We are talking about "enlightened self interest": A common problem must be solved by common efforts. This requires a "precautionary ethic" about what is morally right or wrong in a long term perspective. The *Local Agenda* perspective from Rio in 1992 placed a responsibility on all local communities through the slogan "Think globally and act locally". For instance, in Norway, several municipalities were inspired to present themselves as "environmentally friendly municipalities", and prizes were given to industry, companies, schools etc. which actively showed environmental responsibility by reducing pollution, wastes, energy consumption, etc. Some institutions were acknowledged as "environmental lighthouses": as examples for others to navigate by. Some measures are "win-win situations": for instance reducing costs by reducing energy consumption. In fact, sustainable practices could be regarded as a "public service", since they serve our common future [9].

On the personal level, it has been argued for "the good life" with reduced consumption, under the vision of "voluntary simplicity" [7]. This is "the responsible consumer", who practices a

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"sustainable lifestyle" through "ecological choices". If numerous enough, responsible consumers may achieve "consumer power". For instance, the water quality of Norway's largest lake Mjøsa was saved in the 1970's through a coordinated effort: consumers agreed to stop buying phosphate-containing detergents, and farmers (with economic support) stopped the run off from leaky manure storage cellars. Another example is how environmentally conscious consumers in Europe have forced forestry in Norway, Sweden and Finland to reduce logging in virgin forests of high biodiversity value. Today, large companies like Springer Verlag and IKEA dare not buy paper or wooden products originating from Nordic virgin forest. To practice this, they have to trace the origin of the wooden products, and Nordic Forestry has been obliged to undergo an "environmental certification" to document a "green profile". A part of their duty is to identify biologically important forests by means of sensible "indicator organisms", and if so-called "key habitats" are cut, forest owners may lose their certificate and the possibility to sell the timber. Only within this forestry example, a number of new concepts were developed in order to agree upon aims, principles and control mechanisms. But behind it all stand environmentally conscious European consumers, kept together by "the responsible consumer"-rhetoric. Conclusively, we all matter.

6. Our ability to deny or suppress environmental threats

In his book *Collapse – How societies choose to fail or succeed,* Jared Diamond [2] shows how our choices in critical periods either saves the society, or allows it to collapse. How can, for instance, a society destroy itself by cutting down all available forest? While Japan in due time took care of a part of their limited forests on their islands, the inhabitants of Easter Island chose to cut down all their trees. This happened even though this island community depended on woody material for several purposes like fire wood, buildings and boats. After that, the society collapsed. The isle is famous for its large stone statues, which were probably of great importance. The current hypothesis today is that different tribes competed about making the highest statue, investing great prestige in this competition. Each statue demanded much timber in order to be transported, sliding or rolling, from the quarry to its final place. What did the person think, who cut down the very last tree? Perhaps that this trunk was just what they needed for the transport of the most recent statue?

A steady course towards catastrophe has occurred in several societies throughout history. Diamond's book is important because he tries to understand how it is possible to act in a wrong way with open eyes. He presents the following six forces which may lead to so-called negative handling of crises – even after the crisis has been discovered and understood. They all have to do with the way we think.

1. Some are favoured by "business as usual".

Short-sighted economical interests are often the motive, like destroying tropical forests in an irreversible way, overfishing, or continuing large-scale climate-hostile production and use of fossil energy.

2. Some are afraid of losing power.

Power attains many forms. Wealth often creates power, and rich persons, companies or nations may depend on continued plundering of nature and natural resources. Dictators may suppress democratic movements and even commit genocide to avoid losing power.

3. We are unwilling to change traditions, even if they are environmentally unfriendly.

Nordic settlements on Greenland existed for 450 years, but collapsed during the 15th century. Diamond assumes that the traditional Norwegian lifestyle, which they maintained, led to overgrazing and erosion. They had contact with eskimo people, but were not willing to consider harvesting from the sea, which would have been more sustainable on Greenland. Also, English traditional husbandry in Australia on vulnerable soils, with little forest and limited precipitation, has created several problems: overgrazing, erosion, lack of freshwater, and loss of forests and biodiversity. Diamond suggests that a sustainable Australia has to create new traditions, adjusted to the natural conditions.

4. We are reluctant to think in a long-term perspective.

While a farmer may be eager to leave his farm in an improved condition to his children, both politicians and private persons may evolve a mental obstacle about thinking too far ahead. Politicians may be more eager to be renominated than to grasp challenges demanding long-sighted thinking, and individuals may be more or less self-centered. Economic activity may be highly focused on short-term produce, and investments may easily be moved from one environmental hostile activity to another, with great total economic success.

5. Critical, individual thinking may be paralysed by group psychology.

History illustrates several cases where people have been seduced by charismatic, but dangerous leaders. It may be a demanding task to maintain independent, critical thinking amidst a mentally brainwashed and emotionally heated public. Clever nazi-propaganda in the 1930's made Hitler's crimes against humanity possible. Even a handful of good advisers may give bad advice as a result of unfortunate group psychology. Stressful circumstances and the need for mutual support and approval may lead to suppression of doubts and critical thinking, resulting in a dangerous decision. One example from the book is president Kennedy's advisers during the Bay of Pigs crisis. Later, Kennedy was careful to let his advisers think critically and independently before the group concluded. The movie "Twelve Angry Men" demonstrated how one critically thinking person, presenting his doubt, was able to break an unfavourable group psychology.

6. Psychological denial.

Man has a psychological ability to suppress, often subconsciously, the inconvenient. For instance, people who live just below a dangerous dam may claim that they do not fear a catastrophe. They suppress thinking about it. However, persons living further down the watershed dare to worry, and actively try to reduce the danger.

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When discussing a way to a sustainable future, it is highly relevant to be aware of these psychological traps. "Business as usual" contains them all.

7. Discussion

This review illustrates how sustainable thinking depends on fruitful concepts and well-founded attitudes. We have also stressed the value of powerful rhetoric: It matters how you communicate about environmental problems. On our way towards a sustainable future, concepts, attitudes and rhetoric represent important weapons against "Business as usual". However, these weapons must have the necessary quality.

7.1. About concepts

A common conceptual framework is needed to identify, discuss and solve environmental problems. However, as illustrated by the concept of "sustainable development", a global concensus about foggy concepts creates little progress. During the last 25 years, this concept has been considerably refined. A division between environmental, economic, and social development, and further sub-concepts within each these parts, has been constructive. However, further clarification about aims and methods is necessary. For instance, the concept of "green economy" contains a problematic premise about further economic growth. It is also sufficiently foggy to allow a practice close to "Business as usual". There is good reason to believe that world leaders *wanted* a foggy "green economy" concept at the Rio+20 meeting in 2012.

Concept producers like Edward O. Wilson are valuable people. Several of his concepts, like "biodiversity", "biophilia" and "eremozoicum" were rapidly taken into use globally. It is a tempting idea that concept evolution within the field of sustainable development could be regarded as an important academic discipline, attracting creative people. New concepts should be relevant, sharp enough, and difficult to misuse. Within certain topics, a lack of good concepts may keep important questions outside of today's debate. For instance, the value of deep personal experiences in contact with nature is difficult to communicate to others, but of great personal importance for some people. Several of today's foggy concepts deserve a systematic study in order to make them operable and to avoid misuse. Progress within certain complicated fields, for instance how to combine economic, environmental and social sustainability, depends upon research. Environmental challenges may be of local character, and different social and economic structures may need different conceptual models.

The rise of ecological thinking illustrates how basic, scientific concepts can be modified and applied in sustainable thinking and practice. To cooperate with nature's own processes has become a main aim in environmental sustainability. Furthermore, "ecological service" has rapidly come into international use, in order to illustrate our dependence upon a well-functioning nature. Various types of research have been initiated by the concept, for example attempts to transform the value of pollination into economy. However, the idea of "ecological service" is strongly anthropocentric. We should not forget biocentric motivations to protect nature. For instance, the inherent value of every species was the basic motivation for the philosopher Arne Næss in his fight for nature preservation. Fortunately, the Convention on Biological Diversity urges us to protect all species.

Some writers stress the importance of listing "non-sustainable activities". This is a constructive approach. In this connection, the term "environmental crime", or "ecological crime", has been used. Presumably, business leaders would not be happy to have this label attached to their activity.

7.2. About attitudes

Development of well-founded attitudes is a personal process for each of us. A "ripe" attitude is clear and conscious, and gives us motivation. We must be able to explain our attitude, and to defend it in discussions. In environmental debates, disagreements are often due to different attitudes. If people are unwilling or unable to explain the fundament of their attitudes, debates may become foggy and not very constructive. For instance, a person may find loss of species to be unproblematic, due to lack of biological knowledge. There are people who focus mainly on the "plate biodiversity", which are species we can eat or otherwise use in a practical way. Even among biologists, there have been discussions about "ecologically redundant species", which are species that could be removed without any ecological harm. However, this is a dangerous discussion, because we have several times discovered that "anonymous" species may have key functions in nature. One example is the mycorrhizal fungi which makes it possible to have forests on northern latitudes. In such discussions, the attitude expressed by the "precautionary principle" becomes important.

Concerning the danger of climate change, groups of "climate sceptics" are common. They do not find it sufficiently proven that climate change is due to human activity. Several of them find it wrong to use massive resources to reduce carbon dioxide emissions. However, some of them accept applying the precautionary principle; accepting that they might be wrong. For them, to act is an insurance for the future; we insure our houses even though the chance of it burning down is little.

People who love nature are strongly motivated to defend it. However, attitudes signalizing indifference to nature qualities are not uncommon. We see this attitude practised all over the world, and there are many companies which depend upon destroying nature.

Finally, political leadership is crucial. If political leaders do not act, even engaged people may loose motivation and think that perhaps problems are not so serious after all – since political leaders do not take them seriously. This creates a negative spiral, while the aim should be that people and politicians support each other in a positive spiral, making the necessary possible.

7.3. About rhetoric

While a concensus about concepts is obviously important, and clarifications of each other's attitudes can be crucial in environmental debates, why should we include rhetoric as a premise for success? The answer is that we are short of time. Environmental problems increase faster

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than we are able to solve them. Just as in literature, certain thorough formulations may have great mental power. The power of rhetoric can be used to take future generations seriously, to warn of environmental catastrophes, to expose in a pedagogic way ecological crime – or it enables us to describe possibilities, inspire individual action and create hope. Our leaders need inspiration to use the necessary resources to save biodiversity and halt climate change. Many of them know that it may be more difficult to try to repair damages in the future, than to prevent them, but they are still reluctant to act. Leaders who *want* to act, need rhetoric help to inspire people to cooperate.

Increased use of "sustainable rhetoric" is perhaps the most efficient single factor in order to create change. In debates, we must be ready to meet a "counter-rhetoric" which defends "business as usual". It is a challenge for debate leaders to identify foggy concepts, environmentally unfriendly attitudes, and argumentation based on our mental tendency to deny or suppress environmental problems.

7.4. About "mental enemies"

As shown in Jared Diamond's book [2], the human brain is clever in suppressing or denying threats. The six more or less unconscious mechanisms he refers to are our "mental enemies" and represent a serious halting against sustainability. Therefore, we have to identify them and avoid them. The case of group psychology may deserve special attention. Political leaders often rely heavily on advisory groups, since their advice is supposed to be strengthened by contribution from people with different backgrounds. However, valuable opinions from the best person may be drowned by group psychology, due to stress, loyalty and a common wish about concensus. President Kennedy's dangerous experience in the Bay of Pigs crisis led him to decide that on later occasions, his advisors should think critically and independently before the group concluded. This is an invaluable "take-home-message" also for today's political leaders.

7.5. About hope

Lack of hope is a serious obstacle on the way to sustainability. On the other hand, collective hope may have a strong force. Both concepts and rhetoric are good helpers in creating hope.

Certain concepts should be used actively to create hope, by showing possibilities. Several eco-concepts have this function, as eco-policy, eco-friendly products, and eco-efficiency. In Norway, companies, institutions, schools, etc. which change their practice in a sustainable way, may achieve a diploma for being "environmental lighthouses", by which others can navigate. Fortunately, there are several win-win situations towards sustainability, for instance, reduced costs by conscious energy saving. Another approach is reducing waste, and by regarding the remaining waste as a resource. Re-use following the principle "from cradle to cradle" is a promising principle.

There is a special challenge to develop a strong rhetoric of hope – and to practice such rhetoric. However, constructive hope depends on visions about possibilites. The following formulation is good rhetoric: "If you are part of the problem, you are part of the solution". Here, facts, obligations and hope are signalised in one package. The formulation calls for cooperation, and opens a door for change.

8. Conclusions

In order to realize a sustainable future, we have to deviate from ”business as usual”. This calls for alternative thinking, based on fruitful concepts and well-founded attitudes. A literature review illustrates how the unclear concept of “sustainable development” from 1987 has undergone a considerable conceptual refinement. Today’s conceptual framework is, however, still too weakly developed to encourage community development onto a sustainable track. For instance, the concept of “green economy”, accepted by The World Bank, large companies and national leaders in several of the richest countries at the Rio+10 meeting in 2012, is foggy enough to “greenwash” unsustainable economic activity by making only cosmetic changes. The concept also contains a premise about further economic growth, which is a main cause of environmental degradation. A lack of concensus about precise concepts and principles is a threat to sustainability. The author suggests that concept development about sustainability should be regarded as an important academic task. There is a need to coin and define new, fruitful concepts, to give existing concepts a more precise meaning, to point at misuse of concepts, and to identify topics which are excluded from the debate due to a lack of operable concepts. For example, the value of deep personal experiences in contact with nature is difficult to communicate to others, but of great personal importance for some people. Progress within certain complicated fields, for instance how to combine economic, environmental and social sustainability, depends upon research. Environmental challenges may be of local character, and different social and economic structures may need different conceptual models.

This literature review about the rise of ecological thinking illustrates how basic, scientific concepts can be modified and applied in sustainable thinking and practice. To cooperate with nature’s own processes has become a main aim in environmental sustainability. Our dependence upon a well-functioning nature is illustrated by the concept of “ecological service”. This fruitful concept has initiated many new studies and calculations, and increased our awareness about saving nature qualities. However, the concept is strongly anthropocentric, and too narrow to secure biodiversity. Fortunately, the Convention on Biological Diversity is based on a biocentric view.

Some writers stress the importance of listing “non-sustainable activities”. This is a constructive approach. The concepts of “environmental crime”, “ecological crime”, or “eco-crime” deserve to be used more actively, for instance by NGO’s when criticising environmentally harmful activity.

Well-founded attitudes are another prerequisite for a sustainable development. Attitudes motivate us for change, and support our endurance. However, non-sustainable attitudes are common, as well as a lack of attitudes in this field. A personal developmental process is necessary to alter our attitudes about sustainability - they cannot simply be adopted. A well-founded attitude is based on adequate knowledge and conscious evaluation. This means that

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education pertaining to environmental questions is vital. Furthermore, positive experiences in contact with nature will often trigger motivation for preserving nature qualities. Today, more than half of the world's population recides in cities, with little or no contact with nature. There is a danger that reduced access to nature leads to less concern about it. Therefore, schools at all levels should allow young people to experience the values of nature contact. Closely connected to attitudes is the field of environmental ethics. A "biocentric" view, respecting the intrinsic value of all life forms, may have great practical value.

Armed with fruitful concepts and well-founded attitudes, we should be well equipped to fight for a sustainable future. There is one more factor though, which is our ability to communicate. Because we are short of time, rhetoric matters. Forceful rhetoric may transform eco-fear into motivation, and allow environmental threats to be clear and challenging. Just as in literature, certain thorough formulations may have a strong mental effect. At present, increased use of "sustainable rhetoric" is perhaps the most efficient single factor in order to create change. In debates, we must be ready to meet a "counter-rhetoric" which defends "business as usual". It is a challenge for debate leaders to identify foggy concepts, environmentally unfriendly attitudes, and argumentation based on our mental tendency to deny or suppress environmental problems. People who are skilled in the art of rhetoric are today typically engaged in the advertising business; often convincing people to buy things which they do not need. The rhetoric force is today needed to convince people – and politicians – of a change that we all need. The politicians themselves should use encouraging rhetoric to make us all cooperate. The following formulation is an example: "If you are a part of the problem, you are a part of the solution". Most of all, rhetoric should be used to spread hope. Hope is a strong mental force, and collective hope may change a community.

We need a "mental tipping point" where sustainable thinking takes over – and remains. The way we think is our hope.

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Chapter 6

Punctuations and Displacements in Policy Discourse: The Climate Change Issue in Germany 2007-2010

Volker Schneider and Jana K. Ollmann

Additional information is available at the end of the chapter

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1. Introduction

Climate change or "global warming" is a major issue within the debate about the sustainability of social and natural systems. In this context it has become the prime example for policy problems that are characterized by long time horizons, large uncertainty and high ambiguity [1]. In such a policy context, problem definitions get vague and unstable, preferences become unclear, and the potential of social conflict is high [2]. Under these circumstances, policy making heavily relies on public discourse in which issues and interest conflicts are collectively debated and shared "definitions of the situation" are constructed. For this reason, the issue of climate change has attracted high attention among policy researchers interested in discourse analysis since the early 1990s.

While many empirical studies focus on the rise and decline of discourse activities, some critics have questioned the relevance of climate change discourses at all. For instance, even scholars of cultural studies such as [3] call for a *"return from the world of discourses and systems back to the actions and strategies with which social beings try to manage their existence"*. Such a perspective implies that policy problems are seen as objectively given and self-evident, without any need to be collectively defined and represented. In an epistemological perspective, this is a naïve version of realism [4]. According to our perspective, however, public discourse is an essential part of policy-making, besides the interests, preferences and strategies of all involved actors and the institutional constraints in which policies are decided and implemented. Policy-controversies and debates are not just "surface phenomena" of political processes but are rather an integral part of power structures and exchange relations in policy-making. The analysis of public debates and policy discourses – in a qualitative or quantitative manner – can therefore be seen as an important component of policy analysis [5].

In this paper we will apply a specific form of quantitative discourse analysis to the debate on global warming and related policy decisions. Since qualitative discourse analysis runs short in terms of transparency, comparability and replicability, we use various methods of quantitative structural analysis to specify the role of actors and their interrelations within the policy discourses on climate change [6]. Recent methodological developments, namely the combination of category-based, computer-assisted, qualitative content analysis and social network analysis [7-9] provide new possibilities to analyze discourse coalitions, actor constellations, conflict structures, and their dynamics at the level of discourses and policy debates.

The specific goal of our paper is to trace and interpret the evolution of German public discourse on climate change in terms of punctuated equilibrium theory (PE theory), which is a distinctive version of evolution theory in the natural and social sciences. It rejects gradualist assumptions and emphasizes discontinuities in processes at all levels which have been triggered by great and singular events [10]. When applied to social developments, PE theory explains policy change as a result of major shifts in the public perception of a policy issue, which in turn is triggered by focal, and often "external" events [11]. These processes are intermediated by negative and positive feedback mechanisms that accelerate or slow down developments.

Our study will assess core propositions of PE theory with respect to the impact of the financial crisis on the German climate discourse between 2007 and 2010. Germany has been widely acknowledged to be a front-runner in climate policy on the European and global level. A commonly accepted explanation is that intense public participation and strong public consensus based on "ecological modernization" have contributed to this success. Even though this consensus has dominated the German discourse for over two decades, some scholars [12, 13] have issued concerns that it might prove to be unstable. Since its peak in 2007, public attention to the issue of climate change has been declining. Our data show that this downswing seems to have been strongly amplified due to the financial and economic crisis in 2008 and 2009. In the context of this massive downturn, actors changed their discursive behavior, impacting actor positions and frame constellations.

Our paper proceeds in three steps. In the next section we will give a short outline of various theoretical perspectives in the analysis of policy discourse, emphasizing punctuated equilibrium theory. Our third section proposes a formal and quantitative approach to structural analysis of discourse configurations that are linked to actor networks. In the fourth section we will apply this approach to policy discourse in the domain of global warming in Germany under the influence of the recent economic crisis. In the conclusions we summarize our findings and raise some question for further analysis.

2. The complexity of policy discourse

In the study of public responses to social and environmental problems two opposing perspectives have dominated the academic debate: the objectivist (or naïve realist) and the so-

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cial constructivist approaches. Objectivists define social problems as objectively given, self-evident, without any measurement problem. From this perspective, changes in the atmosphere and their consequences can be determined in an objective and definitive way. They also assume that rational and well informed actors can develop an optimal adaptation strategy [14]. Yet from a constructivist point of view, a social problem *"exists primarily in terms of how it is defined and conceived in society"* [15]. Thus, climate change only turns into a social problem when individuals or groups conceive it to be a threat to nature and society. The individual as well as the collective perception of risk are thereby influenced by social, cultural and political contexts [14, 16].

Over the last twenty years environmental issues have inspired discourse analysis within different sub-disciplines of social sciences, e.g. communication science, science and technology studies, as well as policy science. These studies share the conviction that the constructivist perspective is especially fertile with respect to issues that are characterized by long time frames, large uncertainty and high ambiguity. Climate change matches all these characteristics:

Long time frames. Significant changes within the atmosphere emerge "creepingly" over long periods that do not correspond to the time horizon of everyday life experience. Society thus depends on scientific research to detect, anticipate and communicate these risks. In that way, scientific facts only attract public interest and political concern if they can be linked to social threats and possible solutions [1, 14].

Uncertainty. While human influence on climate change is widely accepted in contemporary science, uncertainties remain about its future development and consequences [17, 18]. Scientific forecasts vary along modeling techniques and measurement methods [14]. Uncertainty complicates risk assessment and communication. Under these conditions, objective cost-benefit analysis of precautionary measures turns into a "mission impossible".

Ambiguity. This property can be defined as a *"state of having many ways of thinking about the same circumstances or phenomena"* [19]. While uncertainty may be reduced by further information, additional information does not reduce ambiguity. Even if there is a complete spread of scientific information, different people will have different perceptions of the problem. For instance, climate change can be understood as a risk to biodiversity, human health, economic development, social equity or political stability. These different problem definitions may not be reconcilable, and hence create vagueness, confusion and conflict [2].

Some social scientists concerned with climate change see their research on a "pragmatic middle ground" between objectivism and constructivism, denying neither that threats are objectively given nor that public perception is subject to significant variation. Especially risk communication researchers are concerned with how objective expert information can be effectively communicated to the public [20]. However, these approaches fail to acknowledge the role of actors and their particular interests to influence public perception – from risks assessment to the reporting and public interpretation of these risks [14]. The constructivist perspective highlights that actor relations and cultural contexts in science, culture and the public sphere are more relevant for the debate on climate change than is the quality of information [14]. Thus, public discourse has to be linked to actor constellations in the policy process. It is this relational dimension that differentiates our method of discourse analysis from traditional forms of discourse analysis within other sub-disciplines of social sciences.

Policy research has traditionally regarded policy making as a linear problem-solving process of a simple "conceive-decide-implement" sequence, starting with problems that are defined in an objectivist perspective [21]. However, the growing complexity of policy problems nurtured skepticism about the rationality of such processes. Policy analysts now increasingly acknowledge that distinct value orientations, specific information processing capacities, and subjective lines of argumentation and interpretation are influencing the policy process. In this perspective, public discourses have to be seen as essential components of policy making [6, 22].

With respect to discourses on climate change, a number of studies have examined the rise and decline of issue attention in public arenas as well as the evolution of political agendas in this policy domain. Studies focused on changes of the public perception of climate change as a social problem as well as the role of different social sub-systems such as science, politics and the media during the successive stages of the issue's career [12, 23, 24]. Some scholars tried to map problem perceptions and conflict lines to explore the possibilities of policy consensus [25, 26]. Malone [27] used a network approach to map similarities between "families" of arguments. Analyzing narrative structures within environmental discourse, Hajer [28] examined how actors build discourse coalitions around story lines that integrate situational factors, general problem interpretations and policy interests within a coherent narrative. Fisher et al. [29], using a methodology similar to ours, analyze discussions about climate change within US Congress and display how consensus around the issue emerged during its 110th session (January 3, 2007–January 3, 2009).

While all these studies have emphasized the need for communication and mediation in public debates, only some of them have conceptualized discourse as an integral part of the policy process. In addition, some of the studies display quite serious methodological deficiencies. For instance, interpretative "process tracing" and "case studies" often raise problems with respect to transparency, replicability and comparability [5]. Qualitative approaches inherently concentrate attention only to relatively few actors and relations, without taking into account the vast plurality and heterogeneity of actors, the multiplicity of linkages, and the complexity of discourse configurations.

For some time, there have been certain theories in policy analysis in which emphasize discourse elements such as ideas or beliefs. One example is the Advocacy Coalition Framework, which describes the policy process as a struggle between different coalitions that share similar belief systems and tries to establish these beliefs as the dominant policy interpretation within a policy subsystem [30]. In the perspective of the Multiple Stream Approach, policy entrepreneurs use discursive tactics to link policy problems to their preferred policy solutions [2].

In the present paper we use Punctuated Equilibrium Theory (PE theory), which emphasizes the role of policy venues, policy images, and the impact of large singular events: policy ac-

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tors try to alter the institutional arena within which a given issue is negotiated (venue) to promote their values and policy beliefs (policy image). Actors attempt to transform the overall "issue culture" by persuading undecided participants or mobilizing hitherto uninvolved actors. In this content external and/or internal focal events can have a deep impact on policy development. Public attention to specific issues may suddenly rise or shift towards other issues, thereby attracting new policy actors and restructuring policy discourse. However, it depends on policy feedbacks whether this intrusion creates a serious challenge to the dominant policy image or the deep-rooted actor constellations. Positive feedbacks (e.g. bandwagon effects, social learning or political entrepreneurship) enhance policy change whereas negative feedbacks (e.g. access barriers or coalition building to sustain the present policy image) reinforce existing images or constellations [11, 31-33].

In general, most analyses based on PE theory track policies over long periods to identify patterns of policy stasis and abrupt punctuations. Our analysis will concentrate on rather short intervals, starting one year before the financial crisis as a "punctuating event" and ending in the first quarter of 2010.

This study conceptualizes discourses as communication processes permitting "*policy issues and conflicts to be collectively understood and defined, (...), meanings to be shared and reconstructed, and arguments to be set forth, debated, and eventually institutionalized*" [34]. Such a view of policy discourse implicitly uses a network perspective of policy making in which decisions and programs are not merely structured by formal institutions and few governmental actors but rather by complex informal relations between multiple and heterogeneous policy actors [35]. Policy systems are functionally differentiated into various sub-systems evolving around specific policy issues, and are composed of actors who regularly seek to influence policy processes that are guided by beliefs and interests.

It is useful to distinguish among two types of policy discourse: *sub-system specific* and more *general public discourse*. Discourses take place in different forums or arenas in which individual or collective actors present their issue interpretation while the audience is observing and evaluating. Actors contribute to discourses in order to persuade others and the audience to adopt their issue perspective [36, 37]. According to PE theory, a high degree of consensus within sub-system specific discourses favors policy making in terms of routine procedures, and in most cases policies evolve in an incremental manner [32]. During the normal course of policy making, actors tend to communicate predominantly within established policy circles [38]. If one or several sub-system members disagree with the dominant problem perception, they try to change the venue of discussion, i.e. they push the issue to the public arena where a broader and more heterogeneous audience can be addressed.

Based on different communication technologies, there are various kinds of public discourse arenas of which this study considers the mass media to have the largest impact on the policy debate. Although principally everybody can participate in the mass media forum (at least as a member of the audience), editors and journalists enjoy privileged positions since they exert some control with respect to who can say what, when and how. Thus, public arenas can be biased by power coalitions in which media actors play an important role as well. In contrast to discourses at the sub-system level, issues are discussed controversially in public discourses. Heterogeneous actors contribute to different problem definitions, and dominant or consensual policy images are established only by way of tedious debates.

Another facet of discourse arenas is their limited *carrying capacity*: only few problems can be addressed at once [39]. While the respective subsystems specialize on a given issue, in most cases a bunch of issues compete for attention. Their competitiveness depends on *novelty* and *dramatic value*. According to Downs [40], public attention follows a cyclical pattern of rise and decline. Such issue cycles have been extensively discussed in the literature, wherein two points have been emphasized: firstly, major external events catalyze issue attention because they create a sense of dramatic crisis that cannot be sustained in their absence [41, 42]. Secondly, claims-making activities alone cannot explain that one issue attracts more public attention than another [43], but they play an important role in connecting a specific event to the definition of a policy problem [44].

This study distinguishes four stages of collective problem redefinition within public discourse [45]:

Entry and exit. Individual and corporate actors (just like the discourse arena) have limited carrying capacities. Because of limitations in time, budget and personnel, they can only process few issues at a time [39]. When there is extensive media coverage of an issue, some actors that were not interested in the issue prior to a media hype now become engaged in public discourse either because they realize the problem's importance or because they use it as an occasion for self-promotion or other policy strategies.

Framing. Problem definitions depend on framing, which is "*a way of selecting, organizing, interpreting, and making sense of a complex reality to provide guideposts for knowing, analyzing, persuading and acting*" [46]. Frames enable actors to get some understanding of complex situations and facilitate communication and action with regard to a perceived problem. The way an issue is framed impacts on whether people notice a problem, how they understand it and what viable solution they take into consideration. The framing of an issue is not necessarily constant – neither the individual nor the collective way of framing. Actors aim to get their frame recognized as the authoritative version of "reality" [36].

Salience. This concept describes how much a frame dominates the discourse [47]. A frame has a low salience if it is used rarely by few actors whereas its salience is high if it is used repeatedly by many actors. When attention to an issue rises or declines, shifts in actor constellations also generate changes in frame constellations. New actors contribute to new frames while old frames vanish when their supportive actors leave the discourse arena [45].

Proposal and debate. Changes in the collective framing of an issue also changes influence debates on policy measures. Based on the multiple stream approach, proponents of PE theory expect that political actors are sometimes more interested in making sure that "their" policy solutions are adopted than in what problem these solutions address [45, 48]. During phases of collective problem redefinition policy entrepreneurs promote their policy ideas as solutions for the problem under discussion. As these ideas do not derive rationally from problem perceptions, they are nevertheless expected to be compatible with different problem interpretations.

An extended application of this approach to policy discourse would suggest that we have data on various discourse arenas and policy venues. Within the constraints of this study we had to concentrate on the discourse at the mass media level. In this respect, our theory-based expectations are that the financial and economic crisis was a punctuating event with regard to actor and discourse dynamics. During and after the crisis we expect significant change in the actor constellation and in the structure of discourse. Both will be measured and described with some methods of social network analysis.

3. Discourses as networks

In this study we use a formal and quantitative approach to discourse analysis. As exposed in the previous section, discourses consist of sets of individuals and organizational actors, groups of actors, and sets of concepts such as frames or positions. All of these refer to issues under discussion and emergent relations in terms of communication. Concepts do not float freely in the air or "hover above society" but are instead attached to concrete actors that use them within discourses to persuade others of their own problem interpretation. Discourse coalitions emerge among actors that are connected by similar issue positions and policy frames. Specific frames and problem definitions must not be mutually exclusive but differ with respect to their reconcilability [25]. This study assumes that the same actor is able to consider a problem from different perspectives and to use different frames within a given discourse. An actor might do so out of conviction or with strategic motives. In any case, two concepts that are used by the same actor in the same way (in the case of positions, the actor supports both or opposes both positions) can be assumed to be reconcilable to a certain extent.

Discourse network analysis formalizes these multiple relations by means of graph theory: A graph *G* consists of nodes from the set of actors *A={a1, a2,a3...am}* and/or from the set of concepts *C={c1, c2,c3...cn}* and edges from the set of interrelations between nodes *E={e1, e2, e3...el}* (Figure 1). Based on these formal concepts several types of graphs can be created:

- an actor network
- a concept network (based on positions or frames)
- an affiliation network linking actors and concepts
- an actor group network aggregating actors into groups
- a positions-frames network aggregating positions into frames.

These networks can be analyzed by conventional tools of social network analysis. This study is interested in the standing of actors as well as in the salience of concepts. Standing designates an actor's visibility in terms of how much he/she contributes to the public discourse. An actor's standing depends not only on his/her commitment but also on whether he/she succeeds in positioning his/her problem interpretation within the media arena. In terms of network analysis, standing designates the actor's centrality within the discourse. Salience designates how much a concept is incorporated in a collective problem definition, how often it is used and how central it is within the affiliation network. Issue coalitions, groups of actors that share similar policy ideas are subgroups within the actor network in terms of network analysis. The reconcilability of issues is reflected by their interconnectedness within the issue network.

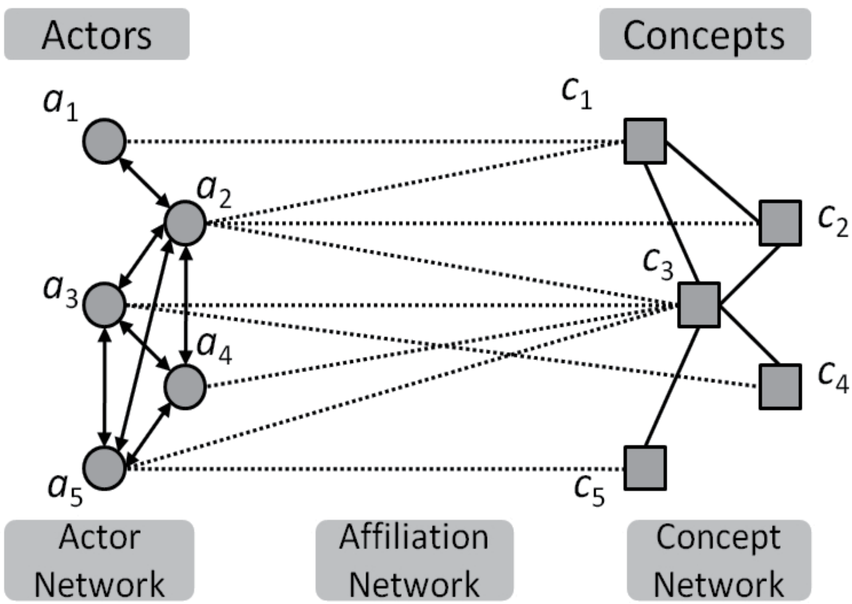

Figure 1. Discourses as Networks (Source: (6))

The sets of actors, concepts and edges change over time as actors enter or leave the discourse and change their respective problem interpretations. When one actor leaves the discourse, this reduces not only the set of actors but also the set of edges a) within the actor network by those edges that previously connected this actor to other actors, b) within the affiliation network by those edges that connected this actor to concepts, and c) within the concept network by those edges that connected the different concepts

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which had been used by this actor. When an actor leaves the discourse, that used to apply many different frames and to comment several policy measures, significant structural changes can be observed in all networks

4. Discourse networks on global warming in Germany

This study applies discourse network analysis to the German discourse on climate change, assessing key propositions of PE theory. The following section portrays the German case and explains data collection, analysis and interpretation of results.

4.1. Climate policy in Germany: The background

Previous studies concerned with climate change policy have discussed Germany as an extreme case because of its outstanding achievements in this policy area [49]. They found that public discourse has played an important role in this development. The dominant perception of climate change and climate policy has been considerably stable: climate change is perceived as a problem that requires state intervention, whereby climate protection also bears economic opportunities. This perception has become known as "ecologic modernization" paradigm. However, there are indications that the economic crisis might have threatened the “German consensus” and changed the dominant perception of the climate issue as suggested by PE theory. The financial crisis provides the opportunity to conduct such a natural experiment.

The issue of climate change entered the sphere of German public discourse and high politics for the first time during the mid-1980s [13]. In 1986, a press release of the German Physical Society (DPG) and its subgroup, the Working Group on Energy (AKE), depicted climate change as an “impending catastrophe” requiring immediate political action and initiated an extensive coverage of the climate change topic within the mass media. Initially, the political sphere remained skeptical, doubting the scientific soundness of these warnings. However, it could not ignore increasing public concern and call for action. After the Chernobyl catastrophe in April 1986, Chancellor Helmut Kohl swiftly established the Ministry of Environment (June 5, 1986). Shortly after that, in March 1987, he declared the climate issue to be one of the world’s most pressing environmental problems [13]. From this point on, Germany has emerged as a forerunner in domestic climate protection and as a pacemaker at the European as well as at the global level. A large range of policies for the reduction of greenhouse gas (GHG) emissions has been passed during the last two decades. Energy efficiency has been raised in all economic sectors [13]. By 2008 Germany had already reached its target of a 21% reduction by 2010 compared with 1990, and the recent government pursues a reduction target of 40% until 2020 [50].

Scholars have largely attributed this success to the broad public participation and the consensual style of German policy making. This style has been enhanced by the integration of the Green movement into political institutions during the late 1980s, by federalism and by the German electoral system of proportional representation [13, 49]. Scholars and policy makers have pointed out that public support for the German government's initiatives is strongly based on the public perception that policy interventions in the field of environmental policy do not weaken but strengthen economic growth. This perception has its seeds in experiences made during the 1980s when demanding and costly measures with respect to another environmental issue, air pollution, did not hamper economic growth, but instead enhanced employment, technological innovation and the modernization of industries. The public perception of "ecological modernization" as a win-win-strategy in solving environmental problems has proven to be very stable, despite of an attention decline with respect to climate issues during the 1990s. However, while the government and proponents of a strong global climate change policy have provided the public with considerable information about net benefits for the country as a whole, they have kept quiet about redistributional effects of current and planned domestic programs and international commitments [13]. They issue the concern that reliance on "ecological modernization", combined with some kind of "distributional opaqueness", might turn out to be a drawback to German consensus. Furthermore, the drive for consensus might backfire as soon as doubts enter the discourse with respect to the reliability of scientific findings on global warming [12]. This could threaten the legitimacy of political decisions based on scientific knowledge.

The issue of climate change passed through the issue-attention cycle for the first time in the second half of the 20th century [23]. Though it has never completely vanished from the public agenda, attention to climate change was relatively low during the second half of the 1990s. A new attention-cycle started at the beginning of the 21st century and reached its peak in 2007 when the IPCC published its Fourth Assessment Report. Since 2007, attention to the issue of climate change has been falling again. The financial crisis seems to have intensified this down-swing since it had more dramatic value and a higher degree of novelty than the issue of climate change [24]. Thus, when trade markets crashed in September 2008, this event drew media attention away from the climate problem, as predicted by the arena model of Hilgartner and Bosk [39]. The application of discourse network analysis on the German climate discourse within this study allows taking a closer look at actor constellations and frame configurations.

4.2. Data selection, coding, and network analysis

This study is based on newspaper articles published in the Frankfurter Allgemeine Zeitung (FAZ) and the Süddeutsche Zeitung (SZ) within the first quarter of the years 2007 to the first quarter of 2010 which treated climate change as a main topic. Both newspapers were chosen as data sources due to their prestigious status and high circulation rates (about 2 million copies each). Both are regarded as important reference media by other journalists and are read most frequently by the members of the German Parliament (Deutscher Bundestag). Hence, they can be assumed to have an influence on the society as a whole as well as on decision makers. Furthermore, both newspapers cover the main political spectrum of German politics. The FAZ has a rather conservative profile, while the SZ is considered to be more social-liberal.

The articles were selected from the online archives of both papers, including the complete news coverage for all days of appearance and all news sections. Within a two-step selection process "Klimaschutz*" (climate protection), "Klimawandel*" (climate change) and "Globale* Erwärmung*" (global warming) were identified as the most valid and effective choice of key words [24]. Articles that contained at least one of these keywords in the headline and/or lead paragraph were copied to the JAVA based software *Discourse Network Analyzer* (DNA) programmed by Philip Leifeld [8]. The data set was manually reviewed and articles that contained the keywords but were not really about meteorological climate change (e.g. "Klimawandel*" in the sense of working atmosphere) were excluded. Opinion columns were excluded as well because of low intracoding-reliability.

Statements were edited within DNA. The unit of analysis was a statement, a part of the text where an actor expresses his beliefs or solution concepts for a policy problem [8]. In this study we look at two kinds of concepts: frames and positions. A first step of coding considered only frames. Tags were assigned to each statement that coded the individual speaker, the organization that he or she was affiliated with and the frame that he or she used. Thereby an actor was defined as an identifiable speaker that is not only mentioned in the article, but is given the opportunity to express his opinion by means of direct or indirect quote. Only those statements were coded that could clearly be attributed to a specific actor – an individual person or an organization. If an actor gave his opinion with regard to a specific policy measure within a statement (i.e. rejection or support for a specific measure), the statement was edited a second time. This time, positions were coded instead of frames. A dummy variable indicating agreement or disagreement with regard to a position was recorded.

This study uses a typology of *frames* which was inductively developed on the basis of a random sample of 10% of all articles sampled for the first quarter of 2008 and 2009. The coding is based on methods and procedures developed by Gerhards and Schäfer [51]. In this way, different arguments of actors are grouped into interpretative patterns that are subject to several strategies of reduction. These in turn are assigned to several categories, following the idea that arguments and actors can be grouped according to the different rationalities of societal sub-systems. Applied to our subject, actors can use political, economic, scientific, ethical, ecological, and policy arguments. Our study thus assumes that with respect to viable policy responses it is important to differentiate whether political responsibility is attributed to the local, national, European or international level. Accordingly, political arguments are grouped into these four sub-categories (Table 1).

The next step of analysis refers to *positions* which are specific policy measures that an actor opposes or supports. The list of positions was inductively extended whenever an actor issued a policy measure not yet on the list. If a policy instrument was suggested several times but each time with respect to another sector (e.g. emission limits for the car industry or energy producers), these measures were categorized respectively.

From this data, several networks were generated with the help of *DNA* [8] and *UCINET 6* [52]. Analysis related to centrality positions and their visualizations were conducted with *visone*, a JAVA based software for the visualization and analysis of social networks [53-54].

Frame		Description
Cultural frames		
1	Individual lifestyle	Statements about practices of individual and community living, consumption patterns, private insurances covering for damages resulting from impacts of climate change, etc.
2	Popular culture	References to information campaigns aiming to raise public awareness of the issue of climate change, books, films, etc.
Ecological/meteorological frame		
References to ecological and meteorological impacts of climate change that are already observable, e.g. rising sea levels, melting ice, heat waves, issues of biodiversity etc.		
Economic frames		
1	Microeconomic considerations	Statements on business aspects of climate change, e.g. economic costs imposed on companies by climate change mitigation policies or business opportunities for companies arising from green technologies
2	Macroeconomic considerations	Considerations regarding national location attractiveness, competition between German and foreign companies, creation of jobs, or economic growth
Ethical and social frames		
1	Sharing responsibility between industrialized and developing world	Discussion on how much commitments industrialized countries can demand from developing countries or on whether they have to compensate poor countries for increased climate risks and damages
2	Moral feeling of responsibility to mitigate climate change	Moral feeling of obligation to mitigate climate change, e.g. in the sense of intergenerational responsibility
3	Financial burden imposed on population	Discussion on who should bear the cost of climate change mitigation measures – i.e. the state, major polluters or the population – and what cost the population can be expected to pay for climate change mitigation
4	Social impacts of climate change	Considerations regarding social impacts such as migration and civil commotions
Politics and policy frames		
Debates on (potential) climate change mitigation or adaptation measures and on responsibilities of different actors in the policy arena		
1	Local level	Local governments take action/are called into account
2	National level	National governments take action/are called into account
3	European level	European institutions take action/are called into account
4	International level	International government actors take action/are called into account
Scientific frames		
1	Causes of climate change	Ideas or beliefs about the geophysical causes of climate change (e.g. the role of human-produced greenhouse gases)
2	Consequences of climate change	Predictions on the ecological consequences of climate change, e.g. changes in Atlantic circulation
3	Effects of climate change mitigation measures	Discussions on the potential effectiveness of mitigation measures and on whether anthropogenic climate change can still be maintained at a non-critical level at all

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Frame		Description
4	Technology and applied science	Statements on new technologies (developed by scientists of research institutes and private companies) and applied science that may be employed to mitigate or adapt to climate change
5	Validity of scientific data and methods	Discussion on the proceedings of scientific research and the soundness of scientific pronouncements

Table 1. Frames

4.3. Discourse network analysis: Findings and interpretations

Our analysis is based on a structural content analysis of 774 articles and 1459 statements. Table 2 gives an overview on how many articles were published on the issue of climate change during the first quarters of the years 2007 to 2010 within the FAZ and SZ. It also displays the dimensions of the discourse networks within the respective quarters, the number of statements, organizations and positions. These numbers may also be influenced and biased by global policy developments, since the first quarter of 2007 was marked by the release of the IPCC Fourth Assessment Report, while possible important events like the UN Climate Conferences Copenhagen took place during quarters of the other years that are not included in the data. Table 2 shows that the discourse networks strongly vary between the different years with respect to actor participation and conceptual affiliation. This has to be kept in mind when we interpret the following findings.

	Articles	Statements	Actors	Position Categories	Positions	Positions/ Statements
2007 Q1	380	774	194	40	268	0,35
2008 Q1	187	303	110	20	59	0,19
2009 Q1	112	206	87	13	39	0,19
2010 Q1	95	176	78	14	44	0,25
Sum	774	1459	469	87	410	0,28

Table 2. Media Coverage of the Climate Issue (FAZ and SZ), First Quarters 2007-2010

In Figure 2 the evolution of media attention is depicted in the context of the main economic indicators. It shows that the economic downturn started in September 2008 with a plunge at the stock exchange and reached the real economy in 2009. As recovery was quick, at least in Germany the crisis was over in the beginning of 2010.

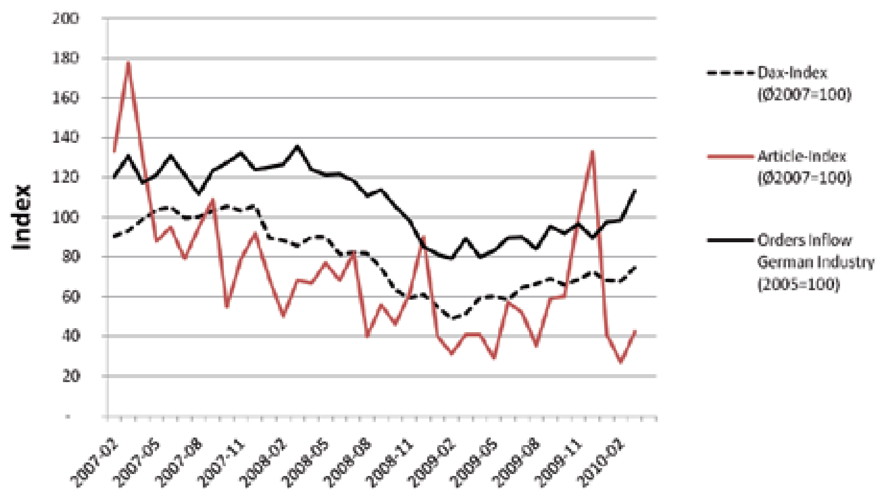

Figure 2. Articles on Climate Change and Economic Indicators

4.4. Changing actor constellations and frame configurations

A first step of analysis relates to possible changes in actor constellations due to the economic crisis. In this respect we are interested, firstly, in the overall actor dynamics in the field of discourse, and secondly in the relative standing of the various actors and significant changes in these positions. Figures 3 and 4, and table 3 give an overview on the dynamics. Figure 3 depicts data on entry, exit, and discourse continuation during the four years. The overall picture suggests a dynamic and pluralist policy arena in which many new actors are entering and constellations are changing.

2007	2008	2009	2010	Freq.	Sum
1	1	1	1	12	
1	1	1	0	15	
1	1	0	1	6	
1	1	0	0	16	
1	0	1	1	6	192
1	0	1	0	14	
1	0	0	1	7	
1	0	0	0	116	
0	1	1	1	1	
0	1	1	0	7	
0	1	0	1	2	61
0	1	0	0	51	
0	0	1	1	2	
0	0	1	0	29	31
0	0	0	1	41	41
					325

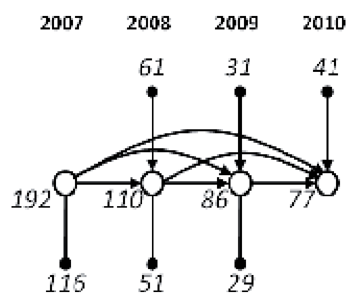

Figure 3. Participation Profiles

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	# of statements				Participation Profiles				Normalized statements			
Name	**2007**	**2008**	**2009**	**2010**	**2007**	**2008**	**2009**	**2010**	**2007**	**2008**	**2009**	**2010**
Federal Ministry for the Environment (BMU)	76	18	4	10	1	1	1	1	9,82	5,94	1,95	5,81
Federal Environmental Agency	6	6	3	9	1	1	1	1	0,78	1,98	1,46	5,23
International Panel of Climate Change (IPCC)	22	4	6	5	1	1	1	1	2,84	1,32	2,93	2,91
Potsdam Institute for Climate Impact Research (PIK)	10	7	2	5	1	1	1	1	1,29	2,31	0,98	2,91
US Government	17	3	7	3	1	1	1	1	2,20	0,99	3,41	1,74
United Nations (UN)	7	1	2	3	1	1	1	1	0,90	0,33	0,98	1,74
Greenpeace	15	2	1	2	1	1	1	1	1,94	0,66	0,49	1,16
Small or medium-sized businesses	9	1	1	2	1	1	1	1	1,16	0,33	0,49	1,16
European Commission, DG Environment	29	4	10	1	1	1	1	1	3,75	1,32	4,88	0,58
Christian Democratic Party (CDU)	24	1	4	1	1	1	1	1	3,10	0,33	1,95	0,58
Green Party (Buendnis 90/Die Gruenen)	17	6	6	1	1	1	1	1	2,20	1,98	2,93	0,58
Oeko-Institut	1	2	2	1	1	1	1	1	0,13	0,66	0,98	0,58
Munich Re	7	0	6	8	1	0	1	1	0,90	-	2,93	4,65
Federal Ministry of Finance (BMF)	4	0	1	6	1	0	1	1	0,52	-	0,49	3,49
Chinese Government	6	0	1	5	1	0	1	1	0,78	-	0,49	2,91
Federation of German Consumer Organizations (vzbv)	3	3	0	5	1	1	0	1	0,39	0,99	-	2,91
UN Framework Convention on Climate Change (UNFCCC)	9	0	2	4	1	0	1	1	1,16	-	0,98	2,33
World Wildlife Fund (WWF)	9	5	0	3	1	1	0	1	1,16	1,65	-	1,74
US Democrats	2	0	1	3	1	0	1	1	0,26	-	0,49	1,74
US Environmental Protection Agency (EPA)	0	1	2	3	0	1	1	1	-	0,33	0,98	1,74
French Government	7	1	0	2	1	1	0	1	0,90	0,33	-	1,16
European Parliament (EP)	6	2	0	1	1	1	0	1	0,78	0,66	-	0,58
Danish Government	2	0	2	1	1	0	1	1	0,26	-	0,98	0,58
EP, Progressive Alliance of Socialists and Democrates (S&D)	2	1	0	1	1	1	0	1	0,26	0,33	-	0,58
German Chancellor	1	1	0	1	1	1	0	1	0,13	0,33	-	0,58

Table 3. Top 25-Actor's Statements

Table 3 lists the standings of the 25 top policy actors that participated in at least three years up to spring 2010. In order to control for variation in discursive activities, we normalized their figures with respect to the yearly total numbers and depicted them as percentages. Figure 4 correlates the four columns of the table (activity profiles) and shows interesting results. While the correlation between the actors' standings between 2007 and 2008 is rather high, the correlations dropped to .47 and .39 in the following years during the economic crisis. The pre-crisis actor configurations differ greatly from within- and post-crisis constellations.

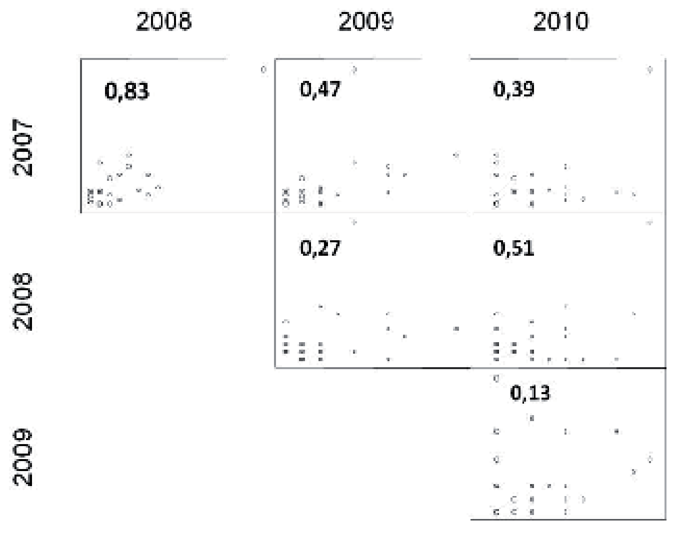

Figure 4. Correlation of 25 Top-Actor's Participation Profiles

A further key question is how the economic crisis affected frame configurations. If Maslow's hierarchy of needs also applies to policy discourse we can assume that economic frames gain importance and possibly crowed out non-economic frames. Figures 5-7 can give a partial answer to that question. They show which organization is utilizing certain frames within the discourse on climate change during the respective quarters. The thickness of links between actors and frames corresponds to the frequency that an actor uses the respective frame. The size and arrangement of frames indicate indegree centrality of frames which equals the relative frequency that a frame is cited by all actors. Thus, the frame with the biggest node area and the most central position within the circular arrangement is used the most often within the respective time period.

Between 2007 and 2009, shifts in the frame constellation can be observed from year to year. Each year, another frame occupies the most central position within the discourse. Thereby, the first quarter of 2009 differs from the other periods of observation in two respects: Firstly, while a politics and policy frame dominates the discourse in all other quarters, the macroeconomic frame is the most central one in the first quarter of 2009. Secondly, while the discourse is evolving around few frames in 2007, 2008 and 2010, it is characterized by a much

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more heterogeneous frames distribution in 2009. The first observation seems to support the proposition that the financial crisis had a direct impact on the individual perception of climate change in so far that it highlights economic aspects of the problem. But, taking into consideration the low degree of overall centralization, the domination of the macroeconomic frame in 2009 is not very strong. It is only short-lived. In addition, this frame is mainly connected to actors from the business sector or foreign political actors, but less to domestic political actors who largely use the national policy frame in 2009. In all other years, the macroeconomic frame is used by a more heterogeneous set of actors. Over all time periods the macroeconomic frame has the most stable position and is always among the three most central frames. Its shift to the center in 2009 is a result of the overall fragmentation of the discourse. In the other years, as the thickness of links shows, governmental actors push forward the respective central frame. In 2007, the Federal Ministry for Environment, Natural Conservation and Nuclear Safety (BMU) promotes the national policy and politics frame, in 2008, the DG Environment of the European Commission pushes forward the European policy and politics frame and in 2010, different federal ministries promote the two politics and policy frames at the center. Such a strong political commitment is lacking in 2009.

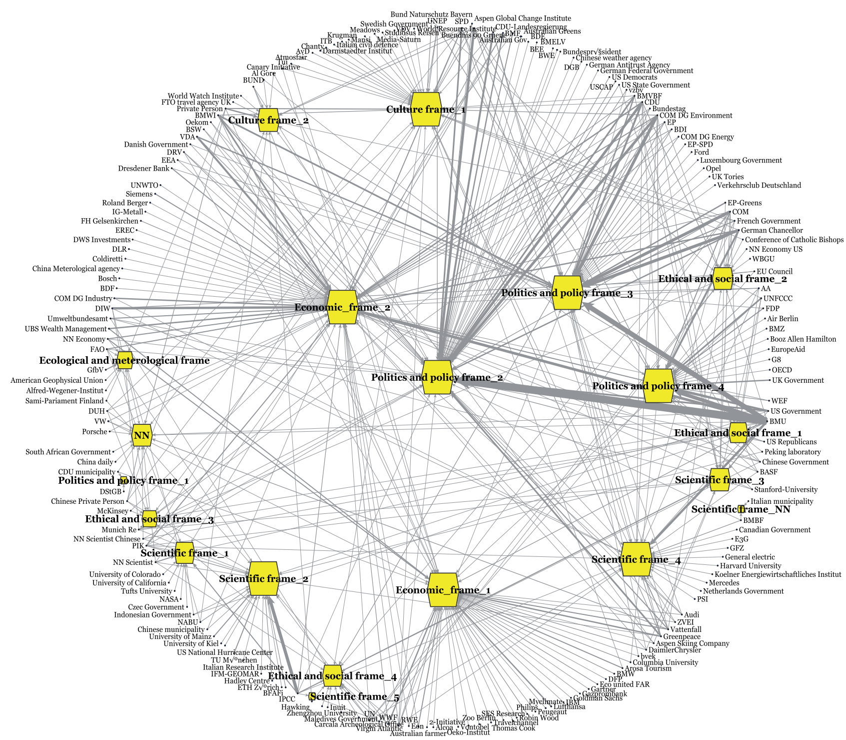

Figure 5. Affiliation Network Organizations-Frames 2007

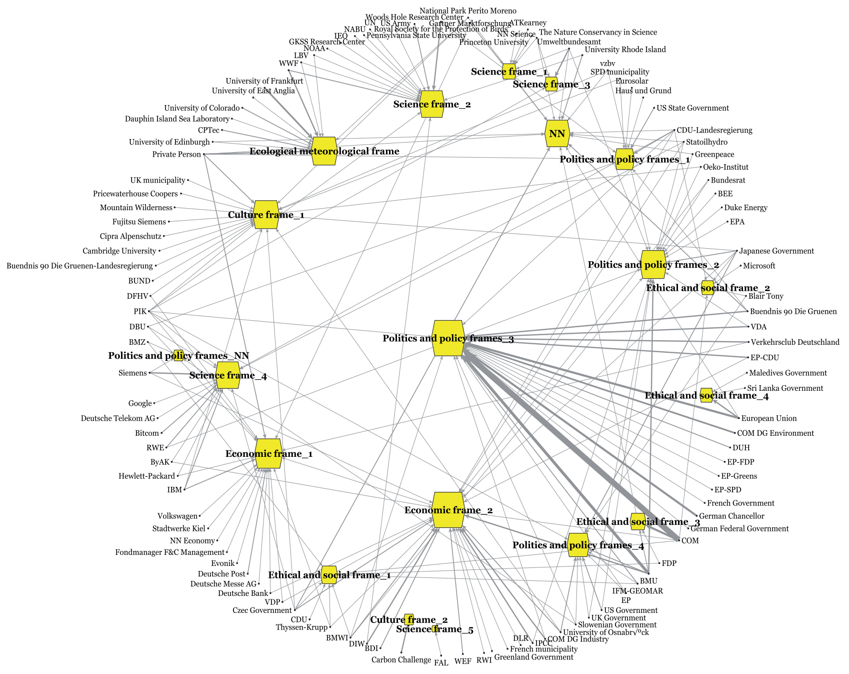

Figure 6. Affiliation Network Organizations-Frames 2008

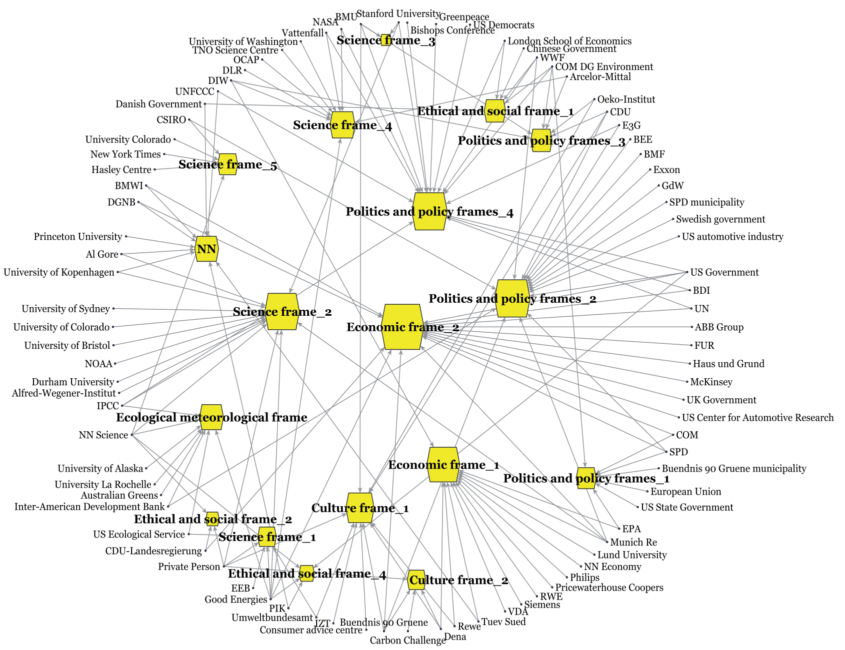

Figure 7. Affiliation Network Organizations-Frames 2009

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A further step is the depiction of various organizations and their policy positions. Figures 8 and 9 show which actors have a position towards policy measures and whether they support (light links) or oppose (dark, dashed links) the relative measure or are undecided (dark continuous line). The size of the nodes reflects *indegree centrality* of the respective policy proposition which equals the relative frequency that a proposition is commented.

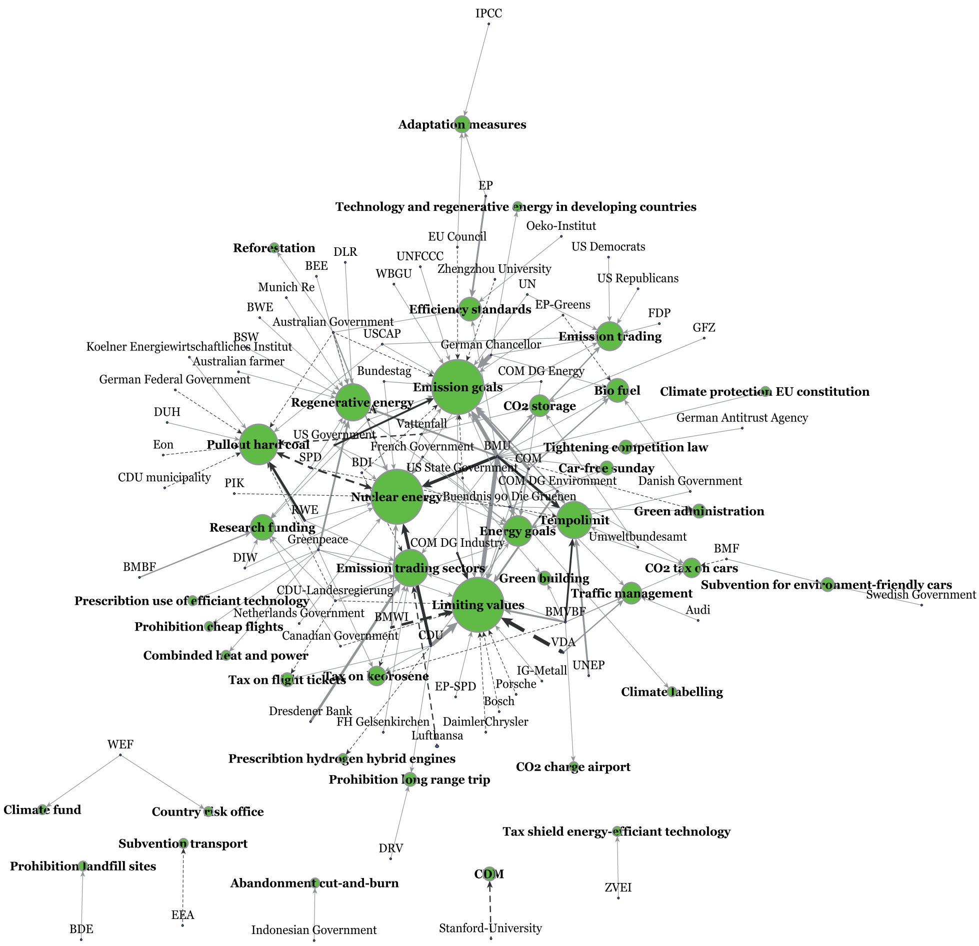

Figure 8. Affiliation Network Organizations-Positions 2007

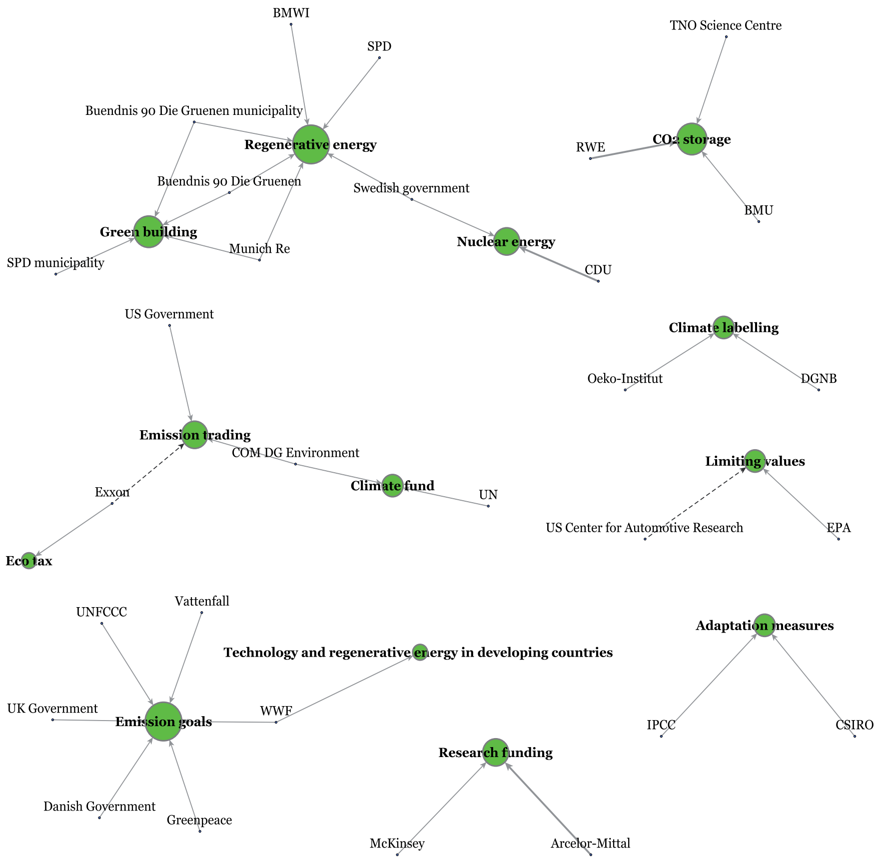

Figure 9. Affiliation Network Organizations-Positions 2009

Only in 2007 and 2008 there is a controversial debate on policy measures. Again, few governmental actors – especially the Federal Ministry of Environment (BMU) – hereby take a central position. The networks are decomposed into several components in 2009 and 2010. We can see that there is a consensus on the promotion of regenerative energy. It might be that - as political conflicts on how to tackle the financial crisis intensified - actors became less inclined to settle political conflicts in the area of climate policy.

With respect to frame analysis, Figure 10 shows the co-occurrence of frames in 2008. The width and darkness of links visualizes the strength of interconnection in terms of how many organizations use both interconnected frames.

Comparing the connections between frames within the different periods of observation, it can be stated that the macroeconomic frame is the frame, which is best connected to other frames, especially in 2008. The connection between the macroeconomic frame and the national politics and policy frame is especially strong in all years. Apart from that, the macroeconomic frame is always strongly connected to the relative dominating frame, which could explain the success of the "ecological modernization" paradigm. The financial crisis does not

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reduce the interconnectedness of the macroeconomic frame. The actors who hold up this interconnection are the insurance company Munich Re, the green party (Bündnis 90/Die Grünen) and the social democratic party (SPD). It seems that advocates of strong climate protection in the light of the financial crisis adopt economic frames to link the climate issue to the crisis and mobilize against the decline of attention to climate change.

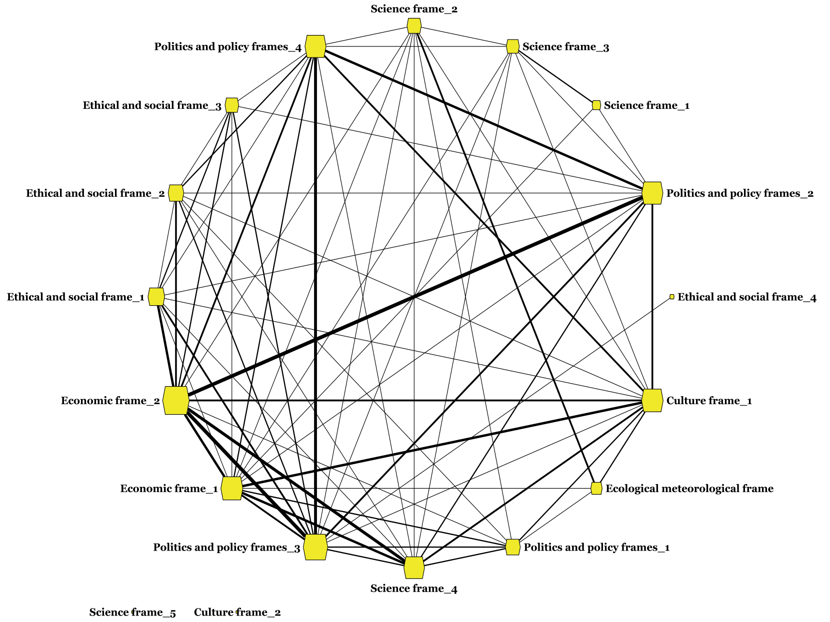

Figure 10. Co-occurrence Network Frames 2008

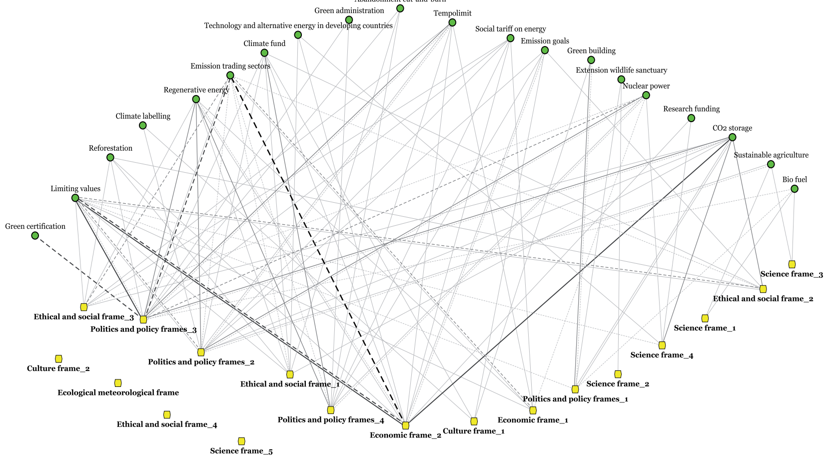

Figure 11. Affiliation-Network Frames-Positions 2008

A further analytical step refers to the frame-position network. In this respect, Figure 11 shows the co-occurrences of and conflicts between frames and positions in 2008. The width and darkness of links correspond to the number of actors that use the frame and the position that the relative link connects in the same way (continuous link) or in opposing ways (dashed link). The network is quite dense; it is not possible to infer the position from the frame or the other way round. The same observation can be made during the other periods of observation. This finding supports the proposition that the linkage between problems and solutions at the collective level is not straight forward [45].

5. Conclusion

While previous studies have often examined climate discourses from a perspective of functional social sub-systems and have conceptualized discourses primarily as a means to overcome difficulties of risk communication, this study conceptualized discourses as an essential part of modern policy making which is characterized by high interdependence and connectedness between societal subsystems. This perspective shifts the focus from differences in communication to the mobilization of actors within an integrative policy process. Public action is not primarily constrained by difficulties of communication on different problem perceptions and policy preferences, but by the limited capacity of actors to process many problems at once. Furthermore, different actors pursue different individual interests and strategically use public discourses to influence the structure of participation within a policy-subsystem. Punctuated Equilibrium Theory suggests that a big focal event may attract high public attention and thereby provides an opportunity to change the public perception of a policy issue and to restructure the policy arena.

Our paper has shown that the financial crisis amplified the decrease of public attention to the issue of climate change in Germany. Analyzing the media discourse on climate change between 2007 and 2010 by means of network analysis we show that actors are strongly involved in cross-sectoral communication and that specific policy positions cannot be directly derived from perceptions of climate change. This may facilitate co-operation in managing global warming across societal subsystems. Our analysis also demonstrates that a sincere debate on different policy measures is only possible when specific governmental actors claim political responsibility. In the aftermath of the financial crisis, when issue attention towards climate change declined, political commitment weakened as well, and the discourse became more fragmented. This fragmentation of the public discourse may impede policy innovation and hinder the management of climate change, especially if it is reflected in the subsystem specific discourse. However, the principle of "economic modernization" associated with the success of past German climate policy seems to have sustained after the financial crisis.

So far little is known about the relation of general public discourses and sub-system and policy specific discourses. Further research is necessary to gain a better understanding of how policy making is shaped by discourses at various levels and subsystems. Therefore, dis-

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course network analysis proves to be a promising tool to grasp the complexity of discourse dynamics which are influenced by structural constraints as well as by strategic actor behavior. Other than qualitative frame analyses, it links actor and frame constellations in a specific and transparent way. This allows for case sensitive modeling but also for replicability and comparability.

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Chapter 7

What Are the Roles of National and International Institutions to Overcome Barriers in Diffusing Clean Energy Technologies in Asia?: Matching Barriers in Technology Diffusion with the Roles of Institutions

Masachika Suzuki

Additional information is available at the end of the chapter

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1. Introduction

While the international negotiation on climate change does not make much progress in designing the post-Kyoto scheme, technology innovation and transfer is becoming a central issue in the negotiation. In Cancun in 2010, the parties agreed to organize the Technology Executive Committee (TEC) and the Climate Technology Centre and Network (CTCN) (UNFCCC 2011). The developed countries have committed to provide $100 billion yearly to assist the developing countries in mitigation and adaptation through the Green Climate Fund (UNFCCC 2011).[1] The scheme of the Fund is currently under discussion at the Transitional Committee for the design of the Green Climate Fund.

This paper consists of two parts. The first part of the paper attempts to show a broad landscape of barriers in technology diffusion in the developing countries by addressing two levels of barriers. The first level is about the barriers that are commonly observed among the developing countries (Section 2.1). The paper classifies these barriers into technological, financial and institutional barriers. The second level is about the barriers that are technology-specific (Section 2.2 and 2.3). Section 2.3 summaries the results of previous case studies that were

1 The text of the COP document states that [The Conference of the Parties] recognizes that developed country Parties commit, in the context of meaningful mitigation actions and transparency on implementation, to a goal of mobilizing jointly USD 100 billion per year by 2020 to address the needs of developing countries (paragraph 98); agrees that, in accordance with paragraph 1(e) of the Bali Action Plan, funds provided to developing country Parties may come from a wide variety of sources, public and private, bilateral and multilateral, including alternative sources (paragraph 99); and decides that a significant share of new multilateral funding for adaptation should flow through the Green Climate Fund (paragraph 100).

conducted to uncover technology-specific barriers in diffusing clean energy technologies in Asia. These case studies include both technologies for industrial use such as wind, bio-energy and building energy efficiency and technologies for individual use such as LED (Light Emitting Diode) and Photovoltaic (PV) panels. It also contains technologies at the innovation stage such as Integrated Gasification Combined Cycle (IGCC) and Carbon Capture and Storage (CCS). Section 2.3 presents an analysis of the barriers through a comparison of the results of the case studies.

The second part of the paper explores roles of institutions to overcome identified barriers in diffusing clear energy technologies in Asia (Section 3). It addresses theoretical discussions on functions (or roles) of international and national institutions in technology innovation. It then attempts to match the barriers in technology diffusion identified in Section 2 with the functions of national and international institutions. The results of matching indicate that there are important roles of institutions both at the early and advanced stages of technological development to encourage R&D cooperation from the public site (early stage) and enhance the enabling environment and facilitate finance for the technologies (advanced stage).

2. Studies on barriers in technology diffusion in the developing countries

Understanding barriers in technology diffusion lead to important lessons in designing policy instruments and institutions for diffusing clean energy technologies in the developing countries. With this understanding, researching about barriers has been part of the tasks under the UNFCCC as well as United Nations Environmental Program (UNEP) (UNFCCC 2011; UNEP Risø Centre on Energy, Climate and Sustainable Development 2011). Painuly indicates that there are several levels to explore and analyze such barriers. Painuly adds that the first level is a broad category of barriers and the lower levels include more detail and specific barriers (Painuly 2001). Section 2.1 illustrates barriers at the first level. Section 2.2 lists case studies that address barriers at a lower level that are more technology specific. Section 2.3 presents an analysis of the barriers through a comparison of the results of the case studies.

2.1. Barriers commonly observed among the developing countries

The barriers at the first level are the barriers that are commonly observed among the developing countries. There are substantial amounts of research projects that have attempted to identify the barriers at this level including Painuly (2001), OECD/IEA (2001), Painuly and Fenhann (2002) and Raddy and Painuly (2004). Table 1 summaries key barriers identified through these and other research. The barriers are classified into technological, financial and institutional barriers[2,3]:

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2 It is not possible to clearly distinguish barriers into the three classifications. Many barriers relate to more than two classifications. Under the circumstances, the paper attempts to fit each barrier into the most appropriate classification.

3Table 1 includes some technology-specific barriers as well as country/region-specific barriers. It is also noted that the table contains selected major barriers only.

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Barriers	Barriers	Explanations	Source(s)
Technological	Limited capacity to assess, adopt, adapt and absorb technological options	• These technologies are primarily targeted at rural areas or poor customers, who have limited capacity to absorb these technologies. There is a general resistance to change, which is magnified due to lack of capacity to understand, adopt and adapt the technologies for greater benefit. The capacity constrains are not only linked to its use but in its production. There is limited manufacturing capacity and as a result not much innovation has taken place. Scale-up of manufacturing and therby reduction in the associated costs has not taken place. (Ravindranath and Balachandra pp.1010) • Technology not freely available in the market, technology developer not willing to transfer technology, problems in import of technology/ equipment due to restrictive policies/taxes etc. (Painuly pp.82)	(Ravindranath and Balachandra 2009) (Painuly 2001)
	Lack of knowledge of technology operation and management	• Lack of knowledge of technology operation and management as well as limited availability of spare parts and maintenance expertise (Doukas et al p.1139)	(Doukas et al 2009) (Luken and Rompaey 2008) (OECD/IEA 2001)
	Lack of skilled personnel/training facilities	• This can be a constraint for producers (Painuly p.80) • Lack of experts to train, lack of training facilities, inadequate efforts. (Painuly pp.83) • In China and much of South East Asia, there is a need for technically trained people and people with strong management skills. Where training of local workforce is provided, it should be recognized that Asians tend to learn more effectively by coping, rather than as individuals, when local language is used and with a practical "hands-on" approach. Also the issue of training in intellectual property rights is important. This is a long term issue but will be important for long term changes in attitudes to intellectual property rights in China. (Guerin pp.71)	(Painuly 2001) (Usha and Ravindranath 2002) (Jagadeesh 2000) (IPCC 2000) (Guerin 2001) (Worrell et al. 2001) (Flamos et al. 2008) (OECD/IEA 2001)
Technological	Lack of standard and codes and certification	• Product quality and product acceptability is affected. (Painuly pp.80) • Lack of institution/initiative to fix standards, lack of capacity, lack of facilities for testing/certification. (Painuly pp.83) • A degree of standardization would improve the penetration of photovoltaics (PVs), it would enable PVs to become more user friendly. (Oliver and Jackson pp.381) • Lack of standardization in system components resulting from the wide range in design features and technical standards, and absence of long-term policy instruments have resulted in manufacturing, servicing and maintenance difficulties of wind turbines. (Jagadeesh pp. 162)	(Painuly 2001) (Oliver and Jackson 1999) (IPCC 2000) (Joanna 2007) (Jagadeesh 2000) (OECD/IEA 2001) (Oltz and Beerepoot 2010)
Financial	Lack of access to financing	• High first costs and investments associated with mass manufacturing remain as barriers. Both the users and the manufactures have very low capital. This problem is further	(Ravindranath and Balachandra 2009) (Painuly 2001)

Barriers	Barriers	Explanations	Source(s)
		accentuated by the rigid lending procedures that limited access to financing even when financing is available on standard norms. (Ravindranath and Balachandra pp.1010) • Capital costs may go up due to increased risk perception. Adverse effect on competition and efficiency. (Painuly pp.79) • Small and medium scale enterprises (SMEs) above all lack the finances for cleaner technologies, but also contact with larger technology manufacturers and formal information channels. (UNFCCC 2003, p.12) • Limited capital availability will lead to high hurdle rates for energy efficiency investments because capital is used for competing investment priorities…High inflation rates in developing countries and CEITs, lack of suffcient infrastructure increase the risks for domestic and foreign investors and limit the availability of capital (Worrell et al 2001, pp.6-7) • International public finance is no longer going into energy (electricity) infrastructure, which is now seen as of interest to the private sector under the neo-liberal or privatization agenda (Thorne, p.3)	(UNFCCC 2003) (Worell et al. 2001) (Jagadeesh 2000) (IPCC 2000)(Thorne 2008)
Financial	Potential lack of commercial viability	• In general, technology imported from industrialized countries is more efficient but also more expensive than technology manufactured locally, and it therefore requires higher initial investment costs. This is of particular importance for the transfer of environmentally sound technologies. Furthermore, as a result of their typically early commercialization stage, environmentally sound technologies are often considered riskier than existing commercial technologies (Karakosta et al., p.1551)	(Karakosta et al, 2010)
	Lack of financial institutions to support renewable energy technologies, lack of instruments	• Adverse effect on competition and efficiency. (Painuly pp.79) • Under-developed capital markets, restricted entry to capital markets, instruments unfavorable regulations. (Painuly pp.83)	(Painuly 2001) (Jagadeesh 2000)
Institutional	Uncertain governmental policies	• Many of the renewable energy technologies in India are still in the development stage. There are no sufficient governmental regulations/ incentives to stimulate the adoption of renewable energy technologies by business and industries. They include: (a) lack of explicit national policy for renewable energy at end-use level; (b) incomplete transition to cost-based electric tariffs for most residential and some industrial customers; (c) poor availability of credit to the purchase of renewable energy technologies in the economy; and (d) lack of application of modern management skills in energy development agencies. (Reddy and Painuly pp.1436)	(Redd and Painuly 2004) (Painuly 2001) (Worell et al. 2001) (Schneider and Hoffman 2008) (Doukas et al. 2009) (Karakosta et al. 2010) (OECD/IEA 2001)

Barriers	Barriers	Explanations	Source(s)
		• It creates uncertainty and results in lack of confidence. May also increase cost of project. (Painuly pp.80) • Uncertainty in policies, un-supportive policies, inadequately equipped governmental agency, red tape, lack of governmental faith in RETs, lack of policies to integrate renewable energy technologies products with the global market, inadequately equipped governmental agency to handle the product.(Painuly pp.84) • National trade and investment policies may limit the inflow of foreign capital. This might be a barrier to technology transfer (Worrell et al. 2001, p.7) • Uncertain ownership, lack of intellectual property-rights protection and unclear arbitration procedures. (OECD/IEA p.14)	
Institutional	Lack of infrastructure	• Problems related to availability of infrastructure such as roads, connectivity to grid, communications, other logistics. (Painuly pp.84) • The places where energy infrastructure has not yet been extended to are, by-and-large, areas where people are poor and unlikely to be able to cover the costs of infrastructure, nor would the users be able to consume sufficient service to make the investment financially feasible alone. Perversely, these are the development niches where many of the immature environmentally sound technologies may already provide least energy cost options. (Thorne pp.3-4)	(Painuly 2001) (Thorne 2008)
	Lack of information and awareness	• It increases uncertainty, and hence costs. (Painuly pp.79) • Lack/low level of awareness, inadequate information on product, technology, costs, benefits & potential of the renewable energy technologies, O&M costs, financing sources etc. Lack of agencies, or agencies ill equipped to provide information. Also, feedback mechanism may be missing or inadequate. Lack of knowledge/access to renewable energy technologies resource assessment data, implementation requirements. (Painuly pp.82) • It is generally believed that the adoption of renewable energy technologies are often not undertaken as a result of lack of information or knowledge on the part of the customer, or a lack of confidence in obtaining reliable information. Households and small firms and commercial establishments face difficulties in obtaining information on renewable energy technologies compared to the simplicity of buying conventional energy technologies. There is hardly any knowledge (software and/or hardware) about renewable energy technologies that is readily available and easily accessible for the consumers. Under these circumstances, information collection and processing consume time and resources which is difficult for small firms and individual households. (Reddy and Painuly pp.1435)	(Kathuria 2002) (IPCC 2000) (Painuly 2001) (Reddy and Painuly 2004) (UNFCCC 2003) (Worrell et al. 2001) (Flamos et al. 2008) (Karakosta et al. 2010) (Luken and Rompaey 2008) (OECD/IEA 2001)

Barriers	Barriers	Explanations	Source(s)
Institutional	Lack of consumer acceptance	• Adoption of renewable energy technologies are generally influenced by consumer perceptions of the quality and usefulness of these items when compared to conventional technologies. Renewable energy technologies are often perceived to be used with discomfort or sacrifice rather than as providing equivalent services with less energy and cost. Also, while purchasing a technology, consumers take the advice of their friends rather than obtaining information from the experts and take decisions which may not be economically rationale. (Reddy and Painuly pp.1436-1437) • Unknown product, aesthetic considerations, products lacks appeal, resistance to change, cultural reasons, high discount rates of consumers, inadequate information. (Painuly pp.84) • Many potential users of sustainable energy technologies have no or little experience with their application and the assistance provided in the development of such technologies is insufficient. Moreover, dissemination of EU experience sustainable energy technology implementation to other countries in the world has been limited (Flamos, p.5)	(Reddy and Painuly 2004) (Painuly 2001) (Flamos et al. 2008)

Table 1. Barriers (technological, financial and institutional) observed among the developing countries

Technological barriers include not only limited access to the international technology market but also limited capacity to assess, adopt, adapt and absorb technological options (Ravindranath and Balachandra 2009; Painuly 2001). As the table indicates, lack of knowledge of technology operation and management as well as lack of skilled personnel/training facilities can be a major barrier for successful diffusion of clean energy technologies (Doukas et al. 2009; Luken and Rompaey 2008; Painuly 2001; Usha and Ravindranath 2002; Jagadeesh 2000; IPCC 2000; Guerin 2001; Worrell et al. 2001; Flamos et al. 2008; OECD and IEA 2001). Lack of standard and codes and certification can be a barrier too since product quality and product acceptability is affected (Painuly 2001).

A lack of financing is a major part of the financial barriers (Ravindranath and Balachandra 2009; Painuly 2001; UNFCCC 2003; Worell et al. 2001; Jagadeesh 2000; IPCC 2000; Thorne 2008). Ravindranath and Balachandra (2009) states that "high first costs and investments associated with mass manufacturing remain as barriers. Both the users and the manufactures have very low capital. This problem is further accentuated by the rigid lending procedures that limited access to financing even when financing is available on standard norms." At this point, Karakosta et al. (2010) further elaborates that "in general, technology imported from industrialized countries is more efficient but also more expensive than technology manufactured locally, and it therefore requires higher initial investment costs. This is of particular importance for the transfer of environmentally sound technologies." Lack of financial institutions to support renewable energy technologies as well as lack of financial instruments is also highlighted as part of the financial barriers (Painuly 2001; Jagadeesh 2000).

Institutional barriers include lack of explicit forms of institutions such as goals, policies, regulations and incentive programs as well as lack of implicit form of institutions such as information, awareness, social acceptance, and conditions of the surrounding environment. As for explicit forms of institutions, Painuly (2001) points out uncertainty in policies, unsupportive policies, inadequately equipped governmental agency, red tape, lack of governmental faith in renewable energy technologies, lack of policies to integrate renewable energy technologies products with the global market, inadequately equipped governmental agency to handle the product. Lack of infrastructure is another aspect of institutional barriers, pointed out by Painuly (2001), that is, problems related to availability of infrastructure such as roads, connectivity to grid, communications, and other logistics. As for implicit form of institutions, Painuly (2001) points out lack/low level of awareness, inadequate information on product, technology, costs, benefits and potential of the renewable energy technologies, O&M costs, financing sources. Flamos et al. (2008) addresses lack of customer acceptance as an institutional barrier. It points out that "many potential users of sustainable energy technologies have no or little experience with their application and the assistance provided in the development of such technologies is insufficient" (Flamos et al. 2008).

Section 2.1 addressed barriers that are commonly observed among the developing countries. Section 2.2 illustrates case studies addressing technology-specific barriers.

2.2. Case studies addressing technology-specific barriers

There are a number of research initiatives that have attempted to identify barriers through the case study approach. The advantage of the case study approach is that it helps to uncover technology-specific barriers, while other studies looking at the developing countries or clean energy as a whole may overlook these barriers. Table 2 lists the case studies that are reviewed in this paper[4]:

	Research organization/individuals	Information on each case study		Sources
		Country	Technology	
Case study 1	SPRU (Science and Technology Policy Research) at University of Sussex and TERI in India	India	Wind power	Ockwell, D., J. Watson et al. (2009)
Case study 2	SPRU at University of Sussex and TERI in India	India	Integrated Gasification Combined Cycle (IGCC)	A: Ockwell, D., J. Watson et al. (2007) B: Ockwell, D., J. Watson et al. (2009)

4 This paper looks into key case studies in Asia only, although there are case studies being conducted in other parts including South America and Africa.

	Research organization/individuals	Information on each case study		Sources
		Country	Technology	
Case study 3	SPRU at University of Sussex and TERI in India	India	LED (Light Emitting Diode)	Ockwell, D., J. Watson et al. (2007)
Case study 4	SPRU at University of Sussex and TERI in India	India	Biomass	Ockwell, D., J. Watson et al. (2007)
Case study 5	SPRU at University of Sussex and TERI in India	India	Hybrid vehicles	A: Ockwell, D., J. Watson et al. (2007) B: Ockwell, D., J. Watson et al. (2009)
Case study 6	SPRU at University of Sussex and TERI in India	India	Photovoltaic (PV) panels	Ockwell, D., J. Watson et al. (2009)
Case study 7	International Institute for Industrial Environmental Economics (IIIEE) at Lund University	Developing countries	Carbon Capture and Storage (CCS)	Dalhammar, C. et al. (2009)
Case study 8	IIIEE at Lund University	Developing countries	Building energy Efficiency	Dalhammar, C. et al. (2009)
Case study 9	United Nations Department of Economic and Social Affairs (DESA)	China	Wind power	United Nations, DESA
Case study 10	Lewis J.	India and China	Wind power	A:Lewis, J., (2007a) B:Lewis, J., (2007b)
Case study 11	Mizuno E. (on a publication by UNEP Risø Centre on Energy, Climate and Sustainable Development)	India	Wind power	Mizuno. (2011)
Case study 12	(Ravindranath and Rao on a publication by UNEP Risø Centre on Energy, Climate and Sustainable Development)	India	Bioenergy	Ravindranath and Rao (2011)
Case study 13	Suzuki, M., Okazaki B., and Jain K.	Thailand	Biogas	A: Suzuki, M., Okazaki B., and Jain K. (2010) B: Jain K., Okazaki B., Suzuki, M. (2011)

Table 2. List of case studies reviewed in this paper

The Science and Technology Policy Research (SPRU) at University of Sussex and TERI in India jointly conducted a research project looking into barriers through several case studies in India including wind power, IGCC (Integrated Gasification Combined Cycle), LED (Light Emitting

Diode), biomass, hybrid vehicles and photovoltaic (PV) panels (Case Study 1-6) (Ockwell, D., J. Watson et al. 2007; Ockwell, D., J. Watson et al. 2009). This is the most comprehensive research project thus far looking into barriers through the case study approach. The IIIEE at Lund University in Sweden conducted several case studies including Carbon Capture and Storage (CCS) and building energy efficiency (Case Study 7 and 8) (Dalhammar, C. et al. 2009). In addition, there are a number of case studies that are conducted on the individual basis (Case Study 9-13).

It is observed that many of these case studies are conducted in China and India. This is probably relating to the fact that these two countries have the largest potentials in diffusing clean energy technologies among the developing countries. Another point to note among these case studies is that two popular targets for a case study are wind power and bio-energy (including biomass/biogas). This is possibly due to the fact that these two technologies are at the stage where they are successfully implemented in some cases but there are still facing barriers to point out for further diffusion. On the other hand, Table 2 also indicates that there are a variety of research interests with respect to the targeted technologies for analysis. Some research interests are geared toward to the technologies at the innovation stage such as IGCC and CCS. Some research interests are directed to the products for individual use rather than industrial use such as hybrid vehicles, LEDs, and PV. The diversity in the targeted technologies for analysis may lead to interesting finding about barriers.

2.3. Comparative study on technology-specific barriers

Section 2.3 compares the results of the case studies identified in Section 2.2. Table 3 summarizes the results of the studies:

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
Case study 1	SPRU (Science and Technology Policy Research) at University of Sussex and TERI in India	India	Wind power			• IPR is the main issue. The transfer of technological know-how to Indian companies was restricted. (p.116) • The high cost of IPR acquisition. (p.118) • In the joint ventures and collaborative ventures, it had been noticed that the [Indian] companies had to depend on their European counterparts for all technical aspects and even operation and maintenance issues. (p.117)

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
						• It is very important to develop the indigenous capacity for technology development and manufacturing. Equally important would be to incentivize innovations from the viewpoint of national priority. (p.120)
Case study 2	SPRU (Science and Technology Policy Research) at University of Sussex and TERI in India	India	IGCC (Integrated Gasification Combined Cycle)	• Limited amount of testing of IGCC that has been done with Indian grade coal. All IGCC demonstration plants to date have been based on coals with different characteristics to Indian coal, especially ash content and ash fusion temperature.(A:p.58) • The long-term success of technology transfer in technologies such as gasification relies on building technological capacity within recipient countries. (A:p.58)	• The two key risks associated with IGCC are high capital costs and the lack of reliable operational history. The risks associated with high capital cost are amplified by the limited operational history and the new nature of this particular application of gasification. (A:p. 58)	• Premature to comment on IPR issues related to IGCC, since this technology is not considered to be commercial globally. (B:p.110)
Case study 3	SPRU (Science and Technology Policy Research) at University of Sussex and TERI in India	India	LED (Light Emitting Diode)	• Although the technical competency in India exists in the fields of material science, engineering, control electronics and other relevant fields, they have to be nurtured in the context of LED technology.(p.72) • Indigenous capacity is to be developed quickly	• No clear indication about the type of market that exists for LED. (p.69) • The leading players worldwide are not considering India as a potential region for investment as they do not see any market in India at present. (p. 72)	• It is a highly protected technology. As there are various processes involved in manufacturing LED chips, each process is patented and requires huge investment. At present the cost of investing in both chip manufacturing and resolving the IPR issues is substantially high compared to importing the chips. Therefore in India, the chips are imported

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	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
				so that when technology is transferred it can be taken up. (p.74)	• Import of LED is much easier and cheaper than to manufacture it because of IPR issues. (p.69) • LED chip manufacturing requires several processes. Each process involves energy as well as capital-intensive equipment. The existing players in India are relatively smaller in size and are not ready/capable of investing huge amounts for LED chip manufacturing. (p.72)	primarily from China, Taiwan, Japan, the US and other countries. (p.72)
Case study 4	SPRU (Science and Technology Policy Research) at University of Sussex and TERI in India	India	Biomass	• The opportunity cost of power outages at briquetting plants. In many regions of India, electricity from the grid cuts out for hours at a time. (p.80) • The lack of accessibility to power presents problems. In India, where electricity connections are often unavailable in rural locales, the power requirement for briquetting machines could prove to be a major barrier to establishing plants in remote areas even if they are rich in	• Entrepreneurs and manufacturers alike identified working capital as a primary barrier to successful commercialization of briquettes. (p.79) • Banks are reluctant to finance agro residue projects. These products have traditionally been viewed as waste, with no collateral value. (p. 79) • Because of the low repayment record, briquetting has developed a poor	• As long as ram and die machines were selling and operating at an acceptable level, manufacturers were not willing to begin a new endeavor that carried with it some measure of uncertainty. (p.77) • The raw material situation is quite different in India, where sawdust is a commodity rather than a waste product and is in fact widely used, unprocessed, as a cooking fuel. (p.78) • The statistics about India's vast biomass resources and statements about the "virtually unlimited" supply of biomass in India can be

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
				agricultural waste products. (p.80) • In the early days of biomass briquetting, Indian machines experienced more breakdowns and required more maintenance than anticipated. Indian entrepreneurs are experiencing high maintenance costs even with ram and die machines. (p.80)	reputation and been labeled as an irresponsible undertaking. Most stakeholders interviewed felt that subsidies are not the answer for the briquetting industry and that briquetting ventures will have to stand on their own. (p.80)	misleading....Competing uses for rice husk, coffee waste, bagasse, mustard stalks, and many other kinds of waste have caused the prices to rise dramatically. (p.79) • The lack of networking and information sharing among the manufacturers. (pp. 81-82)
Case study 5	SPRU (Science and Technology Policy Research) at University of Sussex and TERI in India	India	Hybrid vehicles	• It is as much a concern for governments in developed countries to encourage the development and uptake of this low carbon technology as it is for governments in developing countries. At present, however, all of the companies owning commercially viable hybrid technologies are based in developed countries. (A: p.89) • If foreign firms supplying hybrid technology maintain a high level of integration in their approach to transferring the technology this could make it more difficult for knowledge regarding the technology to diffuse		• Host country companies may be able to develop technological capacity through involvement in supplying parts for, or maintenance services for vehicles fitted with imported hybrid technology. Even so, there may be IPR issues associated with imitating patented hybrid drive trains. A better understanding of the extent to which IPRs might limit the development of new hybrid drive trains by developing country based manufacturers is an important issue that warrants further investigation.(A: p.95) • IPRs are dominated by a concentrated set of foreign companies rather than domestic players in India. Patents exist in a number of areas, including batteries, electric motors and power electronics, engines and system

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
				within the recipient country. (A: pp.94-95)		integration. In addition, patents exist for both products and processes. Thirdly, there is a general consensus by firms and other players (e.g. academic institutions) that they must work together to make advances in this area. (B: pp.84-85)
Case study 6	SPRU (Science and Technology Policy Research) at University of Sussex and TERI in India	India	Photovoltaic (PV) solar	• Mature production technology for silicon cells is available on the market without licenses since related patents have expired. (P.65) • Most Indian companies have focused on producing silicon solar modules, the fourth stage of the value chain. This is changing however, as an increasing number of Indian firms are planning on producing the entire PV value chain and are expanding into other areas, such as thin film technology. (P.65)		• Many informants also argue that recent PV industry development is largely driven by two additional relatively new national policies: 1. The Government of India's Semiconductor Policy Guidelines in September 2007, which is essentially a tax holiday until March 2010 and 2. Electricity Generation Based Incentives (GBI) providing a subsidy for grid connected PV power plants.(pp.74-75) • Regarding policies to support technological capacity, there are almost no policies in place to encourage collaboration at the national or international level.(p.76)
Case study 7	International Institute for Industrial Environmental Economics (IIIEE) at Lund University	Developing countries	Carbon Capture and Storage (CCS)	• An immediate conceptual difficulty with CCS is that it is to be made up of an integrated suite of technologies. Moreover, institutional components addressing the CCS chain will also be a crucial system component. As CCS is not		

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
				market mature and does not have any commercial examples in operation, this report cannot address CCS system transfer. Rather, one example of an incipient technology transfer framework is noted here there are two transfer projects within its remit. (p.69)		
Case study 8	International Institute for Industrial Environmental Economics (IIIEE) at Lund University	Developing countries	Building energy efficiency	• A fragmented and complex construction process, with an inherent split incentives dilemma: Building markets prefer low initial costs, and get no benefits from life cycle energy savings, whereas users may be willing to pay a high upfront cost if significant economic benefits are possible during the use phase. (p. 92) • Uncertain energy savings from equipment due to the influence of users behavior. (p.92) • A lack of formal training and capacity building among construction workers makes it difficult to introduce new techniques and innovation in construction work. (p.93) • Lack of awareness of the potential and	• High initial costs for energy efficient and renewable energy equipment. This means that payback periods are long (up to 30 years) for many investments. (p.92) • The limited importance of energy expenditures as compared other household improvement or financial concerns. (p. 92)	• A lack of awareness and information of the opportunities, technologies and low cost of installing energy saving features. (p.92) • The lack of government interest in energy efficiency and renewable energy, and insufficient enforcement of existing policies also present barriers to energy saving in the building sector. • Poor enforcement of building codes and other mandatory standards, even among front-runner countries. (p.92) • Poor market surveillance and/or certification measures mean that low- quality products can enter the market and destroy consumer confidence in the technology. • Building codes tend to be less effective, due to insufficient implementation and enforcement, and corruption f or instance, in China the compliance rate is much higher

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
				importance of energy efficiency measures, lack of financing, and lack of qualified personnel (p.92) • Mandatory energy audits and similar tools require training of auditors, however, there is often a lack of monitoring of quality of audits.(p.93) • Lack of evaluation and follow-up is a major concern.(p.93)		in large cities than in rural areas.(p.93) • Adaption to the local situation is crucial, not least for utility demand-side management (DSM) programs, and projects should be designed to fit the local situation.(p.93)
Case study 9	United Nations Depertment of Economic and Social Affairs (DESA)	China	Wind power			• Notably, the Chinese Government is considering the implementation of local IP requirements for wind power in an attempt to push international companies to transfer more technology. Such stipulations on IP requirements could be contested by international companies under the World Trade Organization or by simply limiting new FDI in this sector. (p.30)
Case study 10	Lewis J.	India and China	Wind power	• It took China and India less than 10 years to go from having companies with no wind turbine manufacturing experience to companies capable of manufacturing complete wind turbine systems, with almost all components produced locally. This was done		• Both China and India have excellent wind resources and aggressive, long-term government commitments to promote wind energy development...Some of the early support mechanisms in China and India, in particular, led to market instability as developers were faced with regulatory uncertainty, especially concerning pricing

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
				within the constraints of national and international intellectual property law, and primarily through the acquisition of technology licenses or via the purchasing of smaller wind technology companies. While both companies pursued similar licensing arrangements to acquire basic technical knowledge, Goldwind's technology development model lacks Suzlon's network of strategically positioned global subsidiaries contributing to its base of industry knowledge and technical capacity. • Suzlon's growth model particularly highlights an increasingly popular model of innovation practices for transnational firms…Its expansive international innovation networks allow it to stay abreast of wind technology innovations around the world so that it can then incorporate into its own designs through its extensive research and development facilities. (B)		structures for wind power. In the early years of wind development in China and India, difficulties also resulted from a lack of good wind resource data, and a lack of information about technology performance stemming from little or no national certification and testing. • Policy reforms in the electric power sectors of both countries…has led to a series of regional renewable energy development targets in India, national targets in China, and additional financial support mechanisms for wind in particular. There are two key differences in the policy support mechanisms currently used in China and India: (1) China's recent reliance on local content requirements to encourage locally sourced wind turbines, which does not exist in India, and (2) India's use of a fixed tariff price for wind power, versus China's reliance on competitive bidding to set the price for most of its wind projects. (B)

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
Case study 11	Mizuno E. (on a publication by UNEP Risø Centre on Energy, Climate and Sustainable Development)	India	Wind power	• External factors such as the rapidly increasing high-tech characteristics of wind energy technology systems and the fast structural transformations of the industry at the frontier made it difficult for India to cope with the various changes. (p.46)		• A large market size and market certainty and continuity were lacking in India: even though many market demand characteristics were similar to those in the frontier market, without a sizable market and its own pulling power, technology upgrading through replicable technology transfer did not happen. The small market made all demands for technological improvement insignificant.(p.44) • India's experiences with wind technology have some important lessons for how to encourage private-sector replicable technology transfers from developed to developing countries. The small market size, the non- performance-oriented market mechanism, the policy inconsistency, the institutional problems of the power sector, the lack of technological capabilities to meet the increasingly higher quality requirements of wind energy technology and the persistent infrastructure deficiencies in India, along with tighter technology controls by technology providers and collaborators, all contributed to the increasing technology gaps in both product and capabilities with the frontier after the mid-1990s.(p.46)

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
Case study 12	Ravindranath and Rao (on a publication by UNEP Risø Centre on Energy, Climate and Sustainable Development)	India	Bio-energy (including biomass gasification, biomass combustion, biogas, efficient cook stoves)	• Gas cleaning systems are still not robust and hence high in terms of maintenance (p.136) • Poor understanding of managing moisture content (p.136) • Biomass drying techniques are not well established (p.136) • Lack of knowledge (p. 137) • Uncertainty and distrust in the source of information (p.137) • Inadequate training, capacity-building and user-education programs. (p.137)	• Dual fuel systems do not seem economically feasible, and hence the focus is on producer gas. But 100% producer gas engines still are not very common, not readily available at all capacities (p.136) • The high initial costs of bio-energy technologies are perceived by many as a key barrier to the penetration of bio-energy technologies vis-a�vis conventional technologies. The principal capital cost of biomass power projects includes the costs of the gasifier, the engine generator, civil construction, biomass preparation unit, electricity distribution network and electrical and piping connections to the site of gasifier installation and need subsidization (p.138). • Mainstream financial institutions have been reluctant to take risks in lending due to a long history of poor	• The abundance of biomass was initially the push [by the government] needed to promote bio energy technologies. There was therefore little or no interaction with rural communities in formulating the technologies. (p.135) • The institutional framework in India currently lacks a viable strategy to empower local communities. Community organizations and institutions are rarely involved in the planning, implementation and management of, say, the rural electrification program through biomass gasifiers. The failure of a large number of small village systems, such as biogas plants, and stand-alone gasifiers is to a large extent related to the fact that there is no coordinated local, institutional and government support. (p.137) • A critical problem has been overcoming issues arising out of bureaucracy...Many developers have mentioned the significant periods of delay in obtaining technical approvals.(p.137) • Climate change is not being seen an immediate threat or priority for rural communities. (p.137) • Social behavior and expectations.(p.137)

	Research organizations/ individuals	Information on case study		Barriers		
		Country	Technology	Technological barriers	Financial barriers	Institutional barriers
					recovery of loans in rural area.(p.138)	• Absence of an enabling environment. (p.137)
Case study 13	Suzuki, M., Okazaki B., and Jain K.	Thailand	Biogas	• There is no centralized information and orientation regarding biogas technologies and the equipments that are available . It is also very difficult to find data related to projects' performance and information about projects that have already been implemented. (A: p. 20) • There is a lack of awareness. There is also a lack of public support in terms of information, and little information regarding biogas is transferred. In addition to this, since the degree of education of the managers is low, the technology of anaerobic digesters and biogas production appears to the managers as being very complex issues. (A: p. 21) • The anaerobic digesters are complex and sensitive systems. Often, even the managers do not understand how it works. So, due to a low understanding of the new processes, managers rely heavily on the	• Most of the time, the focus of companies is to maximize the profit over a short period. Frequently the managers have little to no information about biogas or anaerobic digester systems and the subsequent technical implications and costs. (A: p.17) • Most technologies for wastewater systems and biogas came from developed countries (Parr et al., 2000). Proper transfer and adaptation to tropical climates requires investment and will result in costs being incurred (importation taxes, logistics, training, etc.). (A: p.20) • The tapioca and palm oil industries are traditional agro-industries, often managed by families with a basic application of management principles under a simple organizational	• The managers do not seek professional support when researching biogas technology due to financial reasons. On the other hand, often the managers do not know where to search for the information they need, since there are no standard guidelines or publicly available information about biogas performance and technologies. There is no support from the government and there are very few initiatives in R&D in regions where biogas is prominent. (A: p.18) • The starch and palm oil industries are traditional agro-industries, normally run by families in an informal manner and structure. In addition, many companies have an incorrect perception of the reality of the market. In these circumstances, a long term strategy or the development of a business plan is not realistic, nor is it a common practice for these industries. (A: pp.19-20)

Research organizations/ individuals	Information on case study		Barriers		
	Country	Technology	Technological barriers	Financial barriers	Institutional barriers
			technology provider. In order to remain focused on the core production process, or to save costs, often the managers do not provide adequate or appropriate training for the operators on the new wastewater/ biogas processes and systems. (A: p.22)	structure. In addition, biogas production is not considered as important as the core business. Thus, on many occasions the operators are not motivated to perform due to a lack of a company performance reward policy or due to a different remuneration compared to his coworkers in the core production business. (A: p.21)	

Table 3. Results of case studies

2.3.1. Barriers for technologies for industrial use: Wind, bio-energy, and energy efficient building

Starting from wind power, the results of Case Study 1 and 11 suggest that there are institutional and technological barriers for diffusion in India and China. According to Case Study 1, the cost of IPR acquisition is a major barrier in India. Case Study 1 points out that "the [Indian] companies had to depend on their European counterparts for all technical aspects and even operation and maintenance issues." Case Study 11 addresses a similar view that technologically, the wind power in India still hinges upon the external development of the industry. It states that "external factors such as the rapidly increasing high-tech characteristics of wind energy technology systems and the fast structural transformations of the industry at the frontier made it difficult for India to cope with the various changes." On the other hand, Case Study 10 provides a positive evaluation on the development of local wind power production in India and China. It observes that "it took China and India less than 10 years to go from having companies with no wind turbine manufacturing experience to companies capable of manufacturing complete wind turbine systems, with almost all components produced locally." The results of these case studies on wind in India and China indicate that although there is a great level of success in producing indigenous local power technologies, there are still technological as well as institutional barriers for further diffusion in these countries.

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Bio-energy is similar with wind power with respect to its successful implementation in the developing countries. On the other hand, the results of the case studies on bio-energy suggest that it faces different types of barriers for further diffusion. According to Case Study 12, implementations of bio-energy projects in India have met both technological and institutional barriers in the operational phase such as poor understanding of managing moisture content, lack of knowledge, uncertainty and distrust in the source of information and inadequate training, capacity-building and user education programs. The case study on biogas power generation in Thailand comes to a similar conclusion (Case Study 13). It recognizes the "no centralized information and orientation regarding biogas technologies and the equipments" as well as the lack of understanding and awareness as the major barriers for successful implementation of the technologies. The results of these case studies suggest capacity building and knowledge development play an important role in the successful implementation of bio-energy technologies.

The case study on building energy efficiency also suggests that the technological barriers such as lack of knowledge and awareness as well as the institutional barriers such as lack of information on available technologies are major barriers in this case too (Case Study 8). The results of Case Study 8 highlights, as the technological barriers, uncertain energy savings from equipment due to the influence of users behavior, a lack of formal training and capacity building among construction workers, lack of awareness of the potential and importance of energy efficiency measures, lack of financing, and lack of qualified personnel. In the case of building energy efficiency, lack of institutional support is another area of institutional barrier. It points out the lack of government interest in energy efficiency and renewable energy, and insufficient enforcement of existing policies, poor enforcement of building codes and other mandatory standards as major institutional barriers.

2.3.2. Barriers for technologies for individual use: Hybrid vehicles, LEDs, and PV

Other than wind power, there are studies that identify IPRs as a major barrier for technological diffusion. The case study on hybrid vehicles in India is one of them. It indicates that IPRs are the major barrier in this case as well since "IPRs are dominated by a concentrated set of foreign companies" (Case Study 5). It states "all of the companies owning commercially viable hybrid technologies are based in developed countries." The results of the case study on LED also suggest that IPRs are the key barrier for the diffusion of LED (Case Study 3). They case study demonstrates that "it is a highly protected technology. As there are various processes involved in manufacturing LED chips, each process is patented and requires huge investment. At present the cost of investing in both chip manufacturing and resolving the IPR issues is substantially high compared to importing the chips." In this regard, there may be important lessons to learn from the previously mentioned case on wind power for producing local technologies despite the existence of IPRs-related barriers. In the case of LED, however, the results of the study indicate there is a separate key barrier for the diffusion of the technology in India. The case study identifies the size of the market as a major financial barrier for technology diffusion in India. It states that there is "no clear indication about the type of market that exists for LED." Furthermore, it stresses that "the leading players worldwide are not considering India as a potential region for investment as they do not see any market in India at present."

Interestingly, in contrast to hybrid vehicles and LEDs, the results of the case study on PV in India suggest that IPRs are not an essential barrier for the diffusion of the technology in India (Case Study 6). It maintains that mature production technology for silicon cells is available on the market without licenses since related patents have expired. Moreover, an increasing number of Indian firms are planning on producing the entire PV value chain and are expanding into other areas, such as thin film technology.

2.3.3. Barriers for technologies at the innovation stage: IGCC and CCS

The results of the case studies on IGCC and CCS indicate that technological barriers are dominant for technologies at the innovation stage (Case Study 2 and 7). Financial and institutional barriers are not relevant for the technologies at the innovation stage. As for CCS, Case Study 7 states "As CCS is not market mature and does not have any commercial examples in operation, this report cannot address CCS system transfer." As for IGCC, Case Study 2 states "It might be premature to comment on IPR issues related to IGCC, since this technology is not considered to be commercial globally".

Thus far, Section 2.3 discussed technology-specific barriers. Another barrier, which this paper could not address this time, are country-specific barriers. It is recognized that in order to design proper policy instruments and institutions, understanding of barriers that are specific to a certain country or region is equally important. With this regard, Case study 10 is an exception among the selected case studies in highlighting several differences between India and China as to how these two countries overcome barriers to diffuse wind power technologies. It demonstrates that "there are two key differences in the policy support mechanisms currently used in China and India; 1) China's recent reliance on local content requirements to encourage locally sourced wind turbines, which does not exist in India; and 2) India's use of a fixed tariff price for wind power, versus China's reliance on competitive bidding to set the price for most of its wind projects." In addition, it discusses key differences on corporate strategies between two Chinese and Indian wind turbine manufacturing firms. This type of comparative studies are much needed in order for us to have better understanding of barriers in the diffusion of clean energy technologies.

3. Roles of institutions to overcome identified barriers in diffusing clear energy technologies in Asia

Section 2 presented the barriers commonly observed in the developing countries as well as the technology-specific barriers. Section 3 explores roles of institutions to overcome these barriers in diffusing clear energy technologies in Asia. Section 3.1 addresses theoretical discussions on the functions of international and national institutions in technology innovation. Section 3.2 attempts to match the barriers in technology diffusion identified in Section 2 with the functions of national and international institutions.

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3.1. Theoretical discussions on the functions of international and national institutions in technology diffusion

There are theoretical explorations about the roles of institutions in changing a system in the area of innovation economics and innovation theory. For Joseph Schumpeter, who is the patron of innovation economics, an evolving institution is an important factor for economic growth. Inspired by Schumpeter, scholars in innovation theory attempt to define functions or roles of institutions in changing a system. Borrás, for example, defines that they are 1) competence-building and generation of incentives including production of knowledge, diffusion of knowledge, financial innovation, alignment of actors, guidance of innovators; 2) generation of incentives and reduction of uncertainty including appropriation of knowledge, reduction of technological diversity; and 3) establishment of limits and reduction of uncertainty including reduction of risk and control of knowledge usage (Borrás 2004). Another example is a study by Suurs and Hekkert. According to Suurs and Hekkert, there are seven functions of institutions including 1) entrepreneurial activities; 2) knowledge development; 3) knowledge diffusion; 4) guidance of the search; 5) market formation; 6) resource mobilization; and 7) legitimization (Suurs and Hekkert 2009).

There are also research initiatives that attempt to understand the roles of institutions in diffusing clean energy technologies both at the national and international level, although the focus of research is geared toward the national level rather than the international level. At the international level, a study conducted by de Coninck et al. is an example of such research (de Coninck et al. 2008). This study classifies technology-oriented agreements (TOAs) addressing climate change into four broad categories including 1) knowledge sharing and coordination; 2) research, development and demonstration (RD&D); 3) technology transfer; and 4) technology deployment mandates, standards, and incentives (de Coninck et al. 2008). According to a more recent study by Benioff et al., there are three roles of international institutions for innovation and transfer of clean energy technologies including research, development, and demonstration (RD&D) cooperation, enhancement of enabling environment, and financing facilitation and support (Benioff et al. 2010).

It is important to note here that the roles of institutions differ along the technological development of clean energy technologies. At the early stages of technological development, institutional support for the empowerment of research groups is needed to demonstrate and deploy technologies (Suzuki 2012). As the case studies on CCS and IGCC indicated in Section 2, the technologies at the innovation stage require strong R&D efforts to remove technological barriers in order to move forward to the next stage. At the innovation stage, the empowerment of network between international and local research groups is needed to enhance the R&D efforts, especially with a stronger initiative from the public side (Benioff et al. 2010; Morey et al. 2011; UNFCCC 2009).

At the advanced stages of technological development, institutional support as well as policy arrangement for the involvement of the actors in the private sector such as project developers, equity investors, manufactures, and commercial banks is essential in technology diffusion

(GtripleC 2010; Carmody et al. 2007). Providing economic incentives for the private sector are an important measure to improve investment conditions and encourage its participations. Therefore, clean energy and carbon finance vehicles may be also effective to introduce technologies at the advanced stage. For example, the economic policy instruments such as CDM may take an instrumental role. If they are designed well, the schemes under discussion for the post-Kyoto regime such as the bilateral carbon crediting mechanism and the sectoral or program-based crediting mechanism can be also a good policy candidate for technology diffusion. At the national level, an introduction of a feed-in-tariff program has received greater attentions among the developing countries, while other economic instruments such as subsidy, emissions trading, and renewable energy certificate scheme can be also recognized as possible policy options. The investment schemes such as co-investments and loans or risk guarantees may help to reduce risk associated with investment from the private sector (Suzuki 2012). In addition, such an arrangement for building a partnership between the private and the public (Public-Private Partnership: PPP) may leverage the interests of the private sector in developing technologies that would not be attracted to clean energy technologies otherwise.

3.2. Matching the barriers in technology diffusion with the functions of national and international institutions

Section 2.3 illustrated technology-specific barriers among different technologies. Section 3.2 attempts to match those barriers with the functions of national and international institutions that were identified in Section 3.1.

The case studies on wind as well as on hybrid vehicles and LED indicated that difficulties associated with IPRs are major barriers in technology diffusions. Indeed, IPRs are complex issues and providing opportunities to learn about the issues can be an important institutional arrangement as the first step. Ockwell, D., J. Watson et al. (2009), on the case of wind in India, states that “there was a need to create awareness among the industry players who do not have deeper understanding of implications of IPR rules and regulations, including those in the context of WTO regime.” Preparing patent pools for licensing inventions is often discussed as a necessary arrangement in diffusing clean energy technologies but it requires careful institutional design not to remove incentives for the private sector and discourage its innovational efforts. At the international level, the World Intellectual Property Organization (WIPO) can facilitate such venues for the private sector in the developing countries to learn about IPRs-related issues.

The case study on LED identified the size of the market as a major barrier. This case, together with the case on building energy efficiency, also pointed out high capital cost as a major barrier. In order to overcome these barriers, the roles of institutions in facilitating and supporting finance are important. On LED, Ockwell, D., J. Watson et al. (2007) states that “as government is already promoting PV integrated energy efficient lighting systems for rural lighting applications, incentives could be provided for LED based PV integrated systems.” As for the case on biomass, low priority in finance is recognized as a major barrier. In this case, knowledge sharing and coordination is the key in overcoming the barrier in technology diffusion. At this point, Ockwell, D., J. Watson et al. (2007) demonstrates that "all the briquetting machine manufacturers felt that there is practically no collaboration or communication among them. The lack of networking and information sharing among the manufacturers is one of the greatest constraints to diffusion of technological developments in the sector. Hence projects aimed at promoting knowledge sharing among the manufacturers and users of biomass briquettes will be very useful for the sector".

The case studies on bio-energy, biomass, and building energy efficiency all emphasized that lack of the enabling environment is the key barrier in technology diffusion. The case study on bio-energy in India highlighted "poor understanding of managing moisture content, lack of knowledge, uncertainty and distrust in the source of information and inadequate training, capacity-building and user education program" as a major hindrance. The case study on biomass in Thailand pointed out a lack of formal training and capacity building among construction workers, lack of awareness of the potential and importance of energy efficiency measures, lack of financing, and lack of qualified personnel. In order to overcome these barriers associated with a lack of the enabling environment, the case study on bio-energy in India suggested promoting collaboration between industry and academia, for field demonstrations, and promoting feedback and communication between developers and implementers (Ravindranath and Rao 2011). It stated that "the development of training schemes could provide a route to alleviating this skill shortage. It is important to ensure that all staff involved in training and development have been adequately trained themselves. Use of R&D institutions in training could be beneficial" (Ravindranath and Rao 2011).

As for the technologies at the early stage of technological development, the cooperation in R&D between the pubic and the private sectors as well as the cooperation between local and overseas actors are inevitable in order to overcome technological barriers. As emphasized earlier, the strong initiatives from the public side are needed since it is difficult to expect the private sector to play an important role if the business model is not yet visible. The case study on CCS indicated that "given current policy and market conditions, carbon markets appear marginal or inadequate for CCS applications such as industrial-scale demonstration plants to be economically viable without (potentially significant) additional support" (Dalhammar, C. et al. 2009). The case study on IGCC concluded that "one possible approach to overcoming the risks of high capital costs is for government to share the funding of demonstration activities with industry… Financial support from developed to developing countries would be needed to provide for incremental costs and technology transfer fees, through international financing mechanism" (Ockwell, D., J. Watson et al. 2007; Ockwell, D., J. Watson et al. 2009).

Table 4 illustrates both identified barriers and roles of institutions to overcome the identified barriers

	Early stage	Advanced stage
Barriers	• **Technological barriers**: Case Study 2 (IGCC), 7 (CCS) • High capital cost: Case Study 2 (IGCC)	• **IPRs**: Case Study 1 (wind), 9 (wind), 11 (wind), 5 (hybrid vehicles), and 3 (LED) • Market size: Case study 3 (LED) • High capital cost: Case study 3 (LED), 8 (building energy efficiency) • Low priority in finance: Case Study 4 (biomass) • Lack of enabling environment: Case Study 8 (building energy efficiency), 12 (bio-energy),13 (biogas) • Lack of policy support: Case Study 6 (PV), 8 (building energy efficiency)
Roles institutions	In theory… • R&D cooperation • Financing facilitation and support ("resource mobilization" and "market formation") • Entrepreneurial activities	In theory… • Knowledge sharing and coordination (including "guidance of the search") • Enhancement of enabling environment (including "legitimization") • Financing facilitation and support (including "market formation" and "resource mobilization")
	Identified roles	**Identified roles**
	R&D cooperation • Public-supported centers for technology innovation and transfer. • Strengthening bilateral and multilateral network for R&D. Financing facilitation and support • Technology funding mechanisms for the developing country participants in R&D. • Global clean technology venture capital fund. Entrepreneurial activities • Clean energy incubator incentives.	Knowledge sharing and coordination/ enhancement of enabling environment • Patent pools for licensing inventions. • Various capacity building programs covering a whole supply-chain. • Business matching venues among various business actors such as project developers, manufacturers and investors (local and international). Financing facilitation and support • Various clean energy finance and carbon finance vehicles including CDM, bilateral crediting scheme, co-benefit approach at the int'l level, feed-in-tariff, subsidy at the national level. • Co-investments, loans or risk guarantees. • Public-Private Partnerships (PPPs).

Table 4. Identified barriers and roles of institutions to overcome the identified barriers

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4. Conclusion

This paper consisted of two parts. The first part of the paper attempted to show a broad landscape of barriers in technology diffusion in the developing countries by addressing two levels of barriers: generic barriers and technology-specific barriers (Section 1 and 2). Section 2.3 summarized the results of previous case studies that were conducted to uncover technology-specific barriers in diffusing clean energy technologies in Asia.

The second part of the paper explored roles of institutions to overcome the identified barriers in diffusing clear energy technologies in Asia (Section 3). It attempted to match the barriers in technology diffusion identified in Section 2 with functions of national and international institutions. The results of matching indicated that there are several different roles of institutions including the role to encourage R&D cooperation from the public site for the technologies at the early stages of technological development and the role to enhance the enabling environment and facilitate finance for the technologies at the advanced stages of technological development.

It is recognized that the existing institutions both at the national and international levels have already been working to overcome barriers in diffusing clean energy technologies. For example, at the national level, the governments in the developing countries are conducting various capacity building programs to enhance knowledge of the private sector about clean energy technologies. At the international level, the financial institutions such as the World Bank and Asian Development Bank are facilitating financial support to encourage diffusion of clean energy technologies. At the innovation stage, there are both bilateral (such as the Global CCS Institute for building a network between Australia and the developing countries) and multilateral (such as the Asia-Pacific Partnership on Clean Development and Climate concluded in April 2011) network to encourage technology innovation. Further research is needed to investigate whether these existing institutions are playing a role in overcoming the barriers that were illustrated in this paper.

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Chapter 8

Policy Arrangement for Waste Management in East Africa's Urban Centres

Christine Majale-Liyala

Additional information is available at the end of the chapter

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1. Introduction

Today waste management in developing countries and particularly in East Africa is characterised by the involvement of both state and non state actors. The types of arrangement for service provision range from self-provision through collective action independent of external agencies to indirect state provision through sub-contracting to other agencies – NGOs, private for profit companies, user groups among others. Generally, there is much agreement that monopolistic provision realized entirely through state agencies is unfeasible, undesirable, or simply rather old fashioned [1, 2, 3]. However, there is little consensus on the alternative. According to arguments presented by Joshi and Moore in [4], there is need to look beyond new discourses like New Public management and Public Private Partnerships indicating that the trend now is towards pragmatism, pluralism and adaptation to specific circumstances because the reality in such developing countries is highly diverse. Some services, it is argued, cannot be effectively delivered to the ultimate recipients by state agencies because the environment is too complex or variable, and the costs of interacting with very large numbers of poor households are too high. In such cases, users become involved in an organized way at the local level. There are arrangements therefore that do not fit into standard categories. Some of these unorthodox arrangements are of recent origin, and are seen to constitute (smart) adaptations to prevailing local circumstances. They are widespread in developing countries but they raise many issues. This chapter looks at these arrangements through the lens of policy arrangement approach [5] to help discern which arrangement results in better waste management.

The urban centres studied are Mwanza, Kisumu, and Jinja which are considered primary urban centres coming just after the capital cities in their respective countries. The three centres lie within the lake Victoria basin (See Figure 1) and therefore their individual efforts in waste management contribute to sustainable management of the lake by among other things, reducing the pollutant load into the Lake. These three were chosen because of certain similarities (and differences) but more so because they are all found on the shores of the lake basin as mentioned earlier and they are all primary urban centers which makes them comparable in urban status.

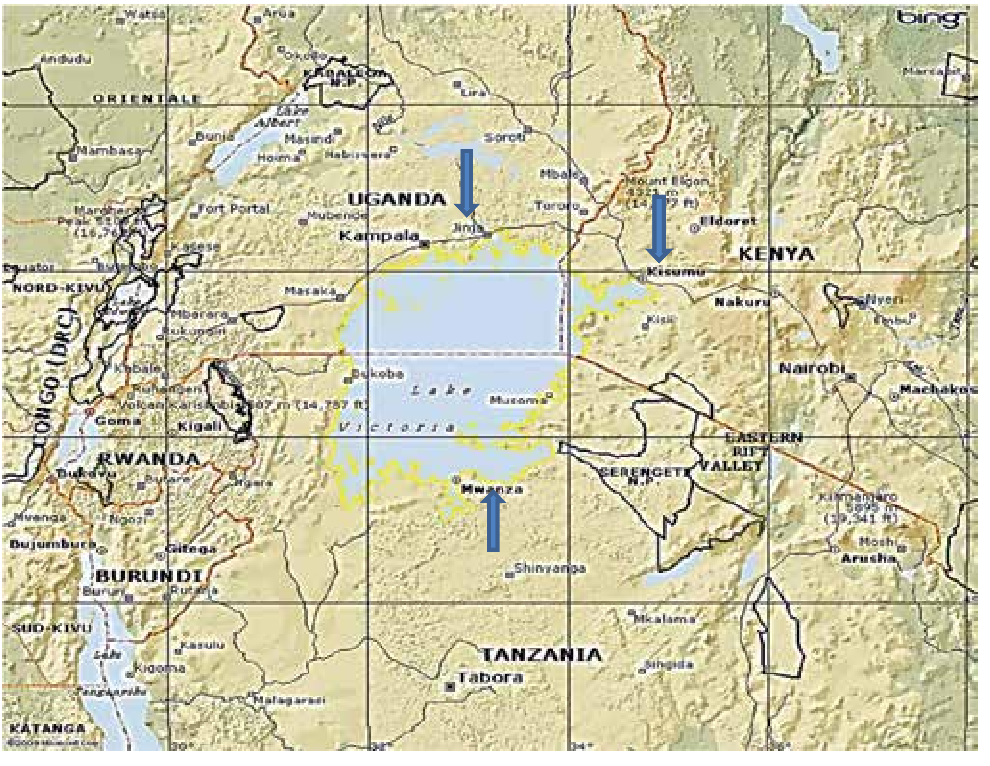

Figure 1. Map of The Lake Basin Showing Location of the Three Areas under Study in their respective countries – Marked With Arrows.

2. Problem statement

Solid waste management is particularly a problem for urban centres in developing countries. Growing economies and swelling population numbers from both in-migration and natural growth are continually increasing the urban centers' sizes. These large and growing population is one of the main forces driving the centres overwhelming environmental challenges including solid waste management. Key interventions to addressing the solid waste management challenges could lie in the policy arrangements. This chapter therefore seeks to compare the policy arrangement of three urban centres in East Africa in order to conclude on which arrangement(s) presents the most flexible, robust and sustainable option for solid

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waste management. Flexible to include both state and non-state actors, robust to keep on running or operating under changing national circumstances (like the economy) and sustainable to contribute to the improvement of environmental conditions.

2.1. Profile of the urban centres studies

Kisumu is the third largest urban center in Kenya after Nairobi and Mombasa. It is located in Nyanza province in the Western part of Kenya. Geologically it sits on the arm of tertiary lava, which extends southwards overlooking the plains to the East and Winam gulf of Lake Victoria to the West. The Lava formation is attributed to the tectonomagnetic activities associated with the Kano-Rift valley system. As a result the city is curved into a trough with the walls of the Nandi escarpment to the East dropping onto the floor of the Kano flood plains and gently flowing to the Dunga wetlands at the shores of the Lake Victoria. Kisumu covers an area of 297km^2 of land mass and 120km^2 under the lake. The population of the council has been increasing rapidly, and at a growth rate of 2.8% per annum it was estimated at about 500,000 in 2007 from 322,734 people in 1999.

Jinja is the second largest urban center in Uganda after Kampala city. It is located 81km East of Kampala. It is situated just north of the equator, on the northern shores of Lake Victoria and at the source of the Nile River. The town lies on a tapering plateau with an average altitude of 1230 meters above sea level. The municipality has an extensive shoreline in the east, south and west of both Lake Victoria and the voluminous waters of the Victoria Nile. It occupies an area of 28km^2. It has a resident population of about 86,512 people (population census 2002) with a day population that doubles that figure due to peri-urban migrant labor. At a growth rate of 2.4% per annum, the population as of 2007 is estimated at 95,121 people, see [6].

Mwanza is the second largest urban center in Tanzania after the city of Dar-es salaam. It covers an area of 1325 km^2 of which 425km^2 is dry land and 900 km^2 is covered by water. Of the 425km^2 dry land area, approximately 86.8 km^2 is urbanized while the remaining area consists of forested land, valleys, cultivated plains, grassy and undulating rocky hill areas. According to the 2002 National Census, Mwanza City had 476,646 people. With an annual natural growth rate of 3.2%, the population as of 2007, is estimated at 714,060 people, see [7].

2.2. Research methodology

The study makes use of both secondary and primary data. The collection of secondary data involved a review of literature on the concept of policy arrangement; network,state and market governance as well as Bylaws and other legislative pieces in Kenya, Uganda and Tanzania. The study obtained primary data from interviews with urban authority officials (Public health Officers and Director of Environment at Jinja Municipal Council, Public health officers and solid waste manager at Mwanza City Council and Environmental Officers at Kisumu City Council). Non-state service providers both formal and informal in the three urban centres were also interviewed. In addition, about 600 questionnaires were administered to households and given the differences inherent in the three towns, different approaches were taken to select samples for the household survey as follows:

For Mwanza:

In Mwanza, there are two districts and each has urban and rural wards. Urban wards (14 in number) were purposively selected because they receive solid waste management (SWM) services. Every urban ward receives services either from a Community Based Organization (CBO) or a private company working under a contract so all urban areas irrespective of income levels receive SWM services [8]. For the survey, stratified sampling was used. It was a disproportionate stratified sampling because for all the 14 urban wards (which were the strata), on average 13-14 households were interviewed irrespective of population figures in each ward. The goal was to have each ward represented by a minimum number of 10 households and to arrive at a maximum total sample of 200 households. Using the population census data and with the help of the ward leaders and the public health officers posted to each ward, households were randomly picked from a list and questionnaires administered.

For Kisumu:

In Kisumu, SWM is patterned much more along income levels. Previous empirical work, see [9], indicated that the council had not officially permitted non-state actors to operate but all SWM activities by these actors went on unofficially. SWM service providers (the non-state actors) defined their clients on the basis of their income. Community self-help groups were common in low income areas while private companies dominated high and middle income areas. Therefore a list of low, middle and high income estates was made, and then a few estates from each of the three categories were randomly picked

NB: Just like in Mwanza, Kisumu has civic wards, some of these wards are estates in themselves for instance, Nyalenda is a ward and an estate at the same time, while in other wards, there is more than one estate. There are in total 17 civic wards covering 41 estates.

There are about 41 estates recognized by the council (11 high income, 17 middle income and 13 low income). The council provides waste management services in only 12 of these estates. The study aimed to administer 200 questionnaires just like in Mwanza. About half the number of estates in each income category mentioned earlier was randomly selected. The study ended up administering questionnaires in 6 high income, 9 middle income and 7 low income estates. About 10 questionnaires were administered in each of the estates selected. The number of households per estate varies from about 3,200 to about 12,000. Selecting households within the selected estates was done differently depending on the kind of estate arrangement. In planned estates like the Railway estates, the houses are numbered and organized in a certain pattern so it was easy to do systematic sampling, selecting every fourth household. In the informal estates like Nyalenda, the houses are not numbered or arranged in any particular order,

the researchers were guided by the village names within Nyalenda which were listed and then one household from each village was randomly selected. To avoid covering a village more than once, the study used one research assistant per estate.

The income categorization used to obtain the sample reflects the general pattern of service provision in the town. The estates were classified according to one of the three distinct income categories. From each group of estates about half was randomly selected. Within each selected estate about 10 households were randomly selected. Therefore, based on the argument of inferential statistics, the data can be considered to reflect the situation of service provision among the different income categories in the town as a whole

For Jinja:

In Jinja, there are three divisions [6]. Within each division there are parishes but solid waste management services have been contracted out per division and the work is given to two contractors. The divisions are:

- Central Division
- Walukuba Division
- Mpumudde Division

One contractor serves both Central and Walukuba divisions while the other contractor serves Mpumudde division. Service is therefore not structured along income levels as in Kisumu neither per ward as is the case in Mwanza. Waste is collected from skips (collection points) and not directly from the households. Contractors are paid per emptied skip. There are 119 collection points (skips) in Central, 10 in Walukuba and 20 in Mpumudde. Central and Mpumudde Divisions were picked for the study in order to show the differences (if any) in service provided by the two contractors. Frequency of questionnaires administered was higher in Central with about 180 questionnaires randomly distributed and 38 randomly distributed in Mpumudde. These frequencies were more or else in line with the distribution of collection points which are many in Central division. In the end, in total 218 household questionnaires were administered, so the aim to get a total minimum of 200 questionnaires, as for the other two towns, was reached.

With a list of street names (also referred to as roads/avenues/zones which are equivalent of the villages in Kisumu), households (numbering up to 10 in certain streets) were randomly selected from each street.

2.3. Theoretical framework

In East Africa, the national state in each country has been and is the predominant actor when it comes to service provision. Recently though, the influence of market and civil society stakeholders is evident particularly in service provision at the local level. In this paper these developments are analysed using the policy arrangement approach developed by Arts and others [5, 10, 11]. As an approach, it has been mainly used in studies conducted in Western countries but can also provide a framework against which solid waste management is analysed in East Africa given the entry of non-state actors. Policy arrangement is defined as the temporary stabilization of the content and organization of a policy domain at a specific level of policy making. It is temporary because arrangements are under pressure of constant change either by policy innovations on the ground or by processes of political modernization. It has four main dimensions namely:

- The actors and their coalitions involved in the policy domain; and
- The division of power and influence between these actors, where power refers to the mobilization, division and deployment of resources, and influence to who determines policy outcomes and how;
- The rules of the game currently in operation, specifically the formal procedures for pursuit of policy and decision-making; and
- The current policy discourses where the concept of discourse refers to the views and narratives of the actors involved—in terms of norms and values, definitions of problems and approaches to solutions—in this case, the study captures network governance

These four dimensions of a policy arrangement are inextricably interwoven. This means that any change on one of the dimensions induces change on other dimensions. This relationship is symbolized by the tetrahedron, in which each of the corners represents one dimension (Figure. 2).

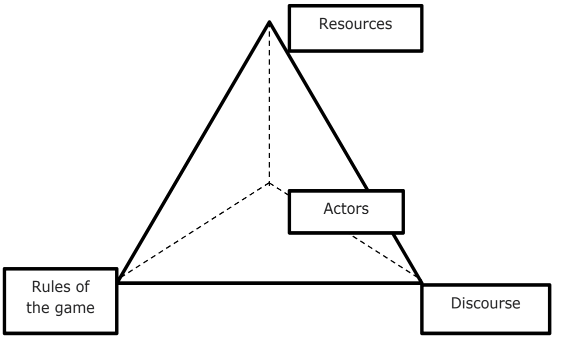

Figure 2. Tetrahedron showing Relation between Dimensions of Policy Arrangement

An analysis of an existing policy arrangement, including its problems or sticking points, concerns all four dimensions of the concept. The methods for mapping out the relevant actors, their coalitions and oppositions are familiar from network analysis. Methods are also available for assessing power relationships. Then existing rules of the game in the arrangement have to be reconstructed: Who decides on the agenda? Who participates in the policy game? Who is excluded? Who takes the decisions? Discourse analysis provides systematic instructions for analyzing the fourth dimension: What are the main concepts in policy discourse and the policy programme? What are the basic assumptions of the policy? What do relevant policy documents contain? How do the various players in the field interpret the policy concepts and basic assumptions?[12].

According to [11], policy innovations can be initiated from each of the dimensions. Policy agents may decide: (1) to allow more or new actors to participate in policy making or in coalition formation; (2) to reshape power relations, for example by adding to or withdrawing resources from a policy arrangement; (3) to reformulate the rules of the game on the basis of which policies are made; and (4) to reformulate the policy discourse concerned, for example by

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redefining its core concepts. However, innovations in one dimension tend to have consequences for other dimensions, and even for the arrangement as a whole. In other words, in some cases changes have been initiated by new coalitions (e.g. the participation of citizen groups), whereas in other cases they are provoked by innovative discourses, or reinforced by rules and resources, setting off a chain reaction of changes in all aspects. Finally, this chain may lead to the change of *entire* policy arrangements. The approach of policy arrangements helps to analyse such changes.

2.4. Changing political dynamics in service provision

The existence and performance of local authorities in East Africa in service provision, has a historical component depicting changes that have occurred dating back to the 1960's when the three East African countries attained independence. Olowu [13] explains that when these countries attained political independence with formal structures of democratic, representative government, political leaders in their bid to consolidate political power then opted for highly centralized modes of governance. This centralized mode of governance was reinforced by a culture of politics of patrimony in which all powers and resources flow from one source of power ('the father of the nation') to clients to shore up the regime. This pattern of power and resource distribution was strongly supported by both domestic and external actors until the late 1980s. The reasons adduced for adopting this approach included –rapid economic and social development actualized through centralized planning, unity and national integration, containment of corruption and political stability. In fact the argument was that if decentralization would be necessary at all it must be in the form of administrative decentralization or deconcentration—the sharing of responsibilities between central and local administrations which do not exercise any discretionary authority nor dispose of resources. Yet the 1990s marked an era of political and democratic approaches wherein decentralization was progressively being seen (by governments, external actors and the increasingly influential civil society lobbies) as a means of enhancing democracy and citizen participation and (by governments and external actors) as a way of reducing the role, and in particular the expenditures, of the central government [14]. Over time, these changes have necessitated governmental reconfigurations, many of which have a powerful 'local' governance orientation. They include resurgent regional organizations, public private partnerships in infrastructure creation and maintenance and service delivery, decentralisation, devolution and deconcentration of expertise and accountabilities within government departments, and contractual relationships between government and community providers, among others [15]. Non-state actors are increasingly getting involved in service provision. To date though, none of the three East African countries has any municipal service that is completely privatized as yet neither are there distinct policies on privatization of service provision within local authorities. The services most experimented with so far are solid waste management and water supply, but the former more than the latter.

2.5. Existing solid waste management arrangements

The arrangements of SWM in the three urban centres differ. This is captured within the four dimensions of policy arrangement:

2.5.1. Rules

2.5.1.1. Jinja

Jinja has three administrative divisions: Central, Walukuba and Mpumudde. Due to the efforts to move towards privatization in the country, the council contracted out solid waste management through open bidding, specifically collection and transfer of waste to the disposal site. The arrangement is an annual contract between the municipal council and the private entrepreneurs and in the financial year 2008/2009 two contractors won the tenders [16]. One serves two divisions: Central and Walukuba, while the other contractor provides service to Mpumudde. The legitimacy of the contractors is realized in a number of ways. First the Jinja Solid Waste Management By-Laws 2005, in their objectives recognize the role of private companies in the collection and disposal of waste when this is practiced in a sustainable manner and at a fee. The two contractors serving then were thus officially recognized by the council and in turn by a number of the households they served. Secondly, the tenders for contracts in SWM are advertised through the media and as earlier mentioned, there is open bidding. Contracts for companies that were involved previously can only be renewed on the basis of their performance. As far as decision making is concerned, the municipal authority is still at the helm of SWM, making policies and seeing to their implementation. The contractors do not attend council meetings and are therefore unable to make or influence decision-making. From an interview with one of the contractors however, it became clear that they are free to voice their opinions directly to the town clerk, which may or may not be taken into account when formulating policies.

2.5.1.2. Mwanza

In Mwanza, there are 21 wards, out of which only 14 wards receive solid waste management services. These are the wards in the urban sections of Mwanza city. Privatization of solid waste management resulted in the council awarding contracts to groups and in the financial year 2008/2009, contracts were awarded to Community Based Organizations and two private companies that serve the wards in the Central Business District [7, 16]. Every other ward is served by one or two Community Based Organizations (CBOs). In terms of legitimacy, it should be noted that first, the CBOs and the two private companies are legitimate organizations, officially recognized by the council and the people they serve as revealed by the interviews and household survey. They are awarded formal contracts after having won through a democratic process. The groups undergo registration as solid waste management service providers and pay a registration fee of Tshs25,000 (USD17.85). The private companies pay taxes to the Tanzania Revenue Authority. Secondly these contractors are well known to the people they serve because the members of these CBOs are local and belong to/are residents in the wards they serve.

2.5.1.3. Kisumu

In Kisumu, even with the municipality as the central locus of authority, see [17], legitimacy remains a key concern. This is so because there are questions regarding the legal mandate accorded to groups providing SWM informally. Most of these informal groups are registered by the ministry in charge of community development, they are however not formally recognized by law as actors in the domain of solid waste management. The presence and activities of these groups are nevertheless known by the council and some of these groups (see table 1 below) even responded to be operating through some form of 'franchise'[1] in areas allocated to them by the municipal authority. With no legal papers to show the arrangements they are part of, most if not all of these groups are not legitimate in the SWM arena. This impinges on a number of issues, for instance seeking legal redress in case of payment defaults becomes a problem. Getting donor assistance also becomes a problem because questions will arise as concerning ties to the public, transparency and adherence to the mission of a group, representative status and the relationship between the group and the community served. On the other hand, in terms of community support, openness of information, democratic decision-making, these groups can be considered more legitimate than some official actors are.

Form of arrangement	Numbers
'Franchise'	11
Quasi contract	1
Partnership	1
Unwritten authority to operate	2
Pay rent to council	1
None	15
TOTAL	31

Table 1. Legitimacy of groups involved in SWM services Source: Author based on field work

2.5.2. Actors and coalitions

Town/SWM Status	Jinja	Mwanza	Kisumu
Waste collection arrangement	Private collectors formally contracted and the municipality	CBOs and 2 private collectors formally contracted and the municipality	CBOs, private companies and operating informally and the municipality
% of households receiving SWM service	60% (n=218)	82.5% (n=200)	46.5% (n= 200)
% of households that pay for waste collection	N/A	96.4% (n=165)	79.4% (n=93)
Satisfaction of SWM amongst households	62.6% (n=130)	51% (n=165)	70.6% (n=93)
% of waste collected in the towns	40-60%	88%	35-45% (municipal and non-municipal)

Table 2. Summation of SWM Indicators in the three urban centres Source: Author based on field work

1 The word franchise is in quotation marks because there are no legal papers to show for it and the arrangement is only franchise by name but not in actual sense.

2.5.2.1. Jinja

Looking at the three urban centres, Jinja's SWM arrangement is a close representation of the model of market and networks. This is because of the presence of economic actors in the SWM arena. It is a close representation because these actors are not exactly the determining players in the field of SWM, yet they provide most of the SWM services to the council and its people. The economic actors are private entities in form of companies with several employees as casuals contracted to provide services. The casuals do the collection and sweeping. There are no coalitions or relations between the companies contracted. Field interviews with these contractors revealed that market competition prevents them from having any form of cooperation. As their contracts have an annual nature, they need to stay on top of the game to win the contract the coming year. Within this arrangement, the percentage of households receiving service stands at 60% (where n=218) (see table 2 above).

The networks in this arrangement refer to other actors with shared interests in SWM though the degree of cohesion varies between them. There is the involvement of women and youth groups in the road sweeping and clean-up activities which are done occasionally and mostly on a voluntary basis. There are also environmental groups that are actively involved, including National Environmental Management Authority (NEMA) as a wing of the government which has established pedagogic centers to showcase exemplary activities and is helping to source additional skips to be used in the council. Also involved are international institutions like Lake Victoria Region Local Authorities Cooperation (LVRLAC) who promote exchange of practices amongst the councils member of the organization. International Labour Organization (ILO) and the Lake Victoria Basin Commission (LVBC) have also actively taken part in capacity building.

2.5.2.2. Mwanza

Mwanza's SWM arrangements comes close to that which can be described as communities and networks. They come 'close' to this model because there are questions on extent to which the CBOs involved can exercise power. Although much of the SWM arena is dominated by CBOs (14 in number and 2 private firms) and these CBOs are the major implementers of the SWM policies, the local authority still dictates these policies, awards the contracts and generally steers everything that has to do with SWM. Unlike the situation in Jinja, as far as the contractors relating with each other is concerned, all the 16 groups interviewed in Mwanza belong to an association called the Mwanza Solid Waste Management Association (MASMA). MASMA meets once every month to share ideas on problem solving and opportunities that can be explored further. Apart from the association, neighboring CBOs (that is CBOs working in neighboring wards) work together in sharing experiences and sometimes even the use of equipment in case the workload is more than expected. This arrangement has resulted to 82.5 % (where n= 200) of households receiving services. As an arrangement it also promotes social sustainability having includes local communities as service providers within their own jurisdictions.

Networks in the Mwanza arrangement are visible in the different actors involved in SWM albeit to different degrees. Apart from the local authority, CBOs and the private companies,

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just like in Jinja, there is NEMA, different government ministries and regional organizations, in particular, LVRLAC to which Mwanza is a member and the LVBC. ILO has been very instrumental in training the CBOs to earn their income from the waste collection and also urging them to form an association.

2.5.2.3. Kisumu

The situation in Kisumu comes close to the model of hierarchy and networks. This is the case because the local authority is still solely responsible for solid waste management and the management style is actually still of the command-and-control type. The Department of Environment receives its directions and authority from the line ministry of Local Government and implements them at the local level. Unlike Mwanza and Jinja, Kisumu has no formal/official arrangement that involves non-state actors in collecting and transporting waste or in sweeping the roads. The local authority does the road sweeping itself, as well as the collection, transfer and disposal of waste, but these local authority services are concentrated in the Central Business District and only a few residential areas also benefit from them. Non-state actors (see table 3 below) provide service to most of the other residential areas in an unofficial manner. This is likely to affect the robustness of the system as the non-state actors cannot be held accountable for the SWM services they provide.

SWM	Existing Numbers	Numbers Interviewed
Recyclers	23	6
Groups: CBOs and youth groups	27	17
Private companies/individuals	18	8
TOTAL	68	31

Table 3. SWM Groups in Kisumu City Council and Those Interviewed Source: Field work in Kisumu

In terms of relationships between the non-state actors themselves, the study revealed that they work together during cleanups and some even share their working equipment. Like in Mwanza, they have also formed an association called the Kisumu Waste Managers Association. This arrangement has resulted to 46.5% (where n=200) of households receiving services (see table 4 below for the percentage of service coverage provided by the different actors).

Service provider	Frequency	Percentage
CBO	21	10.5
Municipality	18	9.0
Private Company	54	27.0
Others	107	53.5
	200	100.0

Table 4. Service providers to Households in Kisumu N=200 Source: Household survey in Kisumu.

Just like the other two towns, the networks refers to occasional involvement of other actors like NEMA, LVRLAC, LVBC, UN-Habitat, Practical Action amongst others.

2.5.3. Resources

2.5.3.1. Jinja

In Jinja, the interviews with public health officers revealed that the municipal authority has a budget for SWM which is mostly funded by the central government. There are also fees collected from business premises (Ugshs20,000 - USD14 per business)[2] and a dumping fee at the disposal site but all these go to the central reserve at the council where they tend to be absorbed by overall council expenditures. The Director of Environment informed that the authority actually has relative autonomy in putting up its own budget, see [18]. Yet it is evident that because most of the funds come from the central government and they are conditional, it is unlikely that adequate resources would be set aside for waste management compared to other 'important' municipal services. For the year 2008, the budgeted expenditure for waste management was Ugshs69,600,000 (USD49,714) but the actual expenditure came to Ugshs120,000,000 (USD85,714) reflecting a deficit of about Ugshs50,000,000 (USD35,714) on the budget.

Payments from the local authority to the contractors are made as per the number of skips emptied to the disposal grounds. The contractor earns Ugshs28,000 (USD20) per small skip (3 tons) emptied and Ugshs30,000 (USD21.4) for a bigger skip (3.5 tons) emptied. On average the contractor serving the two divisions empties 18 skips per day while the one serving Mpumudde division empties on average 7 skips per day. In addition, the contractors use local authority vehicles for transporting the skips to the dumpsite. They hire the vehicles at Ugshs100,000 (USD71.43) per truck per month. They cover the costs for minor and major repairs and fuel as well. The drivers of the trucks are however employed by the local authority and not by the contractors themselves. This is to allow the authority to control and monitor the disposal of waste because the contractor is paid as per the number of skips emptied. One outstanding aspect of the Jinja arrangement which is not the case for Mwanza and Kisumu (and which is also contrary to the 'markets' arrangement), is that households do not pay for the service. The reticence to pay for SWM is because households are convinced that it is the responsibility of the council to provide the service and at no cost. This conviction remains very strong so that attempts to introduce a fee of Ugshs.2000 (USD1.42) per household per month were not successful. This is likely to affect the robustness of service provision as a fee on waste could probably have been ring-fenced and used on SWM instead of entirely relying on transfers from central government. given that the Service satisfaction from the household survey stands at 62.6% (where n=130).

2.5.3.2. Mwanza

In Mwanza, the study learned that the council also gets most of its SWM funds from the central government. There are additional funds from the fee charged at the dumping site and also from the fee charged to CBOs to have their waste transferred to the dumping ground

2 At an exchange rate of Kshs 70 to USD 1 at the time the study was conducted. Kshs 1 to Ugshs 20, Kshs1 to Tshs 20

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but like in Jinja, these funds end up at the central reserve in the local authority. The solid waste manager informed the study that SWM is not properly defined in the authority's overall budget but that their total expenditures for the year 2007 went up to Tshs210,900,000 (USD150,643). This figure like the one in Jinja is small compared to the expenditures in Kisumu and this could be linked to the fact that the costs incurred in Jinja and Mwanza are shared by the council and the private sector contracted to provide SWM services.

The contractors in Mwanza charge different rates for SWM for different land uses but all households pay a standard fee of Tshs400 (USD0.28) per household per month. From the survey 96.4% (where n=165) of households pay for waste collection. Interestingly though only 51% of these are satisfied with service provision. Possible reasons for this could be that the largest percentage of service providers are CBOs who, as it emerged from the field interviews, have no incentive to invest and improve SWM given that it is an annual contract. This could impact on their level of professionalism. It is also possible that the population has very high levels of expectation about the performance of the contractors. A number of the households gave recommendations in line with improving the skills of CBOs, improving the infrastructure used for collection, showing that they expect more than they are receiving.

The CBOs pay Tshs8000 (USD5.7) per trip to the local authority for transferring waste to the disposal grounds. The private companies however take their own waste to the disposal grounds and pay for its disposal. In addition, the CBOs and the private companies that have been awarded the SWM contracts are paid by the city council at a rate of USD1.2 for every 300m length of tarmac road that is cleaned daily.

2.5.3.3. Kisumu

For Kisumu, SWM receives its funds from a conservancy fee of USD 0.67 charged per household per month through the water bill, but this includes only those households that have metered water connection (that is connected to the central grid). There are also other funds originating from the dumping fee charged at USD1.4 per load of a pick-up truck. Businesses, particularly the markets and other commercial areas, are charged for SWM through their business license. The other percentage of funds for SWM comes from what is transferred from the national government to the local authority - the Local Authority Transfer Fund (LATF). All these contributions combined are however, not sufficient to adequately run the SWM system for the municipality as a whole. In the financial year 2006/07, the annual income from solid waste management was USD70,000 against an annual expenditure of about USD420,000.

Kisumu's scenario differs from the other two urban centres when it comes to the payment systems. The areas that are served by the local authority have their costs taken care of in the water bill and some of the households responded that they pay for waste as part of their house rent. The private companies are operating in open competition and work purely on a willing-buyer-willing-seller basis. From the survey, their services are mostly offered in high and middle income estates. Payments are made at the end of the month as per a verbal agreement with the household. CBOs who operate mostly in middle and low income areas also charge fees agreed upon with each household. Given the high number of informal operators, fees charged for waste collection varies but the average fees for different residential areas are revealed through the household survey as shown in table 5 below.

Residential area	Payment rates (Kshs./Month)
Low income areas	40.00 – 100.00 (USD)
Middle income areas	150.00 – 250.00 (USD)
High income areas	250.00 – 500.00 (USD)

Table 5. Payment Rates for SWM services. Source: Household Field Survey in Kisumu

The survey revealed that 79.4 % (where n=93) pay for waste collection and the service satisfaction from these households stands at 70.6%.

2.5.4. Discourse

When collecting primary data, there was a lot of hype from the local authority officers regarding privatization of solid waste management services. This was particularly the case in Mwanza and Jinja where non-state actors have been formally involved in service provision. The term privatization has been applied to three different methods of increasing the activity of the private sector in providing public services: 1) private sector choice, financing, and production of a service;2) public-sector choice and financing with private sector production of the service selected; 3) and deregulation of private firms providing services. In the first case, the entire responsibility for a service is transferred from the public sector to the private sector, and individual consumers select and purchase the amount of services they desire from private providers. For example, solid-waste collection is provided by private firms in some communities. The second version of privatization refers to joint activity of the public and private sectors in providing services. In this case, consumers select and pay for the quantity and type of service desired through government, which then contracts with private firms to produce the desired amount and category of service. Although the government provides for the service, a private firm carries out the actual execution of it. The government determines the service level and pays the amount specified in the contract, but leaves decisions about production decisions to the private firm. The third form of privatization means that government reduces or eliminates the regulatory restrictions imposed on private firms providing specific services. The cases studied are neither here nor there as far as privatization is concerned and therefore based on discussions presented in [3], the paper settles on network governance to describe the desirable direction for the arrangements in the three urban centres. A network approach to governance is decentring the state as the unique organ for governance and replacing it with pluricentric forms of governance. Networks permit inter-organizational interactions of exchange, concerted action, and joint production in a formal or informal manner. These networks vary in composition from domain to domain, but they are likely to consist of government agencies, key legislators, pressure groups, relevant private companies and civil society organisations such as NGOs and CBOs [19]. Also citizens themselves may be engaged in such network arrangements but this has to be achieved

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through constructive reciprocities, as they can not be forced through formal state interventions. This network perspective shows many similarities with the popular notion of partnerships in governance seeking to determine the respective roles of public as well as private actors in collaborating to improved public services [20]. Network governance arrangements intend to achieve their objectives through the combined efforts of these different sets of actors, but the respective roles and responsibilities of the actors involved remain distinct while the state is no longer the sole locus of authority. This is however not the case in the three urban centres where the state is still the locus of authority. Yet given the outcome of the surveys and interviews, network arrangement is a desirable option because its flexibility allows diverse social actors to engage actively in finding concrete options for providing sustainable solid waste management services and does not force them to wait until national and urban state authorities are willing and able to engage.

3. Conclusion

The policy arrangements for waste management in the three urban centres are different. The one in Jinja typifies an arrangement in which the market dominates. Here, private collectors are formally contracted to provide service with some assistance from the municipal authority. The arrangement in Mwanza is community dominated with more than 14 CBOs and 2 private collectors formally contracted to provide service with some assistance from the city authority. In Kisumu, the urban authority itself solely provides waste management services. The involvement of non- state actors in Kisumu is unofficial and informal. Jinja and Mwanza arrangements are not privatized per se but looking at the official involvement of non-state actors and the outcome of the household survey in terms of quantities of waste collected, percentages of households covered and SWM satisfaction amongst households in these two towns, the chapter concludes that a balanced arrangement is needed where all societal actors can play their role. It is clear that involving non-state actors as in a network governance arrangement is truly plausible and these actors, both formal and informal, need to work under an effective and strengthened government in order to afford all income groups access to solid waste management services and to ensure flexibility and robustness of the services provided. This means solid waste management services cannot be left to the state actors only. The collective effort by all actors in therefore is likely to ultimately contribute to sustainable management of the Lake Basin. Since the three towns border the Lake Victoria, proper waste management by both the state and non-state actors in respective towns is expected to contribute to the total reduction of the pollution load into the lake waters.

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Section 3

Community Engagement

Chapter 9

Climate Change and Food Security

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Additional information is available at the end of the chapter

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1. Introduction

Climate change is possibly the most significant environmental challenge of our time and poses serious threats to sustainable development in the world and more so in most developing nations. Impact of climate change affects ecosystems, water resources, food and health. As such inter-related government policies must be designed to avoid conflicts in policy design and implementation. There is a direct link between climatic changes and global food insecurity more so in developing countries where climate change compounded with poverty has exacerbated the impacts. In order to address the challenges posed by climate change, it is necessary to examine the factors contributing to climate change and how such influence food production globally. Climatic factors like precipitation, evaporation, humidity and sunshine duration form the basis for improvement of food security. There is need for policy makers, communities and aid providers to incorporate evidence based technologies in food systems and knowledge. Evidence based technologies are those that have empirically been tested and used. They include zero tillage, integrated soil fertility management; irrigation technologies for example drip irrigation, seed improvement, water harvesting, organic agriculture and incorporation of indigenous knowledge. The impact of some of the technologies can be seen in the light of global improved grain yield through use of integrated soil fertility management, rain-fed and irrigated environment technologies. Drought-tolerant grain crops are also likely to help increase yields.

The results of this study are pertinent to policy makers in the field of food security and livelihood sustainability. Mitigation and adaptation measures must be effective, affordable and appropriate for environmental sustainability and development. This review advocates for the integration of conventional agro-science based systems with traditional agricultural knowledge in order to mitigate the severity of climate change and its impact on food security and livelihoods sustainability. Integration of agro-science and traditional agricultural systems is important if food security is to be sustained.

2. Global climate change

The expression of the term "climate change" according to many people means the alteration of the world's climate as a result of human activities through fossil fuel burning, clearing forests and other practices that increase the concentration of greenhouse gases (GHG) in the atmosphere. This is in line with the official definition by the United Nations Framework Convention on Climate Change that states that climate change is the change that can be attributed "*directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods*" [1]. The Intergovernmental Panel on Climate Change (IPCC) defines "climate change" as *"a change in the state of the climate that can be identified by changes in the mean and or the variability of its properties, and that persists for an extended period, typically decades or longer"* [2]. Climate change can be defined as a systematic change in the key dimensions of climate including average temperature and wind and rainfall patterns over a longer period of time. In recent usage, especially in the context of environmental policy, climate change usually refers to changes in modern climate. It may be qualified as anthropogenic climate change, more generally known as "global warming" or "anthropogenic global warming" (AGW).

3. Impact of climate change

Due to prevailing nature of enhanced greenhouse effect in the atmosphere, the following effects have occurred at the global, regional and national levels.

Based on [3]; [4], there has been evidence of increase in global temperatures that has led to climate change at global, regional and national levels over the past 100 years. Increase in global temperatures experienced over the past century is as a result of accumulation of greenhouse gases in the atmosphere leading to global warming. Using complex climate models, the "Intergovernmental Panel on Climate Change" in their third assessment report has forecast that global mean surface temperature will rise by $1.4^{0}C$ to $5.8^{0}C$ by the end of 2100. Multiple datasets show essentially the same global warming trend over the past 100 years, with the steepest increase in warming in recent decades. The evidence of human-induced climate change goes beyond observed increases in average surface temperatures; it includes melting ice in the Arctic, melting glaciers around the world, increasing ocean temperatures, rising sea levels, acidification of the oceans due to excess carbon dioxide, changing precipitation patterns, and changing patterns of ecosystem and wildlife functions. Reduced agricultural productivity with the resultant food shortages has been experienced. Studies have shown that with higher concentrations of CO_2, plants can grow bigger and faster. However, the effect of global warming may affect the atmospheric general circulation and thus altering the global precipitation pattern as well as changing the soil moisture contents over various continents.

- There has been an increase in sea level observed in some parts of the world due to excess heating of air - which has caused large scale melting of ice covers. Large scale flooding of California in 1999 and parts of western coast in India in the last 5-8 years are testimonies to effects of sea level rise. If the sea level rises by 80-90 cm, perhaps many of coastal cities of the world will be washed away besides great changes in harbours and their facilities, in sea routes and in fishery industry [3]. Loss of fertile agricultural land occasioned by flooding impacts on food security and livelihoods at household and national level. There has been an increase in drought and floods globally. Ironically, changes in the climate due to excess greenhouse gases are causing both increased drought and increased flooding. Violent storm activity increase as temperatures rise and more water evaporates from the oceans. This includes occurrence of more powerful hurricanes, pacific typhoons, and an increased frequency of severe localized storms and tornadoes. These storms often result in flooding and farmland damage hence causing food insecurity. Warming also causes faster evaporation on land leading to drought induced famine.

- Change/shifts in seasons and seasonal characters have been experienced through out the globe due to change in air temperature and rainfall patterns. Some seasons have either been shortened or prolonged. Winters have extended in many places, while summer is more severe in other places. The degree of dependability has reduced and an element of uncertainty has increased. This disorientates the farmers in the rural community who have hitherto depended on indigenous knowledge in predicting weather patterns in food production.

- Major changes have occurred in water resources of the world due to disturbances in hydrological cycles. Heavy rainfall tracts are gradually converted into low rainfall tracts with many humid areas being transformed into arid areas. Similarly, ground water depletion is high and recharging is very low.

- There has been a shift in disease/pest cycles of plants and animals. Many insignificant pests / diseases are attaining major proportions because composition of microbial population is affected by shift in temperature and hydrological cycles. These have impacted on food production output and post harvest loss occasioning food shortages and loss of livelihoods.

- Ecosystems change. Changes in climate will cause some species to shift from one region to another and in combination with other stresses such as development, habitat fragmentation, invasive species, could have negative consequences on biodiversity and the benefits that healthy ecosystems provide to humans and the environment. Water hyacinth, an invasive species in Lake Victoria has tremendously reduced fishing activities impacting on livelihoods.

Figure 1. Depicts typical ravages of climate change in Kerio Valley, Kenya May 2012

4. How climate change will affect livelihoods

The economy and environment could be affected as a result of climate change especially in the absence of countermeasures. The following are some of the livelihood sectors that are likely to face some impacts according to [5] and other literature:-

The health sector impacts will affect the populations by altering the health status of millions of people, including through increased deaths, disease and injury due to heat waves, floods, storms, fires and droughts. Increased malnutrition, environmentally related diseases such as cholera, dysentery, meningitis, lymphatic filariasis, yellow fever, malaria, TB among others in some areas will exert great pressure on the public health resources and development goals will be threatened by longer-term damage to health systems from disasters.

In the water sector, it is predicted that climate change will lead to an intensification of the global hydrological cycle hence having an impact on water resources. A change in both volume and distribution of water will affect both ground and surface water supply for industrial and domestic uses, irrigation, hydropower generation, navigation, in stream ecosystem and water based recreation. Drought-affected areas will likely become more widely distributed. In the event of drought in Arid and Semi arid environments sensitive to slight changes in climate, there is bound to be human – human and human - wildlife conflict with respect to use of the scarce resources. Heavier precipitation events are very likely to increase in frequency leading to higher flood risks. By mid-century, water availability will likely decrease in mid-latitudes, in the dry tropics and in other regions supplied by melt water from mountain ranges. More than one sixth of the world's population is currently dependent on melt water from mountain ranges.

Figure 2. Fragile ecosystems are destroyed during heavy rainfall; a consequence of climate variability. Kerio Valley, Kenya, May 2012.

Biodiversity and biomass energy will be affected by climate change by affecting both plants and animals distribution, population sizes, physical structure, metabolism and behaviour. Climate induced changes will largely influence the distribution of tree parasites and pathogens which will ultimately play an important role in determining future tree distribution. Climate change alters conditions in ecosystem making species unable to cope with sudden changes. There has been direct and indirect impact on the forest ecosystem. The direct impacts result in water stress in plants due to prolonged dry spell. This in turn increases fire hazards in forest areas. The biomass energy sub sector is sensitive to climate variability as productivity is a function of rainfall and temperature. Increased temperatures leads to drying of biomass hence declining biomass productivity like decreased fuel wood supply. Globally, most households rely on wood fuel for the cooking and heating especially in sub-Saharan Africa thus endangering livelihoods and environmental sustainability.

Agriculture/Food sector will see those mid-latitude and high-latitude areas initially benefit from higher agricultural production and many others at lower latitudes, especially in seasonally dry and tropical regions. The increases in temperature and the frequency of droughts and floods are likely to affect crop production negatively, which could increase the number of people at risk from hunger and increased levels of displacement and migration in search of livelihoods.

Human *settlement and business* are the most vulnerable especially those located in coastal areas and river flood plains, and those whose economies are closely linked with climate-sensitive resources. This applies particularly to locations already prone to extreme weather events, and especially areas undergoing rapid urbanization. Where extreme weather events become more intense or more frequent, the economic and social costs of those events will increase. Cities loom as giant potential flood or other disaster traps.

Livestock sector is affected by climate changes by interfering with the distribution, production size and frequency of disease and pests. Livestock industry depends on the balance of pasturage and water resources supply and any form of change in climate will impact negatively the livestock sector. The impacts have largely been felt by pastoralist communities who have been forced to change their livelihood from pastoralists to sedentary agro pastoralist to survive.

Climate causes instability in the *tourism sector* for those countries whose economies are largely dependent on tourism. Addition or reduction in precipitation leads to wildlife devastation and reduces the aesthetic value of sceneries hence impacting on livelihoods dependent on the industry.

Gender is similarly impacted by climate change. The gender poverty link show that 70% of the poor in the world are women and their vulnerability is accentuated by race, ethnicity and age. Most climate change policies, issues and programs are not quite gender neutral despite the fact that women and men are affected differently due to tradition, socially constructed roles and responsibilities.

5. Climate change mitigation and adaptation measures

Mitigation is "an anthropogenic intervention to reduce the anthropogenic forcing of the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks [1]. To ensure that environmental sustainability is maintained some urgent measures need to be put in place to help in sustainability of the environment by way of mitigation. Some examples of mitigation actions include developing new low-energy technologies for industry and transport, reducing consumption of energy-intensive products and switching to renewable forms of energy such as solar and wind power. Natural carbon sinks, such as forests, vegetation and soils, can be managed to absorb carbon dioxide, and technologies are being developed to capture carbon dioxide at industrial sources and to inject it into permanent storage deep underground. There is need also to manage the impact as have occurred on the environment. It is true that future impacts on the environment and society are now inevitable, owing to the amount of greenhouse gases already in the atmosphere from past decades of industrial and other human activity and to the added amounts from continued emissions over the next few decades until such time as mitigation policies become effective. Taking steps to cope with the changed climate conditions is called "adaptation".

Adaptation is "the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" [6]. The measures to be undertaken are those that will try to address the adverse impacts that may occur as a result of non action by humans with the aim of attaining a sustainable environment. Some of these measures may include some of the following; conducting risk assessments, protecting ecosystems, improving agricultural methods, managing water resources, building settlements in safe zones, developing early warning systems, instituting better building designs, improving insurance coverage, developing social safety nets and enhancing public awareness and education. All these measures are intrinsically linked to sustainable development as they reduce the risk to lives and livelihoods and increase the resilience of communities to all hazards. Both, adaptation and mitigation should be considered jointly, as some adaptation measures can contribute to reducing greenhouse gas emissions, while conversely mitigation measures can be planned to help reduce the impacts.

6. Global food security

Food security exists when all people at all times have physical or economic access to sufficient safe and nutritious food to meet their dietary needs [7]. Global food security refers to the situation where each person, member of any household is having physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life – (Food and Agriculture Organization definition). That food has to be affordable, safe and healthy, culturally acceptable, meeting specific dietary needs of the people and is obtained in a dignified manner, produced in ways that are environmentally sound and socially just. Thus there should be no perceived inadequacy of the household food supply expressed through concerns about running out of food and not having enough food to make a meal or malnourished as a result of physical unavailability of food, lack of socio-economic access to food or inadequate food utilization.

The World's efforts to meet the Millennium Development Goal of cutting hunger in half by 2015 are far from reach. With the world's population set to reach 9 billion by 2050, agricultural production will need to increase by 70% in order to meet demand. Climate change adds a new dimension of this challenge as it is one of the key drivers of change affecting the food system and contributing to rising food prices. It leads to changes in growing seasons and rainfall patterns and the increased frequency of extreme events such as droughts and floods. It has been estimated by the United Nations Environment Programme that up to 25 per cent of world food production could be lost by 2050 as a result of climate change, water scarcity and land degradation [8].

In the developing world, nearly 1 billion people are unable to meet their dietary needs. Another 5-10% is at risk of 'acute' food insecurity in times of crisis. Despite improvements, the millennium development goal on hunger is likely to be missed by a wide margin in areas like Sub-Saharan Africa, where persistent food insecurity is compounded by widespread political instability, conflict and the HIV/AIDS pandemic. The UN Food and Agriculture Organization [9] estimate that 820 million people in developing countries are suffering from malnutrition. In a world in which nearly half the population survives on $2/day or less, more than 800 million people go to sleep hungry any given night, and a child dies every five seconds due to hunger-related complications, the need to respond to the needs of the poor for food is ever-present and widespread. Despite the universal recognition of every person's right to food, vulnerability to hunger remains a daily reality for many [10].

The United States of America and European Union together provide about two thirds of global food aid deliveries. The United States of America is by far the most important donor of food aid both for bilateral programme aid and as the main contributor to the World Food Program. The World Food Program (WFP) is the primary agency responsible for administering multilateral food aid. The WFP and various NGOs administer project food aid to support a wide range of developmental projects targeting the poor in developing countries. Others include the UN Food and Agriculture Organization (FAO), the Food Aid Convention (FAC) and the World Trade Organization (WTO). All these organizations have different mandates and are concerned with different aspects of the provision of food aid. Many organizations around the world are working to find ways to produce the food needed in a sustainable way, within the limits of what our ecosystems can support for current and future generations, and to safeguard this production from the impacts of climate change. Food security is the outcome of food system processes all along the food chain. Climate change will affect food security through its impacts on all components of global, national and local food systems. It is important to note that climate change variables influence biophysical factors, such as plant and animal growth, water cycles, biodiversity and nutrient cycling, and the ways in which these are managed. Agriculture is the primary source of livelihood among many rural populations [11].

7. Causes of global food insecurity

There are many causes of global food insecurity and most of them are region specific, except climate change where impacts are felt globally. Some are human causes like destruction of fertile lands and others are non-human like natural disasters (e.g. floods). While human destruction of his mother nature through careless management practices have impacted negatively on his ability to produce enough food for the population, the contribution that humans make to climate change is potentially causing increased food insecurity globally. Industrialization, modern agricultural practices and the need to produce for the market without thinking about environmental sustainability has had disastrous effect as climate change has set in. In some areas, sea levels have risen and increased incidence of extreme events posing danger and threatening livelihoods and at the same time increasing the vulnerability to future food insecurity in the world. Coastal freshwater are being contaminated with salt water and people do not get fresh water for domestic use and plants or food crops that are not salt-tolerant cannot be grown. Storm surges become common occurrences together with flooding. This hinders people living along coast from growing food crops. Increased temperature also leads to heat stress for plants which increase evaporation and lowers productivity. Climate change has also been a cause of more frequent and more intense extreme weather events like increasing irregularities in seasonal rainfall patterns. The changing growing seasons have shifted ecological niches.

Rainfall is becoming more unpredictable and unreliable and has become a common occurrence leading to greater uncertainty among farmers and their traditional agricultural knowledge and coping strategies. The phenomenon has had immediate impact on food production, distribution, infrastructure, livelihoods and human health in all parts of the world. Where climate change has influenced rainfall and temperature patterns, the suitability of land for different types of crops and pasture is affected, including the health and productivity of forests; the distribution, productivity and community composition of marine resources and the increased incidence of pests and diseases. It also affects the functioning of biodiversity and ecosystem of natural habitats; and the availability of good-quality water for crops, livestock and inland fish production. It may also increase aridity of arable lands, induce drought and deforestation, can increase fire danger with consequent loss of the vegetative cover needed for grazing and fuel wood [12]. It also leads to depletion groundwater and induce the internal and international migration thereby triggering resource-based conflicts and civil unrest in either areas of origin or destination. Conflicts over water resources will have implications for both food production and people's access to food in conflict zones [13]. Production from both rain-fed and irrigated agriculture in dry land ecosystems accounts for approximately 25 percent, and rice produced in coastal ecosystems for about 12 percent [14].

Natural fall-back mechanisms during food crisis may also be affected. These include disappearance of traditional fruits, herbs, vegetables, mushrooms, wild foods and other coping mechanisms. It is expected that as the world climate continues to change, 5 000 plant species in sub-Saharan Africa will decrease in size or shift to other agro-ecological zones due to climate change (Levin and Pershing, 2005). All these impacts have negative influence on food security of the people living in the affected areas. At the same time people may resort to unfamiliar ways of surviving and countering food insecurity. It was observed that people may decide not to migrate but find new, unfamiliar ways of earning a living [15]. FAO has been instrumental in assisting various communities all over the World develop the right food production technologies aimed at boosting food security. They possesses technical expertise relevant to climate change adaptation in a variety of ecosystems, including agro-ecosystems (crops, livestock, grasslands), forests and woodlands, inland waters, and coastal and marine ecosystems. It works to build national, local and community-level capacities to raise awareness of and prepare for climate change impacts, assists member countries in identifying potential adaptation options and helps local people understand which are the most applicable to their particular circumstances.

Since 2002, FAO has been promoting National and Regional Programmes for Food Security (NPFS and RPFS) as instruments that help countries enhance productivity and diversify the livelihoods of rural people on a scale sufficient to achieve the 2015 targets set by WFS and the Millennium Development Goals (MDGs). This is an organization committed to eliminating food insecurity in the World. From their advice, people have created artificial microclimates, breed plants and animals with desired characteristics, enhance soil quality, and control the flow of water. Advances in storage, preservation and transport technologies have made food processing and packaging a new area of economic activity. This has allowed food distributors and retailers to develop long-distance marketing chains that move produce and packaged food. The countries that are not able to adopt new technologies need to be assisted. Developing countries urgently need more assistance to help them prepare for the impacts of climate change that are unavoidable. The transfer of the industrialised countries' best energy efficiency and renewable energy technology and assistance with disaster preparedness, agricultural productivity improvements, water management, conflict prevention, reforestation, preventing deforestation and critical infrastructure would be most appropriate.

Other important practices for addressing food insecurity include changing consumption patterns and food preparation practices, efficient water use, improving soil quality, capacity to withstand extreme events and carbon sequestration. Others include promotion of agro biodiversity for local adaptation and resilience, reducing uncertainty by improving the information base and devising innovative schemes for insuring against climate change hazards.

People need to adopt practices that enable the vulnerable to protect their existing livelihood systems, diversify their sources of income, change their livelihood strategies or migrate. Sustainable livestock management practices for adaptation and associated mitigation should also be given high priority.

8. Integrating indigenous knowledge and science based technologies

Integration of both indigenous knowledge and science based technologies is important in combating the effects of climate change on food security. Farmers need to combine the best of their traditional approaches with modern agro-science based technology. Towards this end documenting traditional knowledge of the world is paramount if an integrated approach is to be effective as most traditional knowledge remains as tacit knowledge.

9. Indigenous food systems

Communities have created and developed unique food systems over time in their specific local ecosystems. Communities have used these technologies for a long period of time and have perfected them to improve their livelihoods. Traditional knowledge in the management of agriculture and food production is important. Indigenous people in Sub-Sahara Africa have developed methods of surviving droughts and emergency. However, aid providers have ignored this vital knowledge inherent in the local people during their programme intervention. According to [16], one of the most important methods in combating desertification is the recognition of the value of traditional knowledge in drought management.

Severe changes in global climate are projected to affect livelihoods systems and consequently food security. Droughts and floods have become frequent, occasioning loss of livelihoods migration and insecurity. Compounding the vagaries of climate change is the upward trends of population increase. These are often marginalized, poverty stricken persons. Poverty poses a serious environmental threat as people exploit natural resources with inappropriate technology in order to survive. Population increase occasions agricultural practice in marginal lands. This causes resource degradation and environmental degradation leading to poor harvest and food insecurity. Indigenous food system knowledge is required to reduce the effects of soil erosion leading to poor food production. Family and tribal structures and their autonomous traditional practices of resource management and land tenure have broken down. Therefore, traditional land tenure systems and agricultural practice of improved shifting cultivation should be incorporated into policy. This is because community elders control parcels of land to be used for food production and grazing. Grass stripes are used as a form of land management in Swaziland and grazing rotation by Lake Victoria communities thus, soil erosion and biodiversity loss is checked [17].

Drought influences availability of water for crop production. This is projected to be a major constrain to food security, and economic development in the future. In Africa climate change is expected to intensify the continents critical food situation. Reduction of water quality and availability will increase food insecurity [18]. Governments must therefore fund research on crops that require less rain, are faster in maturity and pest resistant. These are the almost extinct traditional indigenous food crops. This is corroborated by the UN/ISDR 2007. Governments' agricultural policies must allow for diversification of food crops to cushion populations against loss of livelihoods in the face of climate variability. Increased production in traditional root crops and food legumes and lentils for sustainable agriculture and food security must be incorporated into agricultural policies. Production of food grain or root crops must be increased to decrease dependency on food export in Africa. Similarly, value chain actors that include suppliers, farmers, traders and processors must be strengthened in the sector of food production. This calls for the cultivation of more indigenous food crops to reduce aid dependency. Incorporating modern food production methods with indigenous food systems is ideal as people are better able to adopt new ideas when these can be seen in the context of existing practices.

Indigenous systems of crop protection against pests must be integrated into agricultural policy. This is cheap and more available system to the rural poor farmer. The wide spread use of indigenous material, such as agrochemical plants to combat pests that normally attack food crops has been reported. It is likely that climate change will alter the ecology of disease vectors and as such indigenous practices of pest management would be useful for adaptation strategies. Other indigenous systems that are adopted by local farmers include controlled bush clearing. Smoking of seeds to deter stock borers, use of green manure and green mulch spray as herbicide, all improve food production and reduces the vagaries of food insecurity. Pastoralists in Arid and Semi Arid Lands (ASAL) in Africa use a multi-species composition of herds to survive climate extremes. Traditionally they forego large grazers for small browsers like goats and sheep since the feeding pattern of the latter is lower [19].

Men and women play different roles at the household and community levels, climate change affects women disproportionately than men. Women interact with nature more but have limited mitigating and adaptive capacities. Climate change and variability are therefore likely to amplify existing patterns of disadvantage. Women in Africa are custodians of culture and customs. This vast knowledge must be used to mitigate climate change and food insecurity. Women workload in rural Africa is always based on the maintenance of household food security particularly in hardship seasons [20]. It is through this role that while modernizing policies in food production, we must adjust male bias to avoid falling into the trap of food insecurity. Women must have access to land titles, inputs and credits and must be deliberately involved in agricultural extension [21]. Inclusive policy will design and implement programmes that lead to gender equity and food security.

Figure 3. The photos depict impact of climate change and livelihood coping strategies. The photographs were taken the arid areas of Kerio Valley, Kenya May 2012.

Poverty driven environmental degradation has been exacerbated by the erosion of tradition knowledge by westernization. Traditionally, cultural norms and practices and taboos were used to regulate and ensure sustainable exploitation. Poverty drives communities to farm in marginal fragile ecosystems, using rudimentary technology leading to environmental degradation, poor yields and hence food insecurity. It is therefore considerable to conclude that the spiral events of poverty, poor technology, lack of inputs and land tenure culminate in unsustainable underdevelopment. Governments must therefore invest in their populations to eradicate poverty, thus providing a springboard to address food security for sustainable development. A healthy citizen is in a position to adapt new technology and address environmental challenges of climate change.

10. The role of technology in food security

With the world population expected to reach over 9 billion by 2050, the global demand for food is projected to increase by at least 2.5 times over current levels [22]. The challenges of feeding over 9 billion people by 2050 in a sustainable and environmentally friendly way cannot be met without the continued innovation and adoption of new technologies. To achieve notable increases in agricultural productivity, technology and innovations must be applied to the entire agricultural supply chain. From notable advances in biotechnology that can make more efficient use of water and fertilizers and reduce pesticides, to bio-fortification, improved crop varieties and best practices to reduce post-harvest losses and improve irrigation methods, a science-based approach to new and existing technologies must be applied to maximize their potential benefits worldwide. These technologies, along with traditional breeding approaches, are all essential to meeting the demands being placed on agricultural productivity [22].

Throughout the last century, the potential increase in agricultural productivity has been achieved by adopting and applying innovative agricultural technologies worldwide. These increases have not only bolstered food security, but have helped minimize the environmental impacts of agriculture. This is critical, because loss of biodiversity and habitat in turn lead to desertification, loss of fresh water sources, and greater food insecurity. Major innovations in mechanization, the use of fertilizers and pesticides, and plant and animal management and breeding techniques provided the basis for the fivefold increase in US agricultural output over the twentieth century. This increase in output was achieved with less land and labour, and in recent years with less energy and chemical use per unit of output [23].

In many parts of the world – particularly South and East Asia – growth in agricultural productivity has been rapid, largely as a result of the extensive adoption of new agricultural technologies. For millions of poor people, particularly in Asia, the technological advances of the Green Revolution (complemented by a massive increase in irrigation) provided a route out of poverty through: directly increasing producer incomes and wages; lowering the price of food; and generating new livelihood opportunities as success in agriculture provided the basis for economic diversification. Asian industrialization was in essence agriculturally led [24]. Despite decades of investment in new agricultural technology however, hunger and poverty continue to plague large areas of the developing world. The problem is particularly acute in areas of the world dependent upon rain-fed agriculture, in particular sub-Saharan Africa, where the impact of new technologies has been less apparent and agricultural productivity has at best stagnated, and may even have fallen in some areas.

11. Indigenous technology

According to [25], traditional agricultural practices in Africa provide valuable lessons to be learned from local farmers who, through their own innovations and experimentation on farms, have perfected tools such as the hoe and the plough, developed seeds and plants through preservation and selection, and designed crop mixtures and rotations leading to improved productivity. Practices like fallow, terracing, ridging mixed farming, and intercropping were practiced by local people long before the introduction of the Green Revolution. These practices provide advantages that have been identified as those that have ensured soil fertility, controlled pests as well as diversifying sources. Some examples of traditional technology method that have helped guard against food insecurity at household and national level and helped in the sustenance of the environment include but not limited to the following:-

11.1. Farmer's seed saving strategy and water harvesting

For seeds to be of quality and viable in relation to its germination rate, storage and drying are of great importance. One of the common ways of ensuring the dryness of grains even in rainy season is simply to hang on the maize cobs on the ceiling above the cooking fire. Similarly, rain water harvesting through collection pond, irrigation during the evening, water erosion control through plantation, canalling of water through the hard rock area by using wooden conduits, aquifer recharging, etc. are some examples of farmers innovations to ensure sustenance of the food production.

11.2. Solar drying

Rural communities in Africa and south East Asia have used solar to dry their foods as a form of preservation to bolster food security at the home. Fresh vegetables are immersed in salted boiling water for a few minutes and then dry them in the sun for about 3 days. Similarly, edible insects such as white ants, termites, and caterpillars, mushrooms and tomatoes are stored in the same way. According to [7], drying is also often used to preserve meat, fish, and roots. Cassava and bananas are also preserved by fermentation followed by drying. The drying helps prevent growth of the microorganisms and stops biochemical activities that cause foods to decay. This helps in nutrition and energy needs when fresh supplies are not accessible.

11.3. Storage of roots and tubers

Fresh roots and tubers are highly perishable and cannot be stored for long periods thus Cassava has to be processed within 2 days of harvesting to avoid damage. Fresh cassava, therefore, is best left unharnessed until needed. As an alternative, yams, coco yams, and cassava may be stored in underground pits after harvesting. In some instances, root crops such as cassava can be grown as a food reserve, left in the ground for up to 2 years and used as the main source of energy during lean times [26].

11.4. Hunting and gathering

This is a food procuring method used by many communities in their quest to meet their food demands. The whole exercise was done in a sustainable manner so that there is more left for the next season. Hunting was controlled to also maintain the ecosystem. Great care was taken not to kill unnecessarily.

11.5. Fermentation process

In most Africa countries, fermentation is a traditional method of preserving vegetable surpluses which, when used, enhances the overall flavor of the meal. The technique provides a suitable environment for lactic acid bacteria to grow, thus imparting an acid flavor to the vegetable. Cassava and sweet potatoes are the most commonly fermented foods. Alcoholic beverages constitute the largest category of fermented products in Africa [27]. Most of these beverages are processed from fruits. Banana beer, a popular drink in Eastern and Western Africa region is made by allowing banana juice to ferment. Palm and coconut wine are manufactured in the same way.

11.6. Home garden

Home or family garden normally run by the women play a great role in increasing small-scale production of micronutrient-rich foods. The home garden is the most direct means of supplying families with most of the non-staple foods they need year-round. These gardens have saved many families from glaring hunger because being small, they are usually planted early hence the crops ripen at the very time of need though in small quantities

Nevertheless, indigenous technology can be integrated with modern technology to come up with appropriate technologies for communities. Such technology developed with indigenous peoples input is easily adopted, less costly and uses available local knowledge. The Marakwet people of Kenya have had traditional furrow systems that they have been using for irrigation and these systems have been integrated with modern systems for best results.

12. Modern technology

There is need to adapt science-based technological innovations that are affordable and have positive improvement on global food security and have no or insignificant impact on climate and environmental sustainability. The use of modern technologies to boost food production and thus sustain the global population requires political will and sufficient investments in modern agriculture. In the 21st century, many determinants of food security are trans-boundary and multilateral agreements towards this cause, are paramount. Appropriate technological innovations are required and be implemented at all levels.

The Green Revolution drove widespread shifts in the agricultural sector from subsistence and low external input agriculture to mono-cropping with high yielding varieties. By the 1970s, Green Revolution-style farming had replaced the traditional farming practices of millions of developing country farmers. By the 1990s, almost 75% of Asian rice areas were sown with these new varieties. Overall, it is estimated that 40% of all farmers in developing countries were using Green Revolution seeds by this time, with the greatest use found in Asia, followed by Latin America [28]. The rapid spread of Green Revolution agriculture throughout most countries of the South was accompanied by a rapid rise in pesticide use [28]. This was because the High Yielding Varieties were more susceptible to pest outbreaks. Promising increases of yield were thus offset by rising costs associated with increased use of chemical inputs. Modern agriculture practices, such as precision farming, would help convert this concept of "evergreen agriculture revolution" into a reality. There is need to provide modern agriculture implements at reasonable costs, high-tech agriculture knowledge, agronomic support and agriculture extension services and help with farm planning and crop management, allowing farmers to increase their food output and net incomes in the world. Technological advancement and adaptation is vital for food security.

Sustainable development requires that technologies developed to improve food security situation in the world have least negative impact on the environment while maximizing benefits of improved food production and welfare of humans. There is need to focus on the effect of climate change on domestic production in food-insecure countries, assess climate change impacts on foreign exchange earnings, determine the ability of food surplus countries to increase their commercial exports or food aid and analyze how the incomes of the poor will be affected by climate change.

Synthetic fertilizers, pesticides and herbicides are made from non-renewable raw materials such as mineral oil and natural gas or from minerals that are depleting such as phosphate and potassium. As the price of petroleum increases, so does the cost of external inputs and machinery, forcing small farmers who are dependent on these inputs into debt. The production of agrochemicals is also an important source of greenhouse gas (GHG) emissions. In particular, fertilizer production is energy intensive, accounting for 0.6-1.2% of the world's total GHGs [29]. Industrial, chemical-intensive agriculture has also degraded soils and destroyed resources that are critical to storing carbon, such as forests and other vegetation.

The rise in use of chemical inputs has also had adverse environmental and health impacts on farm workers and consumers. A substantial portion of pesticide residues ends up in the environment, causing pollution and biodiversity decline. The extensive use of pesticides has also resulted in pesticide resistance in pests and adverse effects to beneficial natural predators and parasites [30]. The Green Revolution also brought about a shift from diversity to monocultures. When farmers opted to plant Green Revolution crop varieties and raise new breeds of livestock, many traditional, local varieties were abandoned and became extinct. And yet, maintaining agricultural biodiversity is vital to long-term food security as it is vital insurance against crop and livestock disease outbreaks and improves the long-term resilience of rural livelihoods to adverse trends or shocks [31].

In genetic engineering technology, genetically modified organisms (GMO) are created by altering the DNA of an organism, in this case a food producing plant; this is done in order to change the characteristics of the plant. Through this process of genetic engineering (GE) a plant can be made to produce a higher yield, be more resistant to pesticides, require less water and still be fast growing. The problem of food security seemed to be solved by producing plants which produce more food and are resistant to pests, so with very little testing and no real case studies and field trials, genetically engineered seeds began to be produced to grow genetically modified crops. An American company called Monsanto took the lead and became the largest producer of GM seeds as well as their famous herbicide called 'Roundup'. Monsanto made the winning combination; a very successful weed killer and their GM seeds, which are tolerant to their herbicide [32]. A lot of food that we eat today contains genetically modified ingredients and usually without our knowledge. Supporters of this technology maintain that it ensures and sustains food security around the world as the population increases. However, a debate on the socioeconomic ramifications of the way such science is marketed and used continues. Critics believe that the problem of food shortages is a political and economic problem, food shortages and hunger are and will be experienced by the poorer nations and that GE Food is an expensive technology that the farmers of the developing nations would not be able to afford easily.

Substantial improvements are possible in rain-fed agriculture, particularly in sub-Saharan Africa and South Asia. Tapping this potential requires innovative strategies to manage the sudden excesses of water and frequent dry spells. Integrating soil and water management focused on soil fertility, improved rainfall infiltration, and water harvesting can significantly reduce water losses, and improve yields and water productivity. Water storage has the greatest potential to deliver more water for food. Apart from dams, storage can also mean holding water in natural wetlands and reservoirs, in groundwater aquifers, soils, and in small tanks and ponds. Modern irrigation technologies, such as sprinkler and micro irrigation, have potential for adaptation to smallholdings; particularly where farmers are growing high-value marketable crops and where water is scarce. Affordable systems, such as bucket and drum drip irrigation kits, have been developed for small plots and vegetable gardens predominantly cultivated by women. The introduction of treadle pumps, originally developed in Bangladesh, has revolutionized water lifting [33].

Conservation agriculture technology on the other hand is a farming practice being piloted in Kenya by the government. The method contributes to sustainable agricultural production and environmental conservation, by maintaining a permanent or semi-permanent organic soil cover; through the use of mulches or cover crops, employment of zero or minimum tillage and crop rotation. Weed control is done using herbicides or shallow cultivation resulting to minimal soil disturbance, water and nutrients retention. Some of the benefits of conservation agriculture technology are reduced labor and farm-power requirements, improved soil fertility, crop yields increase over time compared to conventional farming, livelihood improvement, decreased carbon dioxide in the atmosphere and reduction of climate change.

Conservation agriculture technology acknowledges the importance of creating and maintaining a healthy soil and integrates various approaches to the management of weeds, pests, diseases, and plant nutrients. Adoption of conservation agriculture technology will help crops adapt to changing climatic conditions and ensure harvest despite unreliable rainfall. This is an innovation whose time has come and cannot be stopped.

13. Adopting evidence based Innovative technology for environmental sustainability

There is need for countries and communities to adopt research based innovations that have proved effective in addressing food insecurity and environmental sustainability. The following are some of the examples;

Integrated pest management: The aim is to produce quality crop yields with techniques that minimize environmental impacts. Pest outbreaks can thus be prevented or limited, by developing and using green mechanical, biological, chemical and other controls only as needed.

Fertilizers: The use of fertilizers helps increase cultivated soil carbon reserves by increasing the photosynthetic conversion of CO_2 to biomass that is subsequently converted to soil organic matter.

Water management: Agriculture depends on water availability and water quality, thus it will be increasingly important to develop innovative strategies for sustainable water management. Innovative methods for conserving water on the farm-level will be important, such as improved irrigation techniques and indigenous furrow/pans irrigation.

Improved seeds: Where appropriate, improved seeds, including those derived through biotechnology, have the potential to make a major contribution to increasing crop yields, nutritional content, and productivity, and mitigating environmental impacts such as climate change. Drought-tolerant crop varieties, for example, have the ability to help protect yield potential when water is scarce, while other crop varieties can be produced with genetics that protect against yield losses due to flood conditions. Salt-tolerant crops can be developed to allow land that has become unproductive for crops to be used for food production. Breeding of plants with improved water efficiency will be important. Plants with an improved nitrogen-efficiency can grow and produce high yields with lower amounts of fertiliser or have much higher yields under the same fertiliser input. Such plants would also help to minimise the emission of nitrous greenhouse gases (GHG) and save energy on the production of nitrogen fertiliser an energy intensive process [34].

Reduction of GHG from livestock: Livestock waste products are a source of GHG emissions. There are a number of examples of how best practices can help reduce emissions. For instance, research to reduce GHG from livestock is looking at selective breeding and biological means of reducing emissions. Examples include biogas production from animal waste by using co-digestion.

Using information technology (IT) for agriculture development: Cell phones offer a means of providing valuable information and advice to farmers in remote places. IT applications in agriculture are limited in the developing countries thus there is significant potential for maximising gains in agriculture through various IT applications, such as drought and flood management coupled with climate and weather information, waste reduction, risk mitigation and market development. Local operators of ICT can search for answers in a central database and provide information on either crop prices, weather forecasts for irrigation, water management and plant diseases. Therefore, it is critical to build capacity among farmers and create conditions that would allow them to access and apply these IT applications.

Minimizing harvest losses: The reduction in pre and post harvest losses would in itself contribute in a major way to food security. There is an urgent need for replacing the rudimentary pre and post-harvest practices with innovative, scientific and low cost models.

Adjustment in farm practices: Farm mechanization will be essential for increasing food production in developing countries. Machinery and implements have to be tailor made to the conditions in each of the agro-climate zones. In addition, the development of prediction tool models and on-site diagnostics can optimize farm practices by minimizing the inputs (fertilizer, water, agrochemicals) and maximizing the yield.

Carbon Sequestration: The process of transferring atmospheric CO_2 into soil and biotic pools can enhance soil quality, increase agronomic productivity, improve quality of natural waters, and lower rates of anoxia (decrease in the level of oxygen) or hypoxia (dead water) in coastal ecosystems.

Conservation agriculture: Conservation agriculture techniques such as low or no-till agriculture, made possible through the use of herbicides and biotechnology-derived crops, prevents wind and water erosion and loss of ground moisture, improves soil biodiversity, increases soil fertility, and in appropriate, carefully managed cases has the potential to reduce carbon emissions. In addition, by limiting soil disturbance and promoting a permanent soil cover, conservation agriculture can contribute to limiting emissions from agriculture by increasing soil carbon content (i.e. reducing emissions) and preventing erosion.

Enzyme applications: The number of enzyme applications in food applications has been growing. Enzyme technologies can improve the quality and quantity of food products. Some examples include reducing the content of unsaturated fat in fat spreads, improving vegetable flavour, increasing cheese yield, improving phosphorous use by certain animals, enhancing fiber digestion, and slowing the staling of baked goods [34].

Figure 4. The photo shows adaptive agricultural mechanization in the Kerio Valley Region of Kenya, 2012

A low-carbon economy would be beneficial to the world. Research, development and deployment of clean technologies would be the most appropriate for the present and future generations not only in food production and distribution but also in all spheres of development. Governments need to encourage this innovation by all players with strong investment frameworks to harness the power of markets and stimulate research, development and deployment. A mechanism to accelerate technology development and transferring support of countries' action on adaptation and mitigation was established at the United Nations climate change talks in Cancun (2010). The mechanism was to be guided by countries' most urgent needs, priorities and national circumstances. They also provided direct in-country advice and support to facilitate prompt action on the deployment of technologies based on identified needs, including through a network of national, regional and international technology centres, networks and organizations. While developed countries have a responsibility to support developing countries to acquire clean technologies, it is important to recognize that new technologies come from all over the world.

14. Conclusion

This study analysed the importance of integrating indigenous knowledge systems and modern science based agricultural technologies to attain a food secure population in the face of climate change hence securing livelihoods and environmental sustainability. The study has shown that it is important to approach food security issues and climatic changes in a multi-faceted approach. The paper argues for an explicit recognition of a hybrid evidence based approach which recognizes the need for the integration of traditional food systems, modern food systems and technologies globally. To address global food insecurity, there is a need for countries to adopt protocols and treaties pertaining to climate change mitigation. There is also a need to translate the available knowledge on climate change mitigation into action through design and implementation of evidence based interventions. Countries are encouraged to implement environmental sustainability best practices that include low carbon emission energy technologies and promote the use of energy efficient processes. Capacity building and awareness of the interrelationship of intricate chemical, physical and biological systems should be enhanced to ensure that communication about climate change and food security is meaningful. This allows people to make informed and responsible decisions towards sustainable food security and environment.

Diversification of livelihoods, adaptation of agricultural technologies, enhancing early warning systems, drought monitoring and seasonal forecasts with respect to food security is important. Improved management of cultivated land and livestock management, the use of new, more energy-efficient technologies by agro-industries and protection of ecosystems are also necessary actions towards sustainable use of the environment for food security

The main challenge to the adoption of an integrated approach is the fact that traditional knowledge exists within diverse communities with diverse traditions and most of it is not documented. Access to such knowledge is limited and therefore more research is necessary to document traditional knowledge for effective utilization in a future hybrid system. Adopting modern technologies is expensive and the process of integrating technologies requires experts who will be supported through local and community based research. The process of capturing and translating traditional knowledge into action will remain a significant challenge in most developing countries.

Recommendations for further research

- We recommend further studies on approaches to integration of indigenous knowledge systems and the science based technologies (Hybrid system) towards improved food security and environmental sustainability
- How communities can be involved in policy design, implementation and evaluation in relation to the hybrid system

- More research on community food systems and coping strategies in face of climate change especially in most developing countries
- More research on intellectual property rights in relation to indigenous knowledge systems as related to food security and climate change.

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Chapter 10

Disaster Risk Management and Social Impact Assessment: Understanding Preparedness, Response and Recovery in Community Projects

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Additional information is available at the end of the chapter

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1. Introduction

Disaster refers to an emergency caused by natural hazards or human-induced actions that results in a significant change in circumstances over a relatively short time period. Typical examples are death, displacement, disease, and loss of crops. Others may include damage to physical infrastructure, depletion of natural and social capitals, institutional weakening and a general disruption of economic and social activity. Disasters may differ somewhat in the trigger, scope, duration and requisite actions (Coletta, 2004, Olorunfemi and Raheem, 2007).

The global scenario in relation to disasters is dismal. World statistics indicate present and future trends of increasing impacts from natural and human made hazards on life and livelihoods (Niekerk, 2002; Ojo, 2003). During the past four decades, hazards events such as earthquakes, drought, floods, storms, fires and volcanic eruptions have caused major loss of human life and livelihoods; destruction of economic and social infrastructure and significant environmental damage. According to Gavidia (2000), natural disasters such as earthquakes, floods and hurricanes can wipe out years of urban development by destroying infrastructure and housing and by injury or killing thousands of people. The 2011 Tsunami in Japan is an example of a disaster characterized by an immense loss of lives and property.

Social and economic structure of a society is a major determinant of the vulnerability of the population to the impact of disasters. This explains the variation in the impact of disasters and environmental emergencies all over the world. The Munich Re-insurance estimated that economic losses due to environmental emergencies have increased three-fold from the 1960s to the 1990s, and in the first few years of this decade, are running about US $50 billion per year.

Although most of these economic losses occurred in industrially developed parts of the world developing countries in Africa and Asia suffer greater burden of the relative impact of these disasters. The effects of disasters on such human and economic sectors as employment, balance of trade, indebtedness from reconstruction and loss of capital continued to be felt for many years after disaster events (CERD, 2000; Mac Entire, 2001).

Developing nations in particular, experience pervasive risk of devastation, human and property loss resulting from human and natural disasters (Gbadegesin, et al, 2010). According to Henderson (2004), this level of risk is attributable to socio-economic stress, aging and inadequate physical infrastructure, weak education and preparedness for disaster and insufficient fiscal and economic resources to carefully implement the preparedness, response, mitigation and recovery components of integrated emergency management.

Disaster risk is a potential factor in many development projects. Environmental hazards can affect a project area, with socio-economic consequences for the project's target populations. Development projects can increase or reduce the risk of natural disaster, through their impact on social resilience and the natural environment. By understanding and anticipating future hazard events, communities, public authorities and development organisations can minimise the risk disasters pose to socio-economic development. Understanding the interactions between projects and environmental hazards is crucial in ensuring the sustainability of development gains. Sustainable development is accepted as a fundamental objective for public policy and decision making because the overall objective of any development process is to enhance the quality of life of the target population. Thus the growing acceptance of sustainable development as an over-arching policy goal has rightly stimulated interest in assessing the impact of particular intervention on sustainable development at aggregate, sectoral or project levels (Centre for Good Governance, 2006). This sustainability objective is justified based on the fact that issues pertaining to the ecosystem's capacity to tolerate and respond to population growth and other human induced stresses have become essential for sustainable management of natural resources and human livelihood systems related to them.(Uito and Morgan, 1996). Thus due to increased pressure on resources accompanied by evidence of environmental deterioration, poverty inequality, and general economic decline needed to be addressed in regards to the immediate or potential environmental damage and social consequence that may be associated.

Social impact assessment can therefore play an important role in the understanding of the consequences and social outcome of projects that are meant to tackle poverty, enhance community development or designed to reduce vulnerability to disasters during environmental emergencies.. According to the Inter-organizational Committee of the U.S. Department of Commerce National Oceanic and Atmospheric Administration National Marine Fisheries Service (1994), "social impacts" refers to the consequences to human populations of any public or private actions-that alter, or are capable of altering, the ways in which people live, work, play, relate to one another, organize to meet their needs and generally cope as members of society. The term also includes cultural impacts involving changes to the norms, values, and beliefs that guide and rationalize their cognition of themselves and their society. Social Impact Assessment (SIA) is the process of analysing, monitoring and managing the social consequences of policies, programmes and projects. These consequences may be positive or negative, intended or unintended, direct or indirect; they may be short-term impacts or long-term changes. As well as helping to explain how a proposed action will change the lives of people in communities, SIA indicates how alternative actions might mitigate harmful changes or implement beneficial ones.

The rest of this paper is subdivided into four sections. After this introduction the next section is devoted to the clarification and definition of major conceptual issues with a view to establishing a link between each of the concepts and providing a framework for the entire paper. We also provide a discussion on the ways disaster risk can be minimised in community development projects. The next two sections in the paper examine respectively the livelihood contexts in disaster management and the need for a process that integrate disaster risk into community projects through social impact assessment. In this section, the paper provides a typical example from previous projects. The SIA process is also discussed as a series of interrelated steps and how hazards and disaster risk typically require a SIA. Finally the last section is devoted to examining the critical challenges to the success of adoption of SIA in community projects.

2. Some conceptual issues in disaster risk management

Conceptually, the relationship between vulnerability, hazard and disasters has been described as the Pressure Model or Disaster Crunch Model by Blaikie et al (1994). These experts claim that vulnerability progresses in the following three states:

- **Underlying (remote) causes:** a set of deep-rooted factors within a society that interact synergistically to form and maintain vulnerability.
- **Dynamic pressures:** this represents a process which channels the effects of negative cause into unsafe conditions. For instance, a lack of basic services at the household level or due to a set of macro-forces.
- **Unsafe conditions:** this stage is the vulnerable context where people and/or property are exposed to disaster risk. An example is the construction of shanty buildings on fragile or sloppy urban land.

Disaster management aims at motivating societies at risk to be more involved in the conscious management of risk and reduction of vulnerability in our various communities. As a cross cutting issue, it demands substantial commitment from public authorities/ Civil society and a greater inter-sectoral and policy coordination at all levels. This section provides a clarification of some terms used in disaster management.

2.1. Hazard

A hazard can be defined as a potentially damaging physical event, phenomenon or human activity which may cause the loss or life or injury, property damage, social and economic disruption or environmental degradation. Hazards can include hidden conditions that may represent future threats and can have different origins. These include natural (geological, hydro-meteorological and biological) and/or induced by human processes (environmental degradation and technological hazards) (ISDR 2002: 24).

According to Niekerk (2002) hazards can be single, sequential or combined in their origin and effects.

Each hazard is characterized by its location, intensity and probability. Typical examples of hazards can be the absence of rain (leading to drought) or the abundance thereof (leading to flooding). Chemical manufacturing plants near settlements can also be seen as hazards.

Similarly, incorrect agricultural techniques will in the long run lead to possible disasters such as loss of crops and famine. Hazards can either be a creation of humans or the environment. Although the farmer can be planned for than the latter, in both cases, the management of hazard will remain the same.

2.2. Vulnerabilities

Vulnerabilities is a set of prevailing or consequential conditions resulting from physical, social, economic and environmental factors, which increase the sustainability of a community to the impact of hazards (ISDR 2002: 24). It can comprise of physical, socio-economic, environmental and/or political factors that adversely affect the ability of communities to respond to events (Jegillos, 1999). Blaike et al (1994) is of the opinion that vulnerability is the characteristics of person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a hazard.

Vulnerability can be expressed as the degree of loss resulting from potentially damaging phenomenon or hazard (Niekerk, 2002). In other words, vulnerabilities can be measured by the level of fatality i.e. amount of deaths, losses of properties or cash etc. Population increases due to high birth rate and the lack of good governance do make communities in developing nations to be highly vulnerable to hazards.

The community and its members may or may not be willing participants in contributing to or tolerating the conditions leading to vulnerability. Taken together, they create a dynamic mix of variables, each of which results from a continuous process. Vulnerabilities can be physical, social or attitudinal and can be primary or secondary in nature. If there are positive factors, that increase ability to respond to needs effectively or which reduce susceptibility, they are considered capabilities or coping mechanics.

Aspects contributing to vulnerability:

- Political factors
- Economic factors
- Physical factors
- Social factors

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- Ecological factors

2.3. Risk

Risk is usually associated with the inability of people to manage hazard events that may eventually lead to negative consequences like destruction of the environment, socio-economic activities, properties and losses of lives.

Risk in terms of disaster management has a specific focus (UN, 1992). It can be defined as the probability of harmful consequences (ISDR, 2002), or expected losses (lives lost, persons injured, damage to property and/or the environment, livelihoods lost, disruption of economic activity or social systems) due to the interaction between humans, hazards and vulnerable conditions. Risk is therefore the possibility that a particular hazard might exploit a particular vulnerability (Nierkerk, 2002).

It is the production of the possible damage caused by a hazard due to the vulnerability within a community. In other words, risk is usually due to hazard events exploiting the vulnerable situation of an environment or community. The poorer communities are more at risk because of their high vulnerability to hazard situations due to their low coping capacities. The perception of risk and causes vary from community to communities and culture to cultures.

Two elements are essential in the formulation or risk: the probability of occurrence of a given threat (e.g. a hazard); and the degree of susceptibility of the element (e.g. a rural community) exposed to that source (vulnerability (ISDR, 2002: 41).

2.4. Disasters

A disaster is a serious disruption of the functioning of a society, causing or threatens to cause, widespread human, material, or environmental losses which exceed the ability of affected community to cope using only its own resources (South Africa, 2002). Disasters can be sudden (flash floods) or progressive (drought). Disasters are caused due to the interaction of humans with their environment.

A disaster is a function of the risk process. It results from the combination of hazards, conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of risk (ISDR, 2002: 25).

Extreme natural phenomena do not in themselves constitute hazards. It is only when such phenomena occur in an environment where they pose a threat to human life, property, infrastructure or the environment that they can be classified as hazards. Similarly in the case of technological developments, it is only when such developments pose a danger e.g. industrial accidents, infrastructure failures. In essence, a disaster is the result of a hazard's impact on society. So the effects of a disaster are determined by the extent of a community's vulnerability to the hazard.

Hazards in themselves do not constitute disasters. The magnitude of disaster, according to Niekerk, is usually described in terms of the adverse effects which a disaster has had on lives, property and infrastructure; environmental damage; and the costs attached to post-disaster recovery and rehabilitation. Simply out, therefore, disaster risk is the product of the combination of three elements – vulnerability, coping capacity and hazard (ISDR, 2004). This interaction is illustrated in the following formula.

$$\text{Disaster risk (R)} = \frac{\text{Vulnerability (V) x Hazard (H)}}{\text{Capacity (C)}}$$

Hazards are increasingly dynamic and with highly varying potential impacts. A wide range of geographical, meteorological hydrological, environmental, technological, biological and socio-political hazards can threaten livelihoods and sustainable development.

Hazards can be classified into three broad categories:

- Natural hazards
- Technological hazards
- Environmental degradation.

It should be noted that all communities be it rural or urban are vulnerable to hazards. However, different regions will be more prone to certain types of hazards than others.

Natural hazards are those triggered by climatic and geographical variability, which is at least partly beyond the control of human activity (Palm, 1990).

Technological hazards represents dangers originating from technological or industrial accidents, dangerous procedures, infrastructure failures or certain human activities, which may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation.

Degradation of the environment is processes induced by human behaviour and activities (sometimes combined with natural hazards) that damage the natural resource base or adversely alter natural processes or ecosystems. Potential effects are varied and many contribute to an increase in vulnerability and the frequency and intensity of hazards.

The linkages between natural hazards and human-driven disasters and distressing environmental and humanitarian situations are increasingly present, particularly as the poor are compelled to exploit scarce environmental resources simply for survival. Deforestation, land degradation, and related food security are shaped by human resource use (e.g. urban squatting on marginalized hillsides), in turn sometimes creating conditions for flooding, landslides and drought.

To ensure an integrated approach by all relevant role players in assessing hazards and determining the risk and vulnerability in our communities, there is need for risk and vulnerability analysis. The following steps should be followed in order to engage in risk and vulnerability analysis.

- Identify the nature, extent, and risk of hazards;
- Determine the existence and degree of vulnerabilities;
- Identify the capabilities and resources available;

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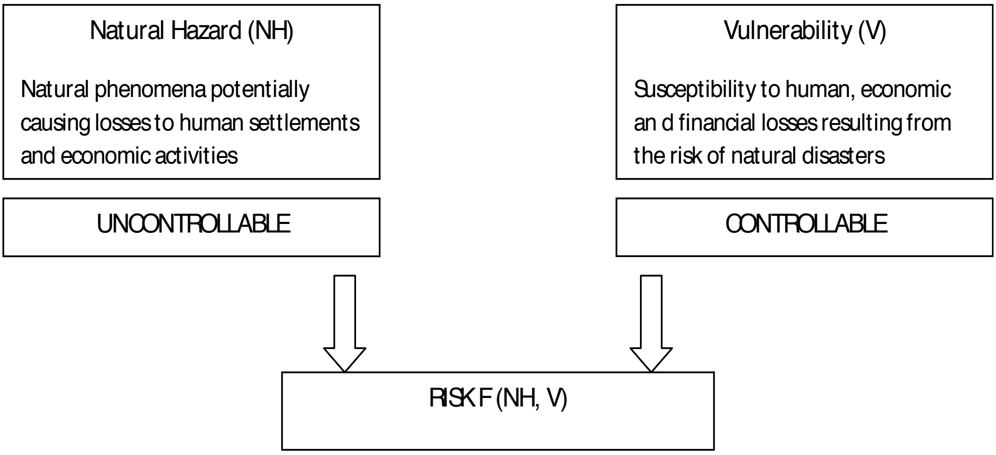


Source: Keipi and Tyson, 2002

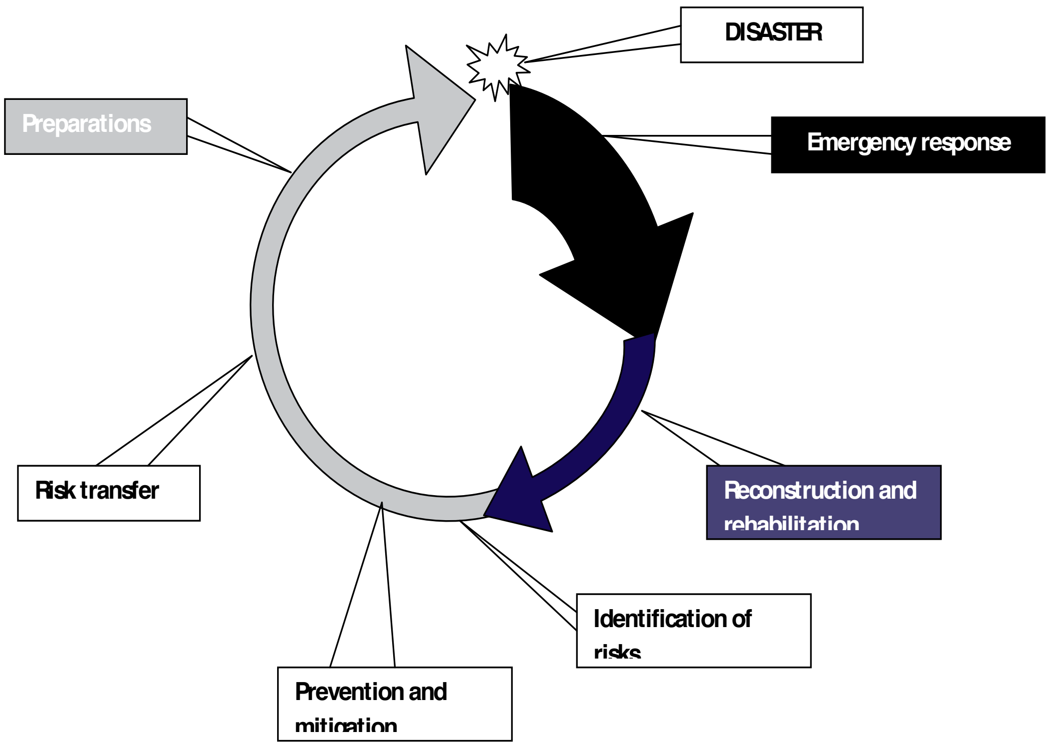
Figure 1. Natural Hazard, Vulnerability and Risk

- Determine the acceptable levels of risk, cost-benefit considerations;
- Develop methods Set priorities relative to time, resource allocation effectiveness of results;
- to protect people and key resources and reduce overall losses;
- Design effective and appropriate management systems to implement and control.

The strategies that can be used for the improvement of the application of risk and vulnerability analysis, according to Niekerk (2002) include the following:

1. Include analysis of natural hazard risk as part of on-going natural resource evaluation and development strategy formulation (in terms of integrated development planning and projects) (see Figure 2).
2. Identify and formulate mitigation measures for development investment project.
3. make information on natural hazard and community vulnerability more widely available more accessible to emergency response and development planning departments.
4. Train planning technicians and decision-makers in hazard assessments, vulnerability analysis, and disaster mitigation appreciation and techniques.
5. Review risk perceptions of different economic groupings, (e.g. farmers, fishermen, small business community, labourers etc.).
6. Special emphasis on "lifeline systems" vulnerability analysis.
7. energy sector vulnerability in relation to natural hazard.
8. Floor hazard assessment and early flood alert systems as part of integrated development (or agricultural) projects.

9. Include hazard assessment and vulnerability reduction measures as a part of provincial and local development plans.
10. Include landslide hazard and vulnerability assessments in metropolitan areas and on critical transportation routes.
11. Use of geographical information systems in national, provincial, and local government level analysis of natural hazards, resources, populations, critical facilities, infrastructure.



Source: Keipi and Tyson, 2002

Figure 2. Risk Management as a Virtuous Circle

3. Risk identification and analysis

To identify the risk of natural disasters at an individual, local or national level, it is necessary to estimate the potential magnitude and probability of natural hazards, as well as to estimate the potential magnitude and probability of natural hazards, as well as to evaluate the vulnerability of each of them. According to Keipi and Tyson (2002), vulnerability may be evaluated from various standpoints (physical, social, political, technological, institutional, environmental, cultural and educational). Vulnerability to natural disasters is the result of anthropogenic factors; that is, factors that result from the interaction between human beings and nature.

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Additionally, vulnerability is a consequence of the individual and political decisions that a society makes before a hazard occurs, which are evident once the disaster takes place (ECLAC-IDB, 2000).

Freeman, et al (2001), analyze the components of different types of vulnerability and cite studies that make an effort to measure the potential physical, social and economic consequences of natural phenomena. Those who concentrate on physical vulnerability analyze the impact on buildings, infrastructures and agriculture. For example, the Latin American's Council on Applied Technology publishes vulnerability studies on the earthquake resistance of 50 types of structures (ATC, 1985). Those who focus on social vulnerability estimate the impacts on especially susceptible groups such as the poor, pregnant women and infants, the handicapped, children and youths. Those interested in economic vulnerability calculate the potential impacts on economic processes and assets.

The results of the hazard analysis and of the evaluation of vulnerability are then combined to yield an estimate of risk (defined as expected loss per period) (Keipi and Tyson, 2002). A full scope evaluation of risk encompasses the appraisal of potential losses generated by the disaster and identification of those affected by the risk. The evaluation of the risk makes it possible to develop risk management strategies with two basic components:

i. prevention and mitigation actions to reduce potential human, social or economic losses; and

ii. measures to establish financial protection against the risks that cannot be reduced.

The availability of information is critical for any action aimed at reducing the impact of disasters. Projection of the likelihood of their occurrence and estimates of their impact allow decision makers to evaluate the total risk to a country, a geographical area or a specific sector, as well as to establish concrete prevention and mitigation measures and investments.

According to Keipi and Tyson (2002), prevention and mitigation actions require a good understanding of natural threats, vulnerability and risk. For example, given the frequency of disaster events that have occurred in Latin America and the Caribbean, on many occasions, investments in prevention and mitigation in the affected countries were not adequate to withstand the natural threats (see also Charveriat, 2002).

4. Livelihoods context for disaster management

While physical tangible assets such as stronger homes, hospitals etc are crucial to reducing risks from disasters, there are many less tangible assets which people depend on to recover and survive. For instance, following an earthquake disaster in India on 26 January 2001, an evaluation by the London-based Disasters Emergencies Committee (DEC), one villager said, "We received 2,000 tents for 900 households because we had a prominent politician in the community". Some villagers proved more capable than others in accessing aid for relief and reconstruction. Why? The DEC's evaluation found that "Women, lower income groups and those representing smaller number stated they were left out of decision-making in the relief committees and hence were also omitted from relief distribution".

The livelihoods – based approach to disaster reduction tries to unpack different aspects of vulnerability and capacity. It describes how people, both rich and poor, access the assets they need, how these assets are controlled and how assets are used both to improve livelihoods and to reduce vulnerability to disasters and "shocks" such as ill-health or unemployment. Tangible assets can be both physical (e.g. relief, safe housing) and financial (such as income, savings, insurance). However, non-tangible assets are just as important. They include alternative skills, training and disaster awareness (human assets); community organization, self-help and solidarity (social assets); representation in decision-making and the ability to lobby leaders for action (political assets). These non-tangible resources are often ignored by disaster managers, but prove pivotal in sustaining disaster preparedness, mitigation and rehabilitation. The non-tangible assets which include skills training to improve earning opportunities, raising awareness of vulnerable people's right, building the capacity of self-help community groups, and strengthening the involvement of the poor in the decision-making process should be enhanced.

The livelihoods approach therefore sits on the cross-roads between disasters and development. It makes clear that disasters are part of everyday life, and must be overcome if livelihood is to be sustainable. Within this approach, disaster mitigation is in effect the act of building up tangible and non-tangible assets to reduce vulnerability. This leads to another key feature of the livelihoods approach which is the need to view vulnerable communities in a holistic rather than a sectoral way. The livelihoods approach sees people as the starting point of all interventions to reduce risk. People's lives are complex and do not fit nearly into the sectoral areas that aid practitioners specialize in. Solidarity among neighbours and their willingness to help in times of disaster, for example, is more valuable than the best drafted preparedness plan. By rooting risk reduction in a developmental context, livelihoods strategies enable disaster managers to take better account of the complex interaction of life that people themselves employ to mitigate, respond to and recover from disaster. According to WDR, 2001-2001, there are three key priorities in accounting for the complex interaction namely:

- *Build non-tangible assets*: Improving the skills, self-help and solidarity of households and communities will prove as important in the face of disaster as investing in physical and financial defenses.
- *Strengthen everyday lives*: Preparing for major disasters are only part of risk reduction. Smaller, ongoing disasters can over a period of time, take a heavier toll than big one-off disasters. So strengthening everyday lives by investing in human, social and political assets will help reduce the risk posed by a whole range of hazards, large and small.
- *Listen to local priorities*: The livelihoods approach puts vulnerable people and their priorities at the center of aid strategies. Despite much rhetoric, thus often doesn't happen. For instance, a London-based Disasters Emergencies Committee Evaluation in Gujarat India discovered people constantly emphasized the need to restore livelihoods rather than receive relief and expressed some frustration that outsiders did not listen to them on this point. They wanted

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to receive cloth and make their own clothes rather than receive clothing but no one took any notice.

5. Integrating disaster risk into community projects through social impact assessment

Sustainable development and disaster reduction are essential preconditions for each other. Natural disaster risk is a potential factor in many development projects. Environmental hazards can affect a project area, with socio-economic consequences for the project's target populations. Development projects can increase or reduce the risk of natural disaster, through their impact on social resilience and the natural environment.

Social impacts can be characterized and defined in many ways. The following definition is widely understood and used:

"By social impacts we mean the consequences to human populations of any public or private actions that alter the ways in which people live, work, play, relate to one another, organize to meet their needs and generally cope as members of society. The term also includes cultural impacts involving changes to the norms, values, and beliefs that guide and rationalize their cognition of themselves and their society."(Inter-organizational Committee on Principles and Guidelines for Social Impact Assessment, 2003).

SIA originated as a socio-economic component of environmental impact assessment (EIA), although it has since expanded and developed considerably, in developed and developing countries. SIAs can be carried out at different stages in project and policy development, from initial planning to implementation and post-implementation evaluation. In project-level assessment, typical applications include considering the likely impacts of new industrial activities, construction, land use or resource management practices. SIA often forms part of a broader social analysis or assessment, but has a distinct and more specific purpose.

As a conceptual model, SIA is equipped to take hazard and related disaster risk into account, whether these are external factors affecting a project or conditions created or magnified by the project itself. In general, SIA can be understood as a framework for evaluation of all impacts on humans and on all the ways in which people and communities interact with their socio-cultural, economic and environmental surroundings.

By providing an understanding of the community and its social processes, SIA makes it possible to:

- identify the direct and indirect social consequences of risks (i.e., the social impacts which could arise from a hazard event); and

- develop appropriate and effective mitigation mechanisms to hazards which harness community resources and recognize community reactions to events.

SIA theory accepts that social, economic and biophysical impacts are interconnected and that change in any one of these domains will lead to changes in the others. Seen in this way, SIA has clear linkages to EIA and other forms of ex-ante impact assessment, as well as with vulnerability and sustainable livelihoods analysis. Guidance on SIA makes it clear that good practice in project design and implementation is risk-averse.

However, while hazards and risk are important features of the SIA process, SIA is not specifically a risk assessment but a means of understanding and measuring human responses to situations that may be risky or threatening.

Therefore, SIA is not commonly used *by itself* as a method of analysing hazard risks generated by a project or external to it. It is more common for a formal risk analysis or a health impact assessment (see Box 2) to be undertaken, either to complement the SIA or within a broader EIA of which the SIA is part.

6. Integrating hazard and disaster risk into the SIA process

According to the Centre for Good Governance (2006), a conventional SIA process comprises the following ten steps, which are set out below with comments about how hazards and related disaster risks can be incorporated into the process.

Step 1. Develop public involvement programme

The first step is to develop an effective plan to involve the public. This requires identifying and working with all potentially affected groups. It should explicitly include those who might be exposed to greater (or lesser) hazard risk as a result of the project. Stakeholder engagement is vital to SIA and should take place throughout the assessment. This should involve genuine participation in the process, not merely consultation.

Step 2. Describe proposed action and alternatives

The proposed action or policy change (and alternative approaches, if appropriate) is described in enough detail to begin to identify the data requirements for an SIA and design the framework for assessment. Potentially key types of social impact, including those related to disasters, should be identified and plans made to obtain relevant data. This step is equivalent to the screening stage in an EIA.

Step 3. Describe relevant human environment and zones of influence

Relevant data on the geographical and human environments related to the project are collected and reviewed through a baseline study or community profile. This study could cover relationships between people and their biophysical environment (e.g., ecological setting, aspects of the environment seen as resources or problems, patterns of resource use) and culture, attitudes and social–psychological conditions (e.g., risk perception, psychological coping).

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Hazards and vulnerability should be factored into the baseline analysis.

Step 4. Identify probable impacts (scoping)

This stage seeks to identify the full range of possible social impacts (including those perceived by affected groups). Early, comprehensive and systematic screening can identify potential hazards and associated risks that might affect the project and communities at any stage in the project cycle, as well as the impact the project itself might have on disaster risk. It is important that the views of all affected people, including those vulnerable to hazards, are taken into account.

Step 5. Investigate probable impacts

Investigation of the social impacts identified during scoping is the most important component of the SIA. A range of methods, including modelling and scenarios, can be deployed to investigate probable future impacts. Hazardous events (as external factors or consequences of the project) and their risk or uncertainty should be included in trend and scenario analysis. As part of the latter, scenarios should be developed of the social consequences of exposure to the hazards identified (e.g., using fault- or event-tree procedures).2 Records of previous experiences (including disaster events) provide valuable data for this process.

Step 6. Determine probable response

The responses of all affected groups to the impacts are assessed, in terms of attitude and actions. This should include responses to changes in social vulnerability as a consequence of the project and to a disaster event with an impact on the project. Differential vulnerability between social groups should be recognized.

Step 7. Estimate secondary and cumulative impacts

Secondary (indirect) and cumulative project impacts are assessed, although it is almost impossible to identify all dimensions of social impacts because of the way in which one change leads to others. Future patterns of vulnerability, both as long-term results of the project and due to other factors (e.g., climate change), should be considered in this stage.

Step 8. Recommend changes or alternatives

The consequences of changes to the plan or alternative interventions are assessed as in step 5 (though usually on a more modest scale) and the same key issues should be considered.

Step 9. Mitigation, remediation and enhancement plan

A plan is developed for mitigating adverse impacts, by not taking or modifying an action, minimizing its impacts through design and operational changes, or compensating for its impact by providing alternative facilities, resources or opportunities. This might include risk mitigation strategies. Impact avoidance should be the first priority, impact reduction or minimization undertaken if avoidance is not possible, and offsetting or compensation for adverse impact used only when no other options are available.

Step 10. Develop and implement monitoring programme

A monitoring programme is developed to track project or programme development and compare actual impacts with projected ones.

7. Critical factors for success

According to IPIECA (2004), the following factors may be important in making sure that social impacts associated with natural hazards are addressed through the SIA process:

- SIA should be linked to the rest of the appraisal process, especially to EIA and associated risk assessments, and the results of these different assessments related to each other in a comprehensive and coherent analysis of project impacts.
- Whilst a holistic view is essential, hazard and related risk issues should be kept in proportion, both with regard to their intrinsic significance and in relation to other social impacts.
- Impact assessment must feed back into project design, leading where necessary to development of avoidance or mitigation strategies.
- Communities' perceptions are important indicators of hazards and associated risks, and of their likely responses to project interventions.
- Affected communities should be fully involved in the assessment, not just as providers of information (i.e., public consultation), where their extensive knowledge of local hazards and risk management strategies will be valuable, but in negotiations with other stakeholders about avoidance or mitigation options.
- Positive benefits of projects in terms of reducing risk should be acknowledged.
- Findings should be communicated to decision-makers and acted upon by them – SIA is a tool to help make decisions.

8. Conclusion

When placed in the context of sustainable development, disaster management represents an important aspect of socio-economic and national security, therefore facilitating a continuous development process. Disaster reduction policies and measures need to be implemented with a two-fold aim; to increase the resilience to natural hazard while ensuring that development efforts do not increase vulnerability to these hazards.

It is important to emphasize that disaster risk reduction is a proactive approach that needs to be integrated in regular development planning and poverty reduction program at all levels. Policymakers in the development and poverty reduction sector need to recognize that disasters are not just "setbacks" or "roadblocks" to development, but result from the paths that development is pursuing. Thus by changing our planning processes, and incorporating disaster risk assessment in the planning of all new development projects, we can make sure that the future natural hazards will encounter resilient communities that are capable of withstanding their impact and therefore remain mere emergencies rather than disasters. We need to recognize that we can mitigate the impact of disaster and make mitigation the cornerstone of disaster management interventions. We must shift the focus to the most poor and vulnerable sections of our society, and ensure that our interventions are community-based and driven. To do this the extent to which a community disaster risk space is linked with environmental management practices must be recognized and given adequate consideration. For instance, during flood events, a sustainable risk reduction must take note of increased flood that is caused by the conversion of natural landscapes into agricultural areas such that flood mitigation does not jeopardize agricultural practices with an attendant risk of food insecurity. In essence, community participation is required since members of the community are directly affected by the disaster and are the ones who need to take decisions to reduce the risk; it is therefore unlikely that risk reduction will be successful without active involvement of the local community in the critical stages of disaster risk reduction efforts. Thus for sustainable risk reduction during disasters, particularly those that may lead, even if in the short-term, to reduced access to natural and environmental resources, local agreement must be sought and obtained to forestall a misinterpretation of the project intention by the local people for which the project is targeted.

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Chapter 11

Different Farming Methods – But No Solution to Improve Rural Sustainability and to Save Australia's Family Farm

Ingrid Muenstermann

Additional information is available at the end of the chapter

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1. Introduction

The title of this book is *Environment and Sustainability.* Having had an interest in the sustainability of the Australian environment as well as in the Australian family farm, it did not take long to expand on some ideas that had been discussed in a journal article regarding cross boundary-farming (Muenstermann, 2009). Cross-boundary farming is embedded in the common property resources system. This is a literature review regarding four different farming methods in Australia, i.e. family farming, co-operative and corporate farming, with special emphasis on farming using the common property resources system. Some thought will be given to the opportunities these different methods can offer the small family farm. This chapter will also look at the results of a forum regarding cross-boundary farming, which was held in 2007, and at the attitudes of farming families in relation to their sustainability as a production unit, expressed at a meeting which was held in 2012. Both events took place in the regional city of Wagga Wagga, New South Wales, Australia. The city has a population of 63,000 and is surrounded by farms, many are for sale, which provides an indication that change is necessary.

Australia produces beef, cotton, dairy, dried fruit, grains, rice, sheep meat, sugar and wool (National Farmers Federation, 2012). According to the National Farmers Federation (2012), there are approximately 134,000 farm businesses in Australia, 99% are family owned. In 2010/11, there were 307,000 people employed in the farming industry. The National Farmers Federation found that "the complete agricultural supply chain, including the affiliated food and fibre industries, provide over 1.6 million jobs". The gross value of Australian farm production in 2010/11 was A$48.7 billion, which was 3% of Australia's GDP. These figures are increased to A$155 billion or around 12% of GDP when processes that food and fibre go through once they leave the farm are added. The Australian Natural Resources Atlas (2002) finds that "in 1996 the median gross farm establishment (farm business) income was estimated at A$96,400 (using 1996 dollars and farms with at least $5000 gross income)" (p. 1). Considering that farm maintenance, seeds and crops, feed for animals and household as well as living expenses have to be paid, farming income is low.

All of these figures demonstrate the importance of Australian agriculture and of the family farm, the contribution to the Australian economy and the high percentage of farm businesses that are family owned, i.e. 99% (National Farmers Federation). Unfortunately, as Alston pointed already out in 1991, the family farm is under increasing stress from fluctuating markets and severe droughts in many parts of Australia. Since 2000, Australia has been subjected to severe droughts and since 2010 Australia has also been subjected to severe floods. Farming and mining will suffer reduced production because of the floods, commodities like wheat, sugar, horticulture and coal are already increasing in price (ABC Rural, December 29, 2010). Between 1971 and 2006, the number of farming families has declined by 46% (Australian Bureau of Statistics, 2006), from 190,466 to 102,606. Farm production in 2002/03 had a downward impact on GPD of 1%, which indicates a decline in chain volume terms of 28.5% (Australian Bureau of Statistics, 2004). In comparison, the corporate farming sector (any agricultural business with an annual income greater than A$2 million) is growing fast. Although overall corporate farms only presented 1.5% of all farms in 2006, the number increased by 55% between 2001 and 2006 (Clark, 2008). Corporate farming businesses increased further: by 2011 the number was 2,601; an increase of 791 or of 44% (Australian Bureau of Statistics, 29.6.2012, pp. 14-15). Corporate enterprises now make up 1.8% of all farms. According to Clark (correspondence 2012),"in 2006 corporate farming generated an estimated A$7.7 billion (20%) of farm production. In 2011 corporate farming generated A$18.9 billion (39%) of farm production".

The findings are important because they relate to rural sustainability and to the future of the Australian family farm. A report by Cara Waters (June 26, 2012) considers "The end of the family farm? 72% of family farms don't earn enough to support the family on them". Farming has always been associated with life style, it was never considered a business only. Could a common property resources system save the Australian family farm from its fate? Looking at the outcome of this research it seems that the individualistic and independent Australian farmers do not want to be 'saved' by such a scheme. However, it is argued here that such a system has some merit.

Australia's best known common property system, the *Tilbuster Commons*, failed after five years despite being economically and environmentally successful. Reasons for the failure could be related to interpersonal relationships. This chapter will look at Elinor Ostrom's philosophy of the commons and at lessons learned from the *Tilbuster Commons*. The purpose of the chapter is to establish the significance and usefulness or otherwise of different farming methods to create sustainable rural societies and economies.

2. Australian farming systems

2.1. The family farm

The family farm means, according to Tanewski, Romano and Smyrnios (2000),

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ownership, place of residence, the family's contribution to labour, the family's responsibility for management, and the family's rural ethos or ideology (p. 15).

Reeve (2001) provides a somewhat more detailed definition:

Business ownership is combined with managerial control in the hands of business, these principles are related by kinship or marriage, family members provide capital of the business, family members include business principals, do farm work, business ownership and managerial control are transferred between the generational passage of time. the family lives on the farm (p. 1).

The definitions are similar, both stating that the place of residence has to be the farm, and that the owners and managers do farm work. The same meaning of a family farm was stressed in a study by Muenstermann (2010, 2011). Is it possible for Australian farming families to continue to exist in the present economic and environmental climate? Alston (1991, 2004) and Alston and Kent (2004) find that the small scale family farm has experienced growing pressure from fluctuating markets and severe droughts for ten years. The Australian Bureau of Agricultural and Resource Economics and Sciences (cited in www.fatcow.com.au) claimed that the 2010/11 floods have reduced the agricultural production by at least A$500 to A$600 million. Alston (1991) also referred to the subsidy war between the European Economic Community and the United States that have had profound effects on Australian agricultural production. She argued that operating in a global economy with major competitors who are heavily subsidised has left Australian farming families facing an increasingly uncertain future. According to Alston (1995a, p. 1), the number of farms has decreased by 39% between 1953 and 1995 (from 204,350 to 125,615). The Australian Bureau of Statistics (ABS) (2006) showed a decline of 46% between 1971 and 2006 (from 190,466 to 102,616). But, according to an Australian Bureau of Statistics Release (29.6.2012), in 2010/11, 121,000 businesses reported agriculture as their main activity which represented an increase of 1% compared with 2009/10. It is assumed that the latest figure includes family farms as well as corporate and co-operative farms operated by families.

Farming as a lifestyle identity is declining and market based farming is growing (Barr, Karnuarama & Wilkinson, 2005). The net farm income has decreased, especially for the smaller farmer, and many women seek off-farm income in order to sustain the farm (Alston, 1995a, 1995b; Alston & Kent, 2004; Muenstermann, 2010, 2011). Raven (1995, September 14) suggested that thirty years ago, costs took 50 to 60% of the gross income, they now take 80 to 85%. Adding to the problem farming families face is a younger generation that feels reluctant to enter the farming industry. The number of young men entering agriculture has declined by 40% over the last twenty-five years; the number of young women in their early twentieth entering the farming industry has declined by 80% since 1976 (Barr et al., 2005). The future of the family farm, as Australia knows it, seems unpromising unless restructuring will take place.

Restructuring is contemplated by Share, Campbell and Lawrence (1991) who looked at this issue, considering vertical restructuring of agricultural commodity chains, and horizontal or spatial restructuring of the labour markets and industries. Vertical integration is a process through which family farming could be integrated into areas of industrial capital. "It is most likely to be initiated in situations where available marketing or supply channels are being closed to the farmer or where pricing mechanisms are deteriorating" (Williamson, 1987, p. 4). Farm-based food and fibre production shifts from 'formal' to 'real' subsumption of capital: industrial capital takes over part of the production process (i.e. fertilizer, pesticide, herbicides, marketing of farm commodities), but the farmer is reduced from a relatively autonomous producer to a labourer (Davis cited in Share et al., 2005, p. 2). Vertical restructuring by industrial or transnational capital affects the integration of family farms into capitalist production and will change the nature of farm work, the marketing and distribution of agricultural products. It will change the autonomy and control of farmers.

Horizontal restructuring relates to changes in the spatial distribution of industry sectors and labour markets. Lash and Urry (cited in Share et al., 2005) found that within so called disorganised capitalism global capital has become "increasingly spatially footloose, while the global labour force is tied to specific localities" (p. 2). This means that global capital takes advantage of optimum production conditions. As a consequence, in a rural area farming may just be one area of development and a region may have several combinations of capital, for instance different industries may co-exist. Share et al. (2005) also discussed traditional primary industry incorporating newer tourist development. There could be relocation of manufacturing or service industries into the area. It is very possible that a region unable to attract mobile capital will decline. Help from the government is not forthcoming: Australia has, in response to global restructuring, removed protection barriers and exposed its economies to international market forces. Keynesian policies have been dismantled, meaning that government support for agriculture is now severely cut because of the introduction of user-pays principles and the withdrawal of subsidies, concessions and price underwriting.

Apart from the issues discussed, there are also personal perspectives of farming families. Gray (1991) explored the values of these families and looked at motivations which guide farm decision making, i.e. foster an understanding of farm responses to economic conditions. He concluded that the ideal of generational succession has persisted mainly among couples to whom the rural aspects of farming are very important. In other families, attitudes which constitute the ideological foundations of the family farming have weakened:

While the ideals traditionally associated with family farming appear increasingly unrealistic as the viability of small farms diminishes, the traditionally valued features of farm life also appear less important as economic concerns become overwhelming and the farm system moves toward fundamental change (Gray, 1991, p. 67).

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Muenstermann (2010, 2011) could establish that young women were encouraged by their mothers to leave the farming tradition, get an education and seek employment opportunities elsewhere.

Overall the literature regarding the future of the Australian family farm paints a fairly negative picture. Therefore, explored in the following are, at first, co-operative and corporate farming methods, followed by an outline of the commons, how it found its way back into modern society and the Australian experience of it.

2.2. Co-operative farming

A co-operative is defined as an autonomous association of persons united voluntarily to meet their common economic, social, and cultural needs and aspirations through a jointly owned and democratically controlled enterprise. (Wickremarachchi, 2003). A co-operative may also be defined as a business owned and controlled equally by those people who use its services or who work at it. Co-operation is intrinsic to human organisation, and the history of modern co-operative forms dates back to the agricultural and industrial revolutions of the 18th and 19th century. In today's Australia, co-operatives exist in most industries, including agriculture, and they are regulated by State and Territory Government legislation (Wickremarachchi, 2003). An agricultural co-operative incorporates primary producers who try to achieve common commercial objectives more successfully than they could individually. All objectives relate to continuation and improved profitability of members' farm enterprises (Australian Co-operative Links, n.d). The most common forms of agricultural co-operatives in Australia relate to marketing, input supply, and agricultural services. Marketing co-operatives embark on transformation, packaging, dispersal, and promotion of farm products. Supply co-operatives accrue purchases, and store and distribute farm inputs. Agricultural services co-operatives include banks, dairy, food processing, and educational services. In the Riverina area, around Wagga Wagga, the Rural Australian Education Centre Co-operative Ltd., Henti Machinery Field Days Co-operative Ltd., Orange Field Days Co-op. Ltd., and Primary Management and Training Concepts Co-operative Ltd. can be found (Co-operative Development Services, 2012). In recent times the co-operative systems have been criticised. According to a report by David Griffiths (2008), farmers have always looked to the co-operative model to provide them with some protection in the free market, but business advisors are now claiming that co-operatives are unsustainable. Griffiths warned:

> Co-operatives are member-owned, member-controlled businesses designed in the case of dairy farmers to maximise the return they receive for supplying their milk. Other business forms, such as publicly listed companies, exist for the sole reason of maximizing the value their share holders receive by way of dividends and increasing share price … the two cannot live together harmoniously for very long. Either you maximise the milk price at the expense of profit and returns to shareholders or you minimise the milk price in order to increase profit and returns to shareholders. There is no middle way (Griffiths, 2008).

Griffiths concluded that the indifference of farmers and their advisors toward the co-operative model could lead to a situation where farmers will have no access to the profits derived from value-adding to the produce they supply.

There can be no doubt that farmers and their co-ops operate in a highly unstable environment (Williamson, 1987). Bijman (2002) raised concerns about co-operative farming and found that many changes in the organisation of agrifood transactions have taken place, that consumers demand high quality products, more variety, and more convenience. Consumers have become concerned about food safety, production conditions, environmental protection, and animal welfare. These changes challenge farmer-owned co-operatives. How do co-operatives deal with the combined innovation in product and marketing? Where does innovation take place: at the level of the member company or at the level of the co-operative? Does the co-operative have the capability to carry out new activities? If so, do members have sufficient knowledge to control the managers executing these new tasks? Can members raise sufficient capital to make the necessary investments in innovation and marketing? Can co-operatives build sufficient market power vis-à-vis large food processing companies and retailers?

Chaddad and Cook (2002) also raised concern regarding co-operatives. These organisations may be referred to as member-owned, however, when they depend on outsiders for financial support that ownership is lost because the financial contribution of the co-operative membership is small compared to the non-member contribution. Despite of the one-member, one-vote principle, non-members who are the major suppliers of capital usually determine the main priorities of the co-operative business. Oczkowski (2004) analysed agricultural bargaining co-operatives that negotiate, on behalf of member farmers, with food processors over price and quantity for raw agricultural output. He flound that

> … the level of prices … depends upon the co-operative's relative bargaining strength. … Given the typical financial, physical and human resources of investor-owned firms such as large food processors and the relatively small resources of farmer bargaining co-operatives, it is expected that members would be more impatient (less able to hold-out) in negotiations. Further there is a general expectation that farmers exhibit a relatively greater degree of risk aversion compared to the entrepreneurial focused investor-owned corporate processor. The consequence of a low co-operative's bargaining strength are relatively low levels for co-operative objective values, and market and member prices (Oczkowski, 2004, p.16).

In 2006, Oczkowski looked at structural changes necessary for co-operatives to survive: the effects of globalisation on agriculture cannot be ignored. He argued that the restructuring of the agricultural sector needs substantial amounts of additional capital which will lead to new co-operative forms. These forms would maintain some of the old traditions and present viable alternatives to full demutualisation and conversion to the invested owned form. Von Pischke and Rouse (2004) provided strategies for mobilising capital in agricultural co-operatives: restructure members' incentives in ways that work constructively (in a commercial sense), and harmonise members' roles as users of the co-operative with their role as investors providing the capital.

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The question here is can co-operative farming save the Australian family farm? How much capital can the cash-stricken, small scale farmer invest in these institutions in order to benefit in such a way that the family farm can be saved?

2.3. Corporate farming

Corporate farming is another way of looking at the Australian farming industry. It must be mentioned that being part of corporate farming requires more capital than participating in co-operative farming and, looking at our definition of the family farm (i.e. ownership, place of residence, family's contribution to labour, family's responsibility for management, and the family's rural ethos or ideology), the concept may not quite fit. Since corporate farming in Australia is on the increase, it was decided to offer some thoughts on the system.

Corporate farming relates to the modern food industry. It encompasses the farm itself and usually a chain of agriculture-related businesses, including seed supply, agrichemicals, food processing, machinery, storage, transport, distribution, marketing, advertising, and retail sales. According to Tont, Halpin, Collins and Black (2003), corporate farms usually have a diverse group of shareholders/owners, the day-to-day management occurs at the property, but decisions are usually made at the corporation's headquarters. The scale of the properties, in terms of land occupied or in terms of production, tends to be high and there is very often a mixture of foreign and Australian ownership.

Clark (2008) published data on corporate farming in Australia. It generated 24% of agricultural production (combined revenue A$9.4 billion), there are 1,806 corporate enterprises with revenue of more than A$2 million. The number of corporate farms has increased by 55% between 2001 and 2006; but they represent only 1.5% of all farms. According to Clark (2008), family corporate farms represent 58% of these businesses. Family corporate farms are mainly found in the grain, pastoral and dairy industries; they are robust businesses with good succession planning and can withstand production variability. The 42% of corporate-corporates, which are larger than the family-corporates, are dominant entities in horticulture, cotton, pigs and poultry. Corporations are generally found in areas where there is ample irrigation water.

Considering the Australian small family farm with an annual income of between A$5,000 and A$94,000 (Australian Natural Resources, 2002), it is difficult to imagine how these families can enter the corporate sector as independent entity. Briton (2005) contemplated that "slowly but surely, the farm is being wrenched off the family farmer and integrated more closely into the corporate modus operandi of agri-business" (p. 28). And he quoted Phil Ruthven as saying "it is far better to swap fierce independence for mutual reliance and higher profitability – 40,000 viable farmers are preferable to 112,000 marginal ones" (p. 28). Compared to these attitudes, it is interesting to note that some states in the US have instigated constitutional provisions to counter corporate ownership (Institute for Local Self-Reliance, 2009): nine states place some restriction on corporate-owned farms, and two states have anti-corporate farming restrictions written into their constitutions. Supporters of the anti-corporate farming laws have argued that, in general, agriculture-dependent counties in states with anti-corporate farming laws fare better: they have less family poverty, lower unemployment and higher percentages of farms realising cash gains compared to agriculture dependent counties in states without such laws.

Anti-corporate farming laws do not exist in Australia and there are, as far as could be ascertained, no comparative Australian studies so far regarding the overall well-being of small farming families in an environment of corporate farming. However, it is assumed that small family farms are disadvantaged when corporate enterprises operate in the same location and within the same line of business.

In the following section, an old system is being reinvented, the commons.

3. The commons

Considering rural sustainability, the commons could play an important part because, if managed, natural resources are used without destroying the ecological balance of an area. In general terms, a common is a piece of land owned by one person or organisation over which other people can exercise certain traditional rights. Commons have a very long history in Europe, the most famous examples are the forest commons in Britain which are still in operation after thousands of years (ABC, 2001). Short (2008, p. 195) found that over a period of 500 years common land evolved as being distinct from other types of land because, while the ownership of the land remained private, the same land was subject to rights of common. These rights were held by other individuals that entitled them to specified products from that land.

Any commons system demands rules. According to Short (2008, p. 195) over the whole of Europe, previously rules were developed independently and, as a consequence, they were complex and the rights varied from one common to another. Today, there are almost 8,700 registered units of common land in England and Wales, representing 3% of the land area in England and 8% in Wales. Legislation is necessary, the last Commons Act was passed in 2006, "to promote sustainable management into the 21st century" (Short, 2008, p. 195).

3.1. The contemporary common

Elinor Ostrom wrote a thought-provoking book, *Governing the Commons* (1990a). She researched the system of the commons and was convinced that it offers an alternative to the traditional (mis)use of land and natural resources. She also provided the following advice to those who want to enter into a contemporary common:

> Any group that attempts to manage a common resource (e.g. aquifers, judicial systems, pastures) for optimal sustainable production must solve a set of problems in order to create institutions for collective actions; there is some evidence that following a small set of design principles in creating these institutions can overcome these problems (Ostrom, 1990b, n.p.).

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Here are Ostrom's (1990a,) principles which have been the basis of long-enduring common property resources (CPR) institutions:

1. Clearly defined boundaries.

2. Congruence between appropriation and provision rules and local conditions.

3. Collective-choice arrangements.

4. Monitoring.

5. Graduated sanctions.

6. Conflict-resolution mechanisms.

7. Minimal recognition of rights to organise.

For CPRs that are parts of contemporary systems:

8. Nested enterprises. Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organised in multiple layers of nested enterprises (p. 90).

These principles seem, at first glance, complex and difficult to implement, however, every institution has its guidelines which need to be followed in order for it to function. If people are serious about rural sustainability and about maintaining farming families, the price to pay may be adherence to these rules. They would need to be negotiated according to different groups and different needs.

Ostrom discussed advantages and problems associated with the system. There was, for instance, *The Tragedy of the Commons*, an influential article written by Garrett Hardin in 1968 (pp. 1-28). Hardin's argument was that the environment will be destroyed "whenever many individuals use a scarce resource in common" (Ostrom, 1990a, p. 2). The purpose of his article was to demonstrate that tragic consequences can follow mistaken morality. This morality relates to expectations of equal justice and universal human rights of participants of commons. To stop such losses external intervention or control is needed. Hardin (1968) argued that "freedom in a common brings ruin to all" (p. 1244). In 1991 he redefined his argument somewhat but reiterates that his "conventional wisdom"... "holds true for unmanaged commons". In 1998 he, again, emphasised that "overuse of resources reduces carrying capacity, ruin is inevitable" (p. 3). Ostrom agreed with Hardin's 1968 criticism to a certain extent but believed that certain principles (rules and regulations) could prevent a tragedy.

Since the writer of this chapter is of the opinion that common property resources systems could have positive consequences for rural sustainability (including the family farm), here is a summary of the Australian experience.

3.2. The Tilbuster Commons

The experimental Tilbuster Commons project existed between 1999 and 2004. A group of four landholders and their families selected the land "on the basis of their shared values, concerns and future aspirations" (Williamson et al., 2003, p. 23).

Source: http://www.southdevon-cattle.com.au/armidale.htm

Figure 1. Tilbuster Commons was established close to Armidale, New South Wales, Australia.

Source: http://www.records.nsw.gov.au/state-archives/resources-for/people-in-regional-nsw/regional-repositories/armidale-regional-archives-repository

Figure 2. A close look at the area where the Tilbuster Commons were established in 1999.

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The four families with adjoining landholdings in the Tilbuster Valley, 20 km north of Armidale in New South Wales, Australia, established *a common property resource system,* embracing some 1300 hectares. Funded with a A$208,000 grant from Land & Water Australia, and facilitated by staff from the Institute of Rural Futures at the University of New England, the group's objective was to produce a legal framework for a self-help resource management institution that was not only viable in their own circumstances but which could be transferred to other groups of landholders in different locations (Brunckhorst, 2003). The key assumptions underpinning this framework can be related to what Tosh (2006) classified as a *prescriptive* historical analogy. It draws on the past to recover best practices that can be adopted in the present: in this case lessons learned from the commons of England.

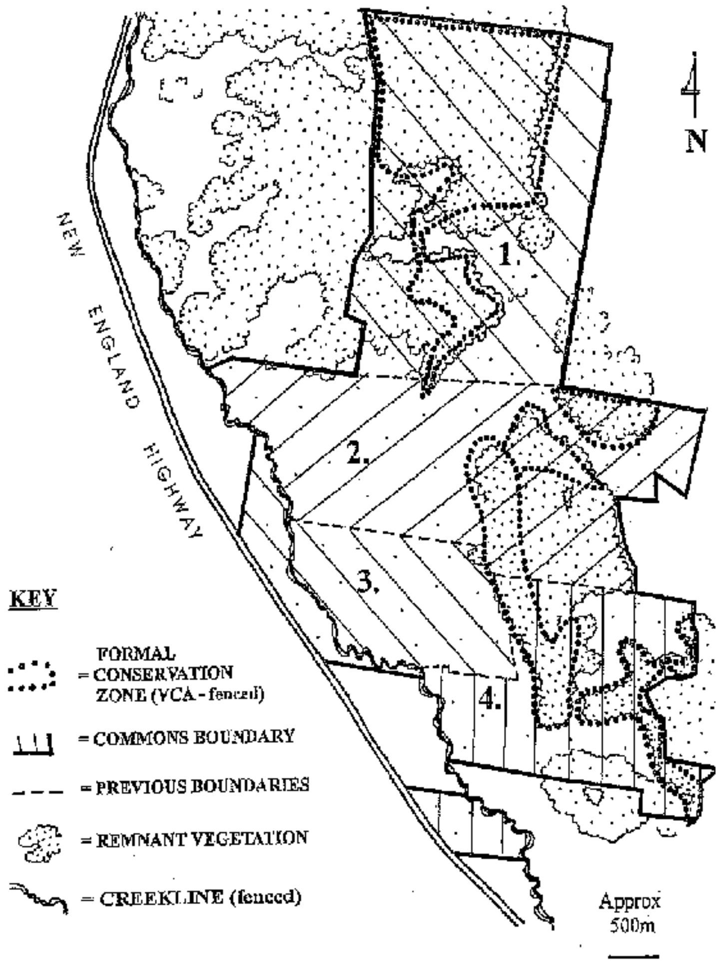

Figure 3. According to Brunckhorst and Coop (2003, p. 16), the Tilbuster Commons involves the collective management of four previously individual properties. The changes management is providing opportunities for increased efficiencies in agricultural production, more sustainable agricultural management practices, long term conservation and maintenance of rate basalt associated ecosystems and the restoration of woodland and stream environment.

Williamson et al. (2003) reported that two years of preliminary discussion provided an important vehicle for the group to begin building the necessary social capital which is required for the transformation towards whole system planning, resource allocation and collective decision-making. The independent owners and managers of properties realised their plans for an improved lifestyle and a more sustainable environment could easily fail if a common ground was not established. This common ground is embedded in social capital, relating to the cohesiveness of people in a community; it comprises trust, reciprocity and exchanges between individuals to make co-operation possible. It took a further eighteen months of planning legal structures and corporate arrangements. The group created a private company which provided for informal tenancy at will with the landholders being lessors and the company being the lessee. This arrangement allowed to start rotational grazing across all properties. The informal tenancy became a fixed term lease, providing stability and protection for both individuals, retaining land title, and the company, using and managing the whole resource base represented by all properties. Issues considered were livestock, grazing and pasture management and allocation of conservation and environmental rehabilitation areas. There were also issues associated with the operation of the commons (management, book-keeping, accounting), allocation of land to the common (private use of small areas, particularly around each member's home), key infrastructure, development of a formula which represent-ed the interests of each member in the common, and allocation of land and resources to the maintenance of ecosystem function. According to Williamson et al. (2003), the group gave the commons a new lease of life: cross-boundary farming is important for sustainable Australian agriculture. In 2001, The *Tilbuster Commons Pty Ltd* was registered and the group started to function as a business in the next financial year.

Williamson et al. (2003) discussed that the arrangement of a common property resource system, the collective decision-making, and trying to achieve the holistic goals of the group created some conflict of interest because the landholders were also directors of the company: with both hats on, individuals are considering the best options to benefit themselves and other members through the company. Hardin's *conventional wisdom* (1991), relating to *managed commons,* and Ostrom's principles *regarding governing commons* (1990a, p. 90) may have been an underlying force in establishing the rules of the *Tilbuster Commons* and maintaining its functioning for a while. Ostrom's guidelines reiterate Hardin's *conventional wisdom* and make clear that regula-tions are important for the management of commons or, as in this case, regarding cross-boundary farming. Table 1 demonstrates how the *Tilbuster Commons* functioned.

What are the advantages of such a system? Table 1 (Williamson et al., 2003, p. 68) defines the differences between conventional property management and cross-boundary farming management. Under conventional property legislation primary producers are required to fully utilise the resources available within their own property in order to survive economically. Faced with various family and economic pressures and only a few resources at the landholders' disposal, there is often no option but to overuse the resources. Input costs tend to increase to help production and counter negative trends of water quality, parasite load; and production from the farmed and grazed areas is reduced. On the other hand, Williamson et al. (2003) found that the *Tilbuster Commons* could allocate the available resources more efficiently and effec-

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tively. The individual and collective benefits of the project included grazing over a much wider area, reduction of input costs, increase of production, improved pasture and weed management (no fertilisers used), water and drought management, as well as more effective pest control. Cropping for winter feed or purchase of feed was not necessary, neither was the provision of natural minerals for stock. The most important benefits included long term conservation and maintenance of ecosystems, restoration of woodlands and stream environment, as well as the freeing up of time and labour. As a consequence of this, the families were able to get away for a holiday leaving the gate open when the livestock was on another property. Overall, by recognising the distinction between resource allocation and utilisation (the geographical elements) and land tenure (a part of the institutional elements), these landholders were able to consolidate their stock and graze them across all properties involved in the agreement.

Institution (social not legal)	Ownership	Owner's Rights	Owner's approach to management
Private property	Individual	Individual control; Exclusive control of access and alienation	Avoid socially unacceptable uses; Subject to some external regulation; Externalisation of pollution and degradation
Common property resources system, (cross boundary farming)	Collective	Exclusion of non-owners; Collective regulation; Internal pressure to comply	Maintenance; Constrain rates of use; Internal monitoring; Internalise negative externalities
State property	Public via government	Determine rules usually through government agencies	Maintain social and political objectives
Open access	None (no property rights or exclusion)	Capture	None

Table 1. Four major property institutions in Australia and their ownership, rights and duties (Source: *Williamson, Brunckhorst & Kelly, Reinventing the Common, 2003, p. 68*).

The positive issues discussed above have to be offset by some adverse aspects of the system. Williamson et al. (2003) pointed out that the change of ownership means a change in directorship and this can create problems. When a property is sold, it affects the system by fragmenting the landholding and the directorship of the company. There is also the issue regarding succession planning: who will inherit the property? Will it go to the child(ren) of the owner who has passed away or will the property go to those who manage the farm? The terms in the lease need to clearly address these issues.

Brunckhorst (2003), following Ostrom, argued that:

> The likelihood of users designing successful common property institutions will be enhanced if the group (or collective) is relatively small and stable; if it is relatively homogeneous, with the members using similar technologies and having similar values and expectations; if there is reciprocity and trust; and if the transaction costs for making and enforcing rules is low (p. 73).

This suggests that common property arrangements are well suited in scale to landholders struggling to maintain family farming operations. Yet a search of the literature reveals that attempts to duplicate implementation of the *Tilbuster Commons* model have, so far, not been successful.

3.3. Complexities of the commons – as seen by Australian farmers

According to the ABC's Landline program (2001), it was hoped that communal, cross-boundary farming, or the common property resources system, could be taken up in Australia to improve ecological sustainability. The *Tilbuster Commons* and the ideas that lay behind it attracted significant interest from practitioners of other disciplines and the media (Muenstermann, 2009; Meinzen-Dick, 2008; Marshall, Fritsch & Dulhunty, 2005; Marshall, 2004; ABC TV Landline 2001). In this process, some critics (Hajkowicz, 2006) contend that common property took on the character of a universal panacea for a rural 'crisis' that was indiscriminately held to apply across Australia. Looking at the decrease of farming families, a crisis exist, however personal communication with academics who are also landholders and farmers, conveys it is over-emphasised. Muenstermann (2009) suggested that a common property resources system has the potential to confer greater benefits on small farmers struggling to be more viable than alternative arrangements such as co-operative or corporate farming. Co-operative arrangements usually do not extend beyond joint purchases of plant and machinery or perhaps the pooling of labour at specified times of the year. Anecdotal evidence suggests that neighbours running sheep as a single flock is not unknown but less common, while joint action to address ecological issues is largely neglected. The Australian Natural Resource Management (2002) reasoned that "Australian farmers generally have a positive but pragmatic attitude towards environmental issues", hence "low farm incomes and high debt are likely to discourage adoption of sustainable practice" (p. 1).

Despite this finding, some farmers were trying to work collectively in order to address shared environmental concerns and to maximise financial gains, as the *Furracabad Valley Project* in northern New South Wales showed (Marshall et al., 2005). The project leader was a member of the Institute of Rural Futures who drew on the *Tilbuster* experience to assist the *Furracabad* farmers in consolidating their environmental gains. But whereas preliminary budgeting suggested that th project had the potential to deliver economic benefits, the project team was unsuccessful during the nine months of project organisation to secure a commitment to a common property regime by a sufficient number of participants. According to Brunckhorst and Marshall (2006), the government supported project started with eighteen parties being interviewed, and five indicating "a serious interest in leasing their land to the proposed group farming arrangement within the near future" (p. 204). The follow-up workshop was only attended by four of the five members of the farm businesses. The individuals emphasised

"... the social and environmental advantages of joining the group farming arrangement, [but] they agreed that their decisions to join would depend ultimately on evidence that they would benefit in economic terms" (Brunckhorst & Marshall, 2006, p. 240).''

The participants were interested to advance towards the business plan for the group farming enterprise. However, at the next meeting one of these businesses had lost interest in joining, which, in turn, raised concerns that the deal may become unbalanced, given that one of the remaining businesses would be contributing three-quarters of the area. It was decided that a group farming enterprise was not viable with this decreased level of committed interest. The project did not progress.

A cross-disciplinary study by Pannell, Marshall, Barr, Curtis, Vanclay and Williamson (2006) regarding the adoption of conservation practices by rural landholders tried to understand why adoption of rural innovations seems to only occur when landholders perceive them as enhancing their personal goals. It is a provocative study, concluding that the "relative advantage" is the major concern. "Relative advantage" relates to the superiority of what is being superseded and to "the capacity to deliver sufficient economic and benefits" (p. 1407). The whole process of adopting innovative practices is "influenced by the characteristics of individual landholders, their families and broader social environments and by the characteristics of the innovation" (p. 1409), and "there is no guarantee that a landholder's subjective beliefs will ultimately lead them to a final decision that is actually the one most likely to best achieve their goals" (p. 1409).

This is an important finding: subjectivity can easily override objectivity when farmers and/or landholders consider innovations. Pannell et al. (2006) determined that because of the way decisions were being made ("heterogeneity of circumstances"), they were only able to discuss "trends and tendencies, rather than deterministic relationships" (p. 1410). But the authors made the point that "economic factors" drive adoption of innovation (p. 1411). It seems that personal gains are more important than community and / or environmental interests.

But an article by Marshall (2004) showed a different picture. He discussed his experiences in working with a jointly owned irrigation company in the Murray Darling Basin, an existing common property regime, which led him to conclude that preparedness to co-operate in implementing agreed plans is "more sensitive to socially oriented factors like perceptions of community benefits … than it is to the private materialistic considerations - like distributive fairness and business security" (p. 271).

May be the difference in outcome can be related to the difference of ownership, for instance private property versus common resource? Overall it is argued here that contemplation of, and investigation into the legal complexities of a successful common property resources system and the rules that are needed to guard against free-riders, sit uneasily with the individualism that remains strong in many Australian farmers.

4. Thoughts on two meetings regarding the Australian family farm

Concerned about the issue of land degradation and the decline of farming families, a forum entitled *Cross boundary farming* was held in September 2007[1]. The forum was advertised widely in the area (local press, Charles Sturt University Internet, a community radio station, contacting interested parties by mail). Just over thirty people of different professional status and from different regions attended. The organisers invited Professor David Brunckhorst (academic, landholder and participant in a common property) to be the main speaker. Representatives of the National Farmers Federation[2], of the National Party and of the Greens[3], a property lawyer[4], two members of the local farming community[5], and two Charles Sturt University academics[6] were invited to present their views or that of their organisations. The local member of the Labor Party was invited but could not attend. Apart from the speakers, forum participants included members of the Wagga Wagga City Council, a representative of Murrumbidgee Catchment Management Authority[7], a member of the Riverina Country Women's Association, a hobby farmer, an organic farmer turned restaurant owner, a previous dairy farmer, a member of the Department of Primary Industries, Ballarat, Victoria[8], and

1 Financially supported by the Institute for Land, Water and Society and the School of Humanities and Social Sciences, Charles Sturt University.

2 Mr Bill Baker, Brucedale, NSW

3 Ms Rachel Siewert, Green Senator, Western Australia; Ms Melanie Pavey, National Party, Member of Legislative Council.

4 Mr Bill Thompson, Cummins Hendrick, Coolamon, NSW

5 Mr Tony Dunn; Mr Paul Nolte, Wagga Wagga

6 A/Prof Deidre Lemerle, A/Prof Ian Gray

7 This authority was established in 2004 to make sure that local people have a say in local resources management.

Charles Sturt University students and academics. Overall the forum represented a good cross section of the local community. The participation of two national politicians gave the forum and its underlying objective special importance.

The objective of the forum was to stimulate discussion whether cross boundary farming or the common property system could benefit contemporary Australian farming families. Brunckhorst provided an overview of his involvement with the *Tilbuster Commons*. He discussed the economic and ecological advantages, and the environmental and economic improvements the project had achieved during its five year existence. He also made clear that a common property resources system needs strict rules and that, despite legally binding regulations, problems can occur and unexpected difficulties can arise. Brunckhorst also mentioned the problem of free-riders and the importance of social capital, trust and reciprocity, which are important elements of a common property resources system.

The president of the National Farmers' Federation pointed to the sharing of large equipment amongst farmers and to the benefit of co-operatives. He did not believe that the common property resources system would be viable in Australia, pointing to the psychologically ingrained individuality and independence of the farmer and of the farming community as a whole.

The member of the Green Party raised serious concerns regarding the sustainability of the environment, advocated that cross-boundary farming offers economic and ecological advantages, but she could understand if farmers opted for an approach that was easier to put into practice than the common property resources system. The importance of the family farm in relation to Australia's economic well-being was emphasised.

The latter point was agreed to by the representative of the National Party: farming families are a very important part of Australia. Regarding the common property resources system, a pessimistic view was presented; it was thought that farmers under present climatic circumstances were acting appropriately but that the government fails farming families and should provide financial assistance to those in difficulties. Financial help is important because overseas farmers [USA and Europe] are highly subsidised.

The Charles Sturt University academics pointed to the psychological stress that would occur if farmers and their families were to form closer relationships with other people. They may share the same aspirations and hopes, they could be strangers or long-time friends and neighbours; but it would be difficult to initiate strict rules and regulations. Would trust and reciprocity endure or would participants eagerly observe each other in anticipation of free-riding? The academics also pointed to the fact of climate change and that many years of drought have had a negative effect on the Australian environment and on farming. It was suggested that the farming community took a more long-term, sustainable approach.

8 Had travelled considerable distance to participate in the forum.

The property lawyer presented concerns regarding succession planning if the common property resources system was implemented. He made the point that this issue would be the greatest impediment to overcome. There was no suggestion on how to solve the problem: if cross-boundary farming was taken up, each case needed to be assessed at its own merit. There was no suggestion that one rule could apply to all.

Despite disapproving comments and discussions, some positive ideas emerged. One of the councillors of the Wagga Wagga City Council suggested the following:

Cross-boundary farming may be an appropriate venture for the land holders on the East Bomen Road and may reduce noxious weeds. Councillor W. also suggested that the introduction of community title could be considered in the Local Environmental Plan review in order to provide the community the opportunity to jointly purchase community land. Thus individuals could be joint shareholders in ventures from environmental initiatives to farming (Wagga Wagga City Council, October 2007).

After several attempts to find out whether any action had been taken regarding this proposal, a reply included the following messages:

Council's previous Local Environmental Plan and Development Control Plan do not indicate that provisions were implemented for Cross Boundary Farming in 2007.

In addition, Council's introduction of a new Wagga Wagga Local Environmental Plan and Development Control Plan in 2010 has no provisions for Cross Boundary Farming (Wagga Wagga City Council, 2012).

A more positive outcome had been anticipated. In a way, the answer of the Wagga Wagga City Council covers the lesson learned from the forum: no change in attitude or behaviour is likely. There was consensus amongst the participants that productivist farming methods need to be changed so that rural sustainability and maintenance of the family farm can be achieved, however, the way in which to achieve this could not be determined. The common property resources system was not appealing because of legal implications and inherent difficulties, but the loss of the farmer's independence seemed to be of equal importance for not wanting to implement the system.

The above forum took place in 2007. Since then, further droughts and floods have devastated Australian farmlands. Have these natural disasters changed the attitudes of farmers? According to Don Boadle (personal communication, June 2012), a workshop on *The*

Future of Family Farming was held in June 2012 in Wagga Wagga. Boadle reported that the meeting was well attended by local residents. Most participants were interested in succession planning and joint ventures, mainly based on leasehold that stopped short of common property system arrangements. There was also anecdotal evidence of collaborative arrangements among farmers on the Northern Table Lands in New South Wales, typically involving joint purchase of expensive plant and equipment. According to Boadle there is, at this point in time, no indication that the Australian farmers are prepared to surrender their independence and individuality to take up a system that will restrict them, even though it may provide some relative advantage.

The pessimistic attitudes at these two meetings are similar to those experienced by Brunckhorst and Marshall (2006, pp. 191-219) (as discussed earlier). These authors stipulated circumstances, conservatism and time as important reasons for farmers not wanting to commit to common property resources system:

1. Circumstances need to be such that a critical mass of farm businesses are ready to embrace the concept at the same time. Negotiations take years, circumstances improve, people with whom they would like to work leave the area (p. 205).

2. Conservatism: due to their conservatism farmers need considerable time to change their attitudes. They see themselves as rugged individualists and changes to attitudes of this nature do not occur overnight (p. 206).

The outcome of the meetings indicates the division between academia and the farming industry.

5. Discussion

The findings of this research suggest that many Australian farming families are struggling to survive because of fluctuating markets, ten years of drought and two years of major flooding. The number of family owned farming businesses has declined substantially during the last thirty, forty years, and the social fabric of the farming industry is deteriorating within the global, competitive market system. Australian farming was previously linked to a lifestyle, today farming has to be considered within the market-driven global society as business.

Considering the environmental, economic as well as individual difficulties experienced by farming families, it was expected that some joint venture would be appealing to the Australian farming sector. However, this assumption is incorrect. Independence is highly valued and many farmers prefer to get out of the farming industry, are trying to find employment either in a related field, (managing a farm for someone else, work as farm labourer or in feedlots) or elsewhere in the labour market. An example is the story of a student: He was a fourth generation dairy farmer who was greatly disappointed with the overall system[9], discouraged by the year long drought, sold the business, and started to study. He successfully completed a PhD and is now employed as an academic. When asked whether he would have liked to enter into a common property resources system, his answer was a categorical *no.* It has to be realised that not every farmer will have the opportunity of such a career change, however, it is hard to determine a system that would prevent a small scale farmer from leaving his/her property. Family farming has been an important aspect of the Australian economy, and, unless more transnational and corporate farming businesses are accepted[10], will remain an essential part of society. But, as Pannell et al. (2006) established, innovations are likely to be adopted only when they have a high "relative advantage" (p. 1407), indicating that economic factors drive their decisions (p. 1411). Similar opinions were established by Brunckhorst and Marshall (2006, pp. 205-206) when they tried to introduce group farming (embedded in the common property resources system) in the *Furracabad Valley* in New South Wales. These authors determined that conservatism of the farming community plays a significant part of not wanting to change habits.

Where to from here? The lesson learned in relation to rural sustainability and the maintenance of the family farm is that corporate farming is not a viable option: the financial resources are not available. Co-operative farming also presents the problem of investment: in its present form it cannot support the family farm and restructuring of the agricultural sector needs substantial amounts of additional capital which would lead to new co-operative forms (Oczkowski, 2006). Since the rules of the common property resources system seem not practical or are too challenging for farming families, here are some thoughts that advocate improved sustainability of the land which would, in turn, mean a chance to maintain the family farm (economic and ecological benefits). It is the so-called adaptive ecosystem management network which is described by Manring and Pearsall (2006). The system requires networking between public, private, and non-profit organisations. It is called inter-organisational networking, and is a system that does not involve legal processes but good will, trust, reciprocity and organisational learning, it is consensus building through collaboration. Applying the system to the Australian farmers, they would have to make "balanced, multivariable decisions about how best to conserve ecosystem integrity while sustaining ecosystem services" (n. p.). Individual farmers have specific interests and knowledge in relation to the sustainability of the land and expectation of maintaining the family farm, all of which they could negotiate with other stakeholders. The system would include the *public*, which is interpreted here as meaning an official organisation, i.e. the appropriate council; the *private*, which is interpreted here as meaning members of the farming family, and *non-profit* stakeholders, meaning other farmers or landholders. All of these people would form an inter-organisational network. Working with the council may provide input into future planning, so may negotiations with non-profit stakeholders. Manring and Pearsall (2006) find that these networks are the basis of "many ecosystem management initiatives", using "certain forms of network and collaborative decision making" (n. p.), the outcome would be a sustainable environment.

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9 The squeeze of the price for milk by large supermarkets

10 Chinese foreign investment into the farming industry is at present vigorously debated.

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Looking at the Australian farmers, they will lose some of their highly valued independence and individuality. On the other hand, it could be argued that the conservation of the environment is very important, that anthropogenic land cover change (removal of native plants and using the land for farming) had a significant effect on the global and regional climate (McAlpine, Syktus, Deo, Lawrence, & McGowan, 2007, p. 1) which, in turn, produced droughts and flooding. Extending this argument, land degradation could be reduced if groups of farmers used their social capital and would network to look after the environment, i.e. improve sustainability. *The Tilbuster Commons* definitely demonstrated several positive ecological and economic outcomes.

6. Conclusion

The findings of this research did not put my mind at rest regarding concerns about rural sustainability and the future of the Australian family farm. Ten years of drought and major floods between 2000 and 2012, findings in the literature, as well as attitudes at meetings regarding the future of family farming, justify the concern. Participants at the meetings were concerned about income and succession but did not seem to be overly concerned regarding the environment and committed to change practices. So how can rural sustainability be achieved and the family farm be maintained? One fundamental aspect of the common property resources system was to improve the ecology, which was achieved, as scientific studies demonstrated. Further, economic profits as well as individual and collective benefits could be realised. The system seemed like an appropriate solution considering the struggle of small scale farming enterprises. But research suggests that such a system is based on principles and rules that need to be followed strictly in order to function which makes implementation difficult. The Australian farming community is very conservative: individualism and independence are important aspects of their psychological make-up, which were major reasons for objecting to the common property resources system. On the other hand, changes in the farming industry are necessary. But what changes should be aimed for? If we are looking at issues from a neoliberal perspective, progress and change can result from letting the market operate freely. Here progress is seen as increased production, which supports a large part of the population as financial growth, produced by economic freedom, trickles down to socio-economically disadvantaged populations (Boutilier, 2009). But environmentalists (McAlpine et al., 2007) and people especially concerned about rural sustainability (Barr et al., 2005; Brunckhorst, 2002b; Institute for Self Reliance, 2009; Manring & Pearsall, 2006; Marshall et al., 2005; Ostrom, 1990; Pannell et al., 2006; Smajgle & Larson, 2006; Williamson et al., 2003) alert us that greater caution must be taken if sustainability is to be achieved. Sustainable development has, according to the World Commission on Environment and Development (WCED, 1987), to meet "the needs of the present without compromising the ability of future generations to meet their own needs" (p. 8). The point here is that Australia does not seem to be on the correct path. Efforts have been made to improve sustainability and reduce the social costs of farming by promoting structural change in agriculture, however,

> Conventional attempts to address these issues are hampered too frequently by an entrenched narrow focus on individual property rights... as well as by institutional arrangements implemented at inappropriate scales for sustainable landscape futures (Brunckhorst & Marshall, 2006, p. 191).

It is difficult to provide any practical suggestions which are acceptable to the farming community. This research found a clear divide between academic discourse and the pragmatic perspective of the farming industry. The key variables of the common property resources system, i.e. salience and heterogeneity (Brown, 2006, pp. 56-75), may have a different meaning and are of different importance to various groups of people. This leaves the author of this chapter rather dispirited. Does it mean that the farmers and landholders should be left alone to deal with their problems? But how can we? The important issues of rural sustainability and the family farm have not been solved, they remain problems. Given the structural conditions of the Australian economy and the larger global food economy, Australian farmers must carefully decide how to achieve rural sustainability. He or she may restructure vertically or horizontally, or may sell the property so that it can be integrated into a corporate business. Will rural sustainability be achieved? Time will tell.

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Environments around the globe are undergoing human-induced change. Human population growth, rapid urbanization, expanding global economy, and the diffusion of western consumer lifestyles are placing increasing pressure on natural and social systems. Global institutions, nation-states, and local communities are seeking to identify and employ sustainable solutions to these environmental and socio-economic challenges. Sustainability has emerged as a policy discourse that seeks to balance the desire and need for economic growth with the protection of the environment, and the promotion of social and environmental justice. This book contributes to the study and search for sustainable responses to global environmental change. The authors of this volume explore environmental change in different places around the world and the diverse responses to such changes. The chapters demonstrate the need for place-specific sustainable development; the authors suggest the need to see sustainable responses to environmental change as a negotiated outcome between various social actors living and working in diverse spatial, environmental and socio-economic contexts.

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