Ethiopian Academy of Sciences
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EPCC
ETHIOPIAN PANEL ON CLIMATE CHANGE

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FIRST ASSESSMENT REPORT

WORKING GROUP II- CLIMATE CHANGE IMPACT, VULNERABILITY, ADAPTATION AND MITIGATION

III

BIODIVERSITY AND ECOSYSTEMS

ETHIOPIAN ACADEMY OF SCIENCES

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ETHIOPIAN ACADEMY OF SCIENCES

Ethiopian Academy of Sciences House No. 199, Woreda 9, Gulele Sub-city Near Commercial Bank of Ethiopia, Gulele Branch **P. O. Box:** 32228 Addis, Ababa, Ethiopia

Tel: +251 112 59 57 45/50 or +251 112 59 09 43
E-mail: *eassecretariat@gmail.com or eas@eas-et.org/* *epcc-officer@eas-et.org*
Website: *www.eas-et.org/ www.epcc-et.org*

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Lead Authors: Menassie Gashaw (PhD), Motuma Didita
Authors: Fanuel Kebede (PhD), Feyera Senbeta (PhD), Mulugeta Lemenih (PhD), Brook Lemma (Prof.), Habtamu Hailu, Solomon Abegaz (PhD), Roxanne O'Conelle
Review Editors: Tesfaye Awas (PhD), Abeje Eshete (PhD)
Substantive Editor: Seyoum Mengitou (Prof.)

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About the Ethiopian Academy of Sciences

The Ethiopian Academy of Sciences (EAS) was launched in April 2010 and recognized by an act of parliament (Proclamation No. 783/2013) as an independent institution mandated to provide, inter alia, evidence-based policy advice to the Government of Ethiopia and other stakeholders. Its major activities include undertaking consensus studies, conducting convening activities such as public lectures, conferences, workshops and symposia on issues of national priority; as well as promoting science, technology and innovation.

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Masresha Fetene (Prof.)
Executive Director, Ethiopian Academy of Sciences

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Executive summary

Ethiopian major Ecosystems such as: 1. Afroalpine & subafroalpine, 2. Forest, 3. Dryland, 4. Wetlands, and 5. Agrobiodiversity ecosystems were reviewed for any impacts, vulnerabilities, adaptations and mitigations to climate changes. Secondary data were gathered and reviewed to indicate trends or changes in the biophysical features of these ecosystems with climate change under the Biodiversity and Ecosystem Sub-Working of Working Group II of EPCC.

However, the present knowledge in this regard is almost nil. No pertinent data or information is available to substantiate trends and effects of climate change in these ecosystems. In situations, where data is absent, information were extracted and analyzed based on the general truths, trends and researches so far being undertaken from similar types of other African, tropical and temperate ecosystems.

The various impacts, vulnerabilities, adaptations and mitigations of the mentioned major types of ecosystems to climate changes were discussed under each ecosystem type. Generally, findings of this review and analysis have indicated that both climate related and human induced drivers of climate changes could cause increase in major ecosystem disturbances such as ecosystem processes and functions; degradation and loss of habitats; shifts in geographical ranges of some native plants and animals; change in timing of life history events; spread of invasive species and disease; declines in species, populations, and genetic resources as well as extinction or loss of biodiversity resources. Finally, the review is concluded forwarding research gaps, policy implications and recommendations for each ecosystem type of the country linked with climate changes.

Afroalpine and Sub-Afroalpine Ecosystem

Description

The areas which on the average are higher than 3200 meters above sea level m (a. s. l) are generally referred to as the Afroalpine and Subafroalpine (Hedberg, 1957). The lower limit of the afroalpine belt falls at about 3500 m, while the upper limit of vascular plants lies around 5000 m (Hedberg, 1964), and subafroalpine areas ranges between 3200- 3500 m. These areas include chains of mountains, mountain slopes and tops of highest mountains in the country. The highest peak in Ethiopia is Ras Dashen (4,620 m a .s. l), where an alpine climate near 0°C persists all year round, sometimes even with a snow cover lasting a couple of days (Hurni, 1986). However, dry lowland savannas and deserts surround this moist highland area. Ethiopia has the largest extent of afroalpine habitats in Africa (Yalden, 1983).

Comparatively there are more floristic and faunal studies from the afroalpine and subafroalpine ecosystems of Bale and Simien Mountains than from the same ecosystems of other regions such as Wello, Gemgofa, Arsi, etc.

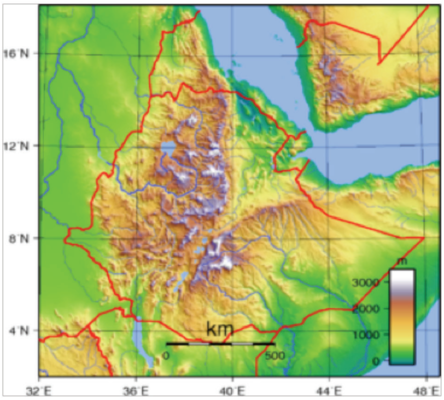
In a series of publications, Hedberg (1962, 1964, 1975, 1986 and 1992) made important analyses on the vegetation and ecology of afroalpine regions in Ethiopia. Miehe and Miehe (1994) made a detailed study on ericaceous vegetation and plant communities within the ericaceous zones of the Bale Mountains. Yalden (1992) made studies on the small mammals of the Bale Mountains. Yalden and Largon in 1992 documented that the highlands of Ethiopia supported 60% of Ethiopia's rodent fauna, among which14 are endemic, and over 40% of these endemic species are confined to alpine ecosystem.

The climate of Afroalpine ecosystem is governed by two fundamental geographical circumstances: the vicinity to the equator, and the high altitude above sea level (Hedberg 1964). According to Hedberg (1965) the Afroalpine climate is characterized by "summer every day and winter every night". Seasonal variations in climate are less important than the diurnal ones. Afroalpine and subafroalpine have traditionally been characterized as harsh and variable environments (Billings 1973). Extreme temperatures and large diurnal variation in growing-season temperatures, in conjunction with high levels of ultraviolet radiation, accompany large variations in the amount of precipitation.

Soils of many of the Ethiopian alpine areas have been little studied. Menassie Gashaw and Masresha Fetene (1996) made soil analysis from the alpine and subafroalpine belt of the Bale Mountains, Senettie Plateau. The various studied soils of alpine ecosystems are of volcanic origin, and the composition of the bedrocks are lavas of various kinds, basalts, agglomerates, and tuffs, etc. The soils of upper alpine belts are comparatively porous with low water-holding capacity, but offer good drainage. The soil conditions in the lower part of the alpine belt are different, where the closed vegetation has facilitated accumulation and retention of more fine-textured material. The extent of humus accumulation largely depends on the degree of moisture available, and on temperature conditions. The more plant cover and moisture content, the more humus is accumulated in the soil (Hedberg, 1964). Within the alpine belt, the extent of humus accumulation appears to decrease with increasing altitude (i.e. decreasing temperature and decreasing growth rate of plants). This was evidenced in one of the Ethiopian high mountains at Senettie plateau (Menassie Gashaw and Masresha Fetene, 1996).

Distribution

Land over 3000 m in Ethiopia is about 1589 thousand ha or about 1.3 % of the total area of Ethiopia (Daniel Gamachu, 1988). These high mountains are mainly distributed along the northern and southern sections of the country. Most of the high peak mountains are confined to the Amhara National State Region (Gonder, Gojam, Wello and Shewa), to the Oromia National Region (Bale and Arsi), to the Southern People´s Nations and Nationalites Region (Gamgofa and Sidamo), and to the Tigray National State Region. The extensive high mountains of Ethiopia are located scattered, as a BBC film producer once commented that the mountains are “islands in the air”. The great Rift system forms a distinct Rift Valley through the center of Ethiopia, averaging 80 km wide, and separates the two great plateaus with high volcanic mountains and deep river valleys, whereas the south-eastern plateau slopes south gently into Somalia, and the north-western one slopes west but is more abrupt due to faulting along the western border of Ethiopia.



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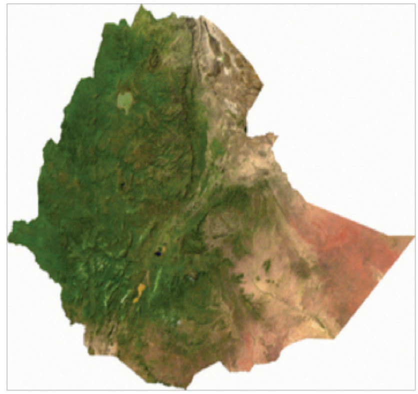

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Fig. 1. A. Map showing the highland blocks of Ethiopia. B. Topographic map & Satellite image of Ethiopia

The highest peaks are found in the Semien and Bale ranges. The Semien Mountains lie northeast of Lake Tana and culminates in the snow-covered peak of Ras Dashen, which has an altitude of 4,620 m a.s.l. A few kilometers east and north, respectively, of Ras Dashen are Mount Biuahit and Abba Yared, whose summits are less than 100 meters below that of Ras Dashen.

The Bale Mountains are separated from the larger part of the Ethiopian highlands by the Great Rift Valley, one of the longest and most profound chasms in Ethiopia. The highest peaks of that range include Tullu Demtu, the second-highest mountain in Ethiopia (4,377 m a.s.l), Batu (4,307 m a.s.l), Chilalo (4,036 m a.s.l) and Mount Kaka (3,820 m a.s.l).

Parallel with the eastern escarpment are the heights of Biala (3,810 m a.s.l) Mount AbunaYosef (4,190 m a.s.l), and Kollo (4,300 m a.s.l), the last-named being southwest of Magdala. Between Lake Tana and the eastern hills are Mounts Guna (4,210 m a.s.l), and Quara Sahia (3,960 m a.s.l). In the Choqa Mountains of Misraq Gojjam, Mount Choqae (also known as Mount Birhan) attains a height of 4,154 m a.s.l.

Diversity

Since the high massifs of Ethiopia have long been separated from the rest of the lowland areas, they are rich in terms of species diversity and in endemics. Hedberg (1951) has made a taxonomic revision of the afroalpine flora of the East Africa, which contains only about 280 species. These species, according to Hedberg (1986), by no means are restricted to the afroalpine belt but occur also lower down in the ericaceous belt or subafroalpine areas, and sometimes in the montane forest belt. Furthermore, species number gets lower with increasing altitude (Menassie Gashaw and Masresha Fetene, 1996). Hedberg (1986) considered the high level flora to be exceptionally interesting from phyto-geographical, ecological and evolutionary points of view. The percentage of endemics is much higher among those taxa, which are restricted to high levels than among those occurring at lower levels.

Hedberg (1986) further discussed that although the first afroalpine known to science came from Ethiopia, the afroalpine flora of Ethiopia has not yet been extensively explored. This is mainly because of the large-scale destruction of natural vegetation on most mountains, where it is difficult to have a clear delimitation of vegetation belts and transition zones.

The Ethiopian Afroalpine flora has gained some attention and has been investigated since the start of the Ethiopian Flora Project in 1980, particularly the Bale Mountains on the southeastern plateau. The Simien Mountains have been also investigated for their floral and faunal compositions as early as 1980. Nievergelt and Guttinger (1998) for instance, made a comprehensive listing of the flora of Simien Mountains, which consisted of 165 taxa. Simien and Bale Mountains are endowed with a unique botanical and zoological combination of species, which have been able to resist human interference because of the extreme topography, altitudinal range of the landscape, and the extreme inhospitable climate. Therefore, except for these two high plateaus (Simien and Bale), the floral and faunal resources of the other afroalpine areas are poorly known.

Various floristic studies by large number of researchers have listed out the following major or characteristic species from the Ethiopian afroalpine and subafroalpine areas: *Lobelia rhynchopetalum, Rosularia semiensis, Knifofia floliosa, Euphorbia dumalis, Alchemilla haumannii, Alchemilla* *ellenbeckii, Hypericum revolutum, Hagenia abyssinica, Erica aroborea, Erica trimera, Philippia keniensis, Thymus schimperi, Hebenstreitia dentata, Cineraria abyssinica, Helichrysum citrispinum, H. splendidum, H. gofense, H. formosissimum, Festuca abyssinica, Haplocarpha ruppellii, Haplocarpha schimperi, Carex monostachya, Euryops prostratus, Aira caryophyllea, Anthemis tigreensis, Arabis alpina, Conyza stricta, Geranium arabicum, Erigeron affroalpinum, Euphorbia dumalis, Saturei abiflora, Senecio schultzii, S. steudelii, S. unionis, S. vulgaris, Swertia volkensii, Trifolium burchellianum, Trifolium acaule, Romulea fischeri, Cerastium octandrum, Ranunculus multifidus, R. oreophytus, Stachyssi damoënsis, Veronica glandulosa, Sagina afroalpina, Silene burchellii, Anagallis serpens, Bartsia petitiana, Cotula abyssinica.*

The Ethiopian afro-alpine and subafroalpine ecosystems harbor a very unique habitat and wild animal species. Endemic, rare and threatened mammals and birds are the unique features of this ecosystem. For instance four of the Ethiopia's seven endemic larger mammals are represented in the Simien mountains national park (alpine/sub alpine ecosystem). These four endemic large mammals account for 57% of the total endemic large mammal assemblage of the country. One of the most notable flagship species conserved in alpine/sub alpine ecosystem is the Walia Ibex. This species is not only endemic to Ethiopia but is also endemic to the Simien Mountains alpine ecosystem. The rarest canid in the world, the Ethiopian Wolf is also restricted to this ecosystem. In addition to harboring the above mentioned unique fauna, this ecosystem serves as seasonal feeding ground for 21 northern migrant bird species. These birds occur in the SMNP (afro alpine and sub-afroalpine) ecosystem for restricted time of the year i.e. only from end of September to mid-March.

Although the floristic and faunal resources of the Ethiopian alpines are rich, it lacks some of the most conspicuous species occurring in East Africa (Hedberg, 1986). However, intensive exploration and comparative studies between the East African and the Ethiopian alpines; and between the northern and southern alpines of Ethiopia are lacking, and should get due attention to solve the taxonomic, evolutionary, phyto-geographical and ecological problems (Hedberg, 1971).

Use and values (Ecosystem services)

The following ecosystem services are considered to be major values and uses in the afroalpine and subafroalpine ecosystems:

1. Watersheds - Regulation of water quality and water flow;
2. Climate Change mitigation (carbon storage) sequestration;
3. Tourist attraction and generation of foreign income;
4. Medicinal, food and forage resources.

Threats and rates of change

The afroalpine and subafroalpine environments are highly fragile due to the extreme climatic conditions (low temperature, harmful short wave radiations, etc). Survivals in these ecosystems are only possible with certain anatomical, physiological and morphological adaptations or modifications. Each of the most common five types of phanerogamic life forms such as Giant rosette plant, Tussock grass, Acaulescent rosette plant, Cushion plant and Sclerphyllous shrub representing the alpine belt (Hedberg, 1986) has its own form of adaptation.

But due to intensive human pressure, most of the faunal and floral resources are now at risk. Degradation of natural resources, particularly vegetation and soils, is widespread and leads to a chronic food deficit. Demographic trends since the 1950's show a doubling of the population every 25 years, resulting in scarcity of good land, shortening of fallow periods on shifting cultivation land, and deforestation even in the last remnants of natural forests. Soil degradation is widespread in the high mountains and a major threat to the ecosystem in general (Hurni, 1986). The loss in vegetation and soils obviously implies great losses in valuable genetic material.

The subafroalpine belt particularly, is suffering from encroaching cultivation and increased burning to produce pasture. Traditionally, these areas were used for grazing, harvesting of grass for roof thatching and barley cultivation. There is also a great danger of epidemic diseases transmitted from domestic animals, mainly from dogs to wild carnivores such as the Ethiopian wolf, Golden jackals; there is also a fear of hybridization between Walia ibex and domestic goats. The intensified use of the flat highland plateau for livestock grazing, farming and the intensified use of both highland Erica forests and lowland broadleaf forests are major disturbances in the Simien Mountains, which has lead to the restriction of Walia ibex to a narrow belt on the steepest cliffs (Hurni, 1986).

Uncontrolled and deliberate fire set to gain agricultural land and fresh green fodder is also a major threat to wild animals and plant resources. Heather burning is much common in most of the subafroalpine ecosystems; its effect on the biodiversity of the ecosystem is not yet investigated.

Population pressure has pushed the farmers onto steeper and steeper slopes, which can only give yields for a few years before the soil is washed away. On such harsh and inhospitable environment, one could barely produce crops with the same amount and rate as below the tree line, since the growth rate is largely hampered or slowed down by the inconvenient weather conditions. The woody vegetation belt, particularly giant heather, *Erica arborea* L., has been burnt and/or cleared from many areas further threatening the naturally fragile environment (Hedberg, 1971). Generally, the afroalpine ecosystems are less disturbed compared to the lower belt ecosystems (subafroalpine), this is mainly due to the climatic limit for crop cultivation and the capacity of the ecosystem to resilience to some of the disturbances.

The *Erica-Hypericum* woodland is being over utilized. The area covered by this type of woodland has diminished during the past 30 years. If the heavy utilization of wood resources continues at the same pace for the coming decades, the more easily accessible highland, *Erica-Hypericum* woodland might disappear. Hurni (1986) further noted that in the Simien Mountain, a soil loss of 123 t per hectare per year was estimated from a village named Argin, which is above 3000 m a. s. l. However, only 3 t per hectare are compensated by soil formation every year. As land use intensified considerably, erosion rates increased and soil depths decreased, the retention capacity of the soil has drastically diminished. Reduced retention capacity leads to less infiltration of water and to higher runoff values, while increases erosion rates in the upper course of rivers and will lead to higher sediment concentrations further downstream, and decreased water quality (Hurni, 1986).

The highlands of Ethiopia were widely covered with Afroalpine moorlands and grasslands until 10,000 years go (Messerli *et al.,* 1977). But, man has altered large regions of the highlands for centuries, and the rate of change is very alarming and has endangered the original species richness. Thus the original afroalpine and subafroalpine natural communities are now restricted almost entirely to scattered and not easily accessible areas, which are surrounded and isolated by agricultural areas. The extinction of many original species in vast regions has to be seen in connection with this process of insularisation. Therefore, due to increasing human pressure into such fragile environments of the afroalpine and subafroalpine ecosystems, much more attention is needed to halt further threat and rate of destruction.

Conservation status

The afroalpine and sub-afroalpine ecosystem of Ethiopia in general are not as such protected, or conservation measures are absent in most of highland ecosystems to protect loss of species diversity and maintain sustainable use of these ecosystems.

Due to their rare and endemic animals and spectacular landscape features, these ecosystems have received the attention of the global community, which have called for its protection and sustainable utilization of the natural resources.

The Simien Mountains National Park and Bale Mountains National Park were established with the primary objective of conserving the wildlife and other valuable natural resources in the area.

Scope of the present review

Climate change is eroding the valuable benefits and services thatour diverse ecosystems provide, and the impacts could be costly. The following sections are trying to describe the general situations and scientific understanding of climate change impacts, vulnerability and adaptations of Ethiopian Afroalpine and Sub-afroalpine ecosystems. Data gaps, research needs and policy implications will be examined and recommended for better sustainable Afroalpine and Sub-afroalpine ecosystem management.

Drivers of Climate Change

Climate-related

Temperature and precipitation, particularly the timing and extent of snow cover, and frost formation have been identified as key process drivers in this zone. Furthermore, variation in snow depth and duration, soil temperature, soil moisture, atmospheric loading, types of radiation (Ultraviolet light, UV) are considered to have significant role in the Afroalpine and Sub-afroalpine vegetation.

Temperature rise

Over the last five decades there has been a warming trend in the annual minimum temperature of Ethiopia. The increase in minimum temperatures is more pronounced with approximately 0.4° C per every ten years (reference). In Ethiopia, it is assumed that the temperature has been increasing annually at the rate of 0.2°C over the past five decades. It is also documented (NAPA, 2007) that the mean annual temperature of Ethiopia may also increase in the range of 0.9 -1.1 °C by 2030. This clearly indicates that the rise in the atmospheric temperature overall the nation will be affected and as a result a large number of animal species will be threatened to the extent of local extinction in a given ecosystem when climate conditions are changing too quickly for them to adapt.

Drought

Ethiopia is highly vulnerable to drought, and which some part of the country is prone to drought is the single most important climate related natural hazard impacting the country from time to time. Drought occurs anywhere but become severe due to low adaptive capacity of ecosystems. The afroalpine (fragile) ecosystem could be one of the most affected regions due to its less resilience to environmental variability and high sensitivity to dry air.

Natural fire

The probability of natural fire to occur in Alpine ecosystem is insignificant and very unlikely. However, when it occurs, it has a significant impact on the afroalpine ecosystem since its incidence is rare to induce adaptation and resilience. Electrical discharge in the atmosphere is often accompanied by thunder, Thunderstorm, when it strikes the ground and vegetation, could result in fire that can cause huge damage.

Erosion

In the afroalpine and subafroalpine ecosystems, soil erosion strongly affects the vegetation's potential for regeneration and wildlife habitats such as for Walia ibex and Ethiopian wolf. In a fragile ecosystems (afroalpine and subafroalpine ecosystems), where soil nutrients are poor or nutrient recycling and organic matter depositions are very slow, soil erosion could aggravate the implicated changes and impacts of climate change.

Human-related climate change drivers

Most landscapes in the Ethiopian highlands have been influenced by farming, grazing, firewood collection, and grass cutting over several centuries. Thishas led to a decline in biodiversity. Factors compounding the impact of climate change in Ethiopia are rapid population growth, land degradation, widespread poverty, dependency on rain-fed agriculture, lack of awareness by policy and decision-makers about climate change and lack of appropriate policies and legislation. In general, most of the factors responsible for climate change have anthropogenic origin.

The ever increasing and intensive encroachment of man due to the increasing population pressure and the nature of survival which mainly depend on the exploitation of existing scarce resources has resulted in a widespread destruction of wildlife and their habitats. Although efforts have been made to save the remnant alpine and afroalpine ecosystem in the Ethiopian Mountain ranges, the existing reality indicates that the natural habitat is shrinking and the wildlife population is declining.

Low income

Ethiopia is one of many countries that have identified poverty as a major contributing factor to deforestation. This could be explained by the fact that high dependence on natural resources forces people to over-exploit the surrounding natural resources. The alpine ecosystems are mainly highlands and can easily be affected by anthropogenic factors. Uncontrolled ongoing deforestation in the system leads to land degradation and loss of soil fertility, which eventually weakens livelihoods of local people, undermines their ability to recover, and pushes them towards chronic poverty and destitution.

Agriculture and Settlements

Agricultural and human settlement expansions in the afroalpine and subafroalpine ecosystems are considered to be major threats and driving forces for climate change. This is mainly due to the expansion of new settlements and agriculture to high mountains as a result of the shortage and scarcity of agricultural lands. It has been observed that agricultural practices in the afroalpine ecosystems are new developments and are not compatible with high altitudinal climate as these types of ecosystems are highly fragile and exposed to extreme environmental and climatic factors. Therefore, any kind of agricultural advancements and human encroachments therein threaten biodiversity resources, destroy habitats, and disrupt the climatic setups that may result in the replacement of the original floral and faunal compositions by less adapted and vulnerable species to climate change.

Grazing

In the heavily populated northern highlands (Simien mountains for example), livestock graze on high altitudes all year round. Circumstantial evidence has also suggested that overgrazing in the densely populated highlands may have negatively impacted upon the highland rodent fauna (Nievergelt *et al.,* 1998); as a result wolves may predate more frequently on livestock (lambs) or become nocturnal when human interference is severe (Yalden, 1986).

Fire

Fire is a common phenomenon occurring in the afroalpine ecosystem in Ethiopia. Local people set fire to get access while traveling in the ericaceous belt. Others such as livestock herders and poachers light fires deliberately or fire can emerge from uncontrolled use and cause a huge damage on the ecosystem, particularly in the subafroalpine ecosystem, where the vegetation is relatively denser than the upper belt of afroalpine ecosystem. However, most ericaceous species can survive occasional fires, but they usually resprout slowly. As a consequence, much of the ericaceous vegetation in the afroalpine and subafroalpine ecosystems is currently scrub and dwarf.

Afroalpine *Alchemilla* and *Helichrysum* scrub also needs 5-10 years to recover from fire damage. Fire affects the wild fauna through direct effect killing or damaging their natural habitat.

Poaching

Poaching poses a serious threat to mammal and bird biodiversity of the Ethiopian afroalpine ecosystem. Most of the afroalpine and subafroalpine areas are not fully protected from illegal hunting. As the Ethiopian protected area management has limited facilities, manpower and logistics, there is no effective protection; as a result illegal exploitation of wildlife is going on. Most of the wild animals are hunted for medicinal purpose, for food or due to human wildlife conflict, crop raiding or depredation.

Impact, Vulnerability and Risks

Climate Change Effects and Impacts on Afroalpine and Sub-afroalpine Ecosystems

Afroalpine and sub-afroalpine ecosystems are among the most threatened ecosystems, highly sensitive to climate change. Under natural conditions afroalpine vegetation is even exposed or vulnerable to a number of limiting factors and harsh weather and climatic conditions such as short freeze-free growing season, high radiation, shallow and/or poorly developed soils, physical disturbances from wind, frost and snowpack. Therefore, slight changes, for instance, in temperature patterns and nitrogen availability or in any of the climatic setups can have significant effects on the composition and function of the afroalpine system.

Generally, climate change is expected to affect Afroalpine and Subafroalpine ecosystems, species, and habitats in at least six key ways:

1. Increase in major ecosystem disturbances (ecosystem functions and processes);

2. Shifts in geographical ranges of some native plants and animals in the afroalpine and subafroalpine ecosystems;
3. Change in timing of life history events for plants and animals;
4. Spread of invasive species and disease;
5. Degradation and loss of habitat such as loss of stopover and breeding sites for migratory bird species in afroalpine and sub-afroalpine lake systems;
6. Declines in species, populations, genetic erosion, extinction or loss of biodiversity.

High elevation plants and communities are expected to be sensitive not only to climate variations but are also vulnerable to additional environmental impacts such as airborne contaminants, exotic pathogens and physical disturbance. Many complex interactions shape biotic responses: compensatory effects in species populations may stabilize ecosystem-level properties, but a change in abiotic conditions, phenology, or herbivore or pathogen abundance may alter the outcome of species interactions. Where community composition is strongly controlled by physical factors (e.g., hydrology, thermal regime), or where populations occur at the edge of their range, subtle changes in the environment may have significant long-term impacts on the larger biotic community.

Altitudinal and/or structural shifts in tree-line and tree island communities, earlier egg laying dates for native birds, increased susceptibility and vulnerability of giant lobelia (*Lobelia rhynchopetalum*) and heather moorlands to fungus, insect infestations and fire are all potential manifestations of environmental and climate change in the afroalpine and subafroalpine ecosystems.

In some cases, multiple climate-related disturbances can combine, such as when afroalpine ecosystems are stressed by increased temperatures, reduced snowpack, and reduced summer soil moisture—and then further weakened by disease or insects.

Warmer temperatures allow insects and pathogens to expand their range and increase winter survival. There are evidences indicating invasive species thriving because of climate change is replacing native shrubs and grasses and is transforming native shrub-steppe and grassland habitats.

Warmer temperatures have created opportunities for pathogens, vectors and hosts to expand their range, thereby enabling pathogens to be present in new geographical locations and, potentially, to infect new naïve hosts, which in some cases can result in morbidity or mortality of wildlife, livestock or humans. Diseases that were kept at low infection levels because of temperature restrictions are now reported to have become fatal and endemic.

Today Rabies outbreak on the Ethiopian wolf in Bale Mountains National Park (afroalpine ecosystem) is becoming a common phenomenon. This incidence may have resulted from favorable conditions created for domestic dogs due to climate change to encroach the wolf habitat. The Ethiopian wolf gene pool is also being contaminated due to outbreeding depression. The domestic dogs not only spread the disease, compete for rodents but also breed with the wolves.

Environmental change, particularly climate change influences migratory patterns and will likely have associated impacts on trophic interactions. The reason for spotting the migratory bird species, Wattled Crane on Sanettie plateau all year round is probably the adaptive response of this species towards climate change. Of course this observation should be supported by research and further investigation.

Given the human considerable encroachment, this causes a huge impact on the ecosystem through modification /degradation of the natural habitat (shelter and food). The wild animals seriously affected due to deterioration of habitat quality, fragmentation and reduction of home range. Moreover when human activities continue to encroach on the remnant alpine ecosystem, there will be high possibility of damaging the temporary/seasonal sites for migratory birds which endangers the future survival of the species.

Barley crop is commonly cultivated well into the ericaceous belt, such agriculture expansion lie within the potential range of alpine/sub alpine ecosystem. Moreover, even at higher altitudes, alpine vegetation is used by partly transhumant animal husbandry. Permanent settlements are found up to 3700 masl even in alpine ecosystem representative National Parks (Bale Mountains and Simien Mountains). Here, people still practice cultivation, but mainly depend on livestock production. Intense land use led to a complete replacement of Afroalpine/Sub-afroalpine ecosystem that directly affects the survival of wild animals. Today, most of Ethiopia's high altitude natural vegetation is long gone, to the extent that the state of the natural vegetation is often unknown (Miehe and Miehe, 1994). As a result of such habitat transformation or modification, there will be animal population fragmentation, population decline and high risk species extinction.

Uncontrolled human encroachment in general for example affect mammalian population in the afroalpine and subafroalpine ecosystems through direct alteration of their natural habitat or causing loss of vegetation covers which particularly expose small mammals to increased rates of predation and sometimes competing for food resources (Hoffmann et al., 2003; Grant, et al., 1982)

Changes in water availability of afroalpine lakes affect the flowering and survival of aquatic plant and animal species, as well as the abundance of wildlife species in impacted areas. The afroalpine lakes of Ethiopia are crucial habitat for most of the endemic birds such as Blue-winged goose, Spot breasted plover, and many other regional and intercontinental migratory bird species. Therefore, these birds would probably be the very first species vulnerable and sensitive to any qualitative and quantitative changes in the afroalpine lakes.

Other impacts associated with extreme events include fire. Forest fires are likely to increase in places where summers become warmer and drier. Prolonged periods of summer drought would transform areas already sensitive to fire into regions of sustained fire hazard. There would be major socioeconomic impacts as well, because many sensitive regions are located close to major population centers. The impact of climate change on wild fauna is mainly due to changes that occur on their environment. In addition to changes that occur in the environment, vegetation dynamics is the one that determines the distribution of wild animals.

Gelada baboons (*Theropithecus gelada*) are medium-sized African primates found only in the Ethiopian highlands, with anatomical adaptations to a highly terrestrial life. They are entirely dependent on mountain grasses and are restricted to an altitudinal range between 1 700 and 4 200 meter in Ethiopian mountain ecosystem (Dunbar, 1998). However, the increases in local temperature are likely to push gelada upwards in search of suitable conditions, resulting in their occupying increasingly limited and fragmented habitats. Further fragmentation may arise from expanding agricultural areas, made possible at higher altitudes due to warmer temperatures, unsuitable habitat and gorges, which may confine the gelada to isolated patches , a behavioral study on gelada in the Ethiopian highlands (Dunbar, 1998) indicated that the gelada's ecology is unusually sensitive to ambient temperature due to its effect on the nutrient content of the grasses on which the gelada depend: these grasses only reach high nutritional values at specific temperatures. Gelada behavior is also susceptible to changes in climate. For the gelada to survive in suitable habitats, its activities must include social behavior patterns that allow it to create bonds with groups of con specifics, to feed and rest. Resting includes time needed for thermoregulation when temperatures are high, in order to avoid heat overload. In primates, there is a relationship between group size and the time needed for social bonding, which limits group size. As an increase in ambient temperature requires more time spent on thermo-regulating and resting, the time available for socialization will be significantly reduced, leading to weaker bonds in the group (Dunbar, 1998).

Vulnerability and risks

Climate change is expected to become one of the major drivers of extinction in this century as a result of changes in the species natural mode of adaptations in general, and specifically shifts in distributions caused by the variation in temperatures and precipitation regimes. Some taxa are more susceptible or vulnerable to climate changes than others.

The endemic Walia Ibex and the Ethiopian wolf, both critically endangered, and the gelada baboons, which are restricted with strict ecological constraints, are likely to be most affected and are at highest risk.

Species in the alpine and subalpine zone respond to climate complexly and individualistically. Responses are often non-linear, showing threshold, complexly interacting, and individualistic trends. Responses may include local population extirpations, type conversions, mortality events, uncoupled responses, and heightened insect, disease, and fire disturbance.

The following vulnerabilities to climate changes are extracted from the studies undertaken in other afroalpine and temperate alpine ecosystems. Most of the vulnerabilities to climate changes described below are general truths, which might have been already experienced and are prevailing in the Ethiopian Afroalpine and Subafroalpine ecosystems. This gives us direction in identifying research areas and to maximize our efforts towards designing effective research strategies.

A. Forest Densification (no tree-line change)

a. General Subalpine Forest Infilling

b. Tree-line Zone Infilling

c. Colonization of Formerly Persistent Snowfields

d. Colonization of Sub-alpine Meadows

B. Change in Growth & Form (no tree-line change)

Naturally, each of the most common five types of phanerogamic life forms such as:

a. Giant rosette plant,

b. Tussock grass,

c. Acaulescent rosette plant,

d. Cushion plant, and,

e. Sclerphyllous shrub,

representing the afroalpine and subafroalpine belt (Hedberg, 1986) has its own form of natural adaptation. However, due to the impacts of climate, plants may be vulnerable to change and adapt a new type of growth form rather than the natural mode of adaptations mentioned above.

C. Change in Patterns of Mortality (no tree-line change)

a. Change in Drought and Insect and Disease Effects

b. Change in Genetic Diversity and Adaptation

c. Change in Fire Relationships

D. Change in Aspect (no tree-line change)

E. Change in Elevation (with tree-line change)

a. Differential Shifts in Elevation

b. Shifts Down in Elevation

c. Synchronous Shifts in Elevation

Adaptation, Mitigation and Managing risks

Adaptations/Human intervention actions towards developing an environment resilient to climate change.

Most of the afroalpine and subafroalpine ecosystems of Ethiopia are protected either in the form of national parks or community managed protected areas (indigenous resource management system). Although there are no practical actions and significant ground works so far undertaken, the National System Plan for the Ethiopian Protected Areas has recommended a number of strategies, and some of these strategies can be taken as mitigation measures.

The Guassa area in the central highlands (Afroalpines) of Ethiopia is one of the indigenous resource management systems that have profound contribution and best practices of climate resilient adaptation measure. The area is being managed traditionally by the local community for different uses, including grazing livestock, collecting firewood, and cutting Guassa grass. The indigenous resource management system of Guassa Afroalpine area is known by a local name as “Qero system” and operates as an indigenous common property resource management institution that arose based on the existing land tenure system. Under the rules of this common property resource management system, exclusion governing access to the use of the area resource was the main aspect of the Qero system. The Qero system conferred usufruct right on the living members of a group tracing their lineage to the two pioneer fathers. Only those persons who could prove their lineage to these two pioneer fathers were recognized as full members of the Guassa user community and allowed to exploit resources on an equal footing.

The following climate adaptations and mitigations actions are already under practice or still in action in Ethiopia:

1. Initiate community based rehabilitation of degraded *afroalpine and subafroalpine ecosystems* to mitigate land degradation, soil erosion and water runoff.

2. Undertake environmental rehabilitation campaign in the afroalpine and subafroalpine ecosystems to increase awareness and readiness among the local people.

3. Initiate or support the inclusion of afroalpine and subafroalpine ecosystem development actions into the National Environmental Education Program.

4. Promotion of reforestation and afforestation in the adjacent or buffer areas of afroalpine and subafroalpine ecosystems of Ethiopia so as to mitigate impacts such as removal of vegetation from these ecosystems.

5. Undertake capacity building for local communities living in and around afroalpine and subafroalpine ecosystems for climate change adaptation and sustainable natural resources use.

6. Develop and or adapt technology for alternative sources of energy bio-fuels, solar panels, and efficient cooking stoves in order to minimize the devastating effect on deforestation.

7. Conduct more research on climate change and human induced factors in the afroalpine and subafroalpine ecosystems for better understanding of impacts and vulnerability and to devise adaptation strategies.

8. Identify opportunities and priorities for habitat connectivity, such as buffers, wildlife corridors, and a connected network of conservation areas in afroalpine and subafroalpine ecosystems.

9. Increase the quantity, quality, and size of conservation areas. Expansion of protected areas in mountain ecosystem is not only an important strategy to promote biodiversity conservation but

could also be a means to mitigate climate change.

10. Define priorities for land management particularly in the subafroalpine areas and in areas important to biodiversity to emphasize resilience to fire and decrease the likelihood of severe fires.

11. Take early action to eliminate or control non-native invasive species in the afroalpine and subafroalpine ecosystems that take advantage of climate changes, especially where they threaten native species or current ecosystem function.

12. Conduct assessments and studies on species and habitat vulnerability to climate change in the afroalpine and subafroalpine ecosystems to determine appropriate management approaches.

13. Conserve genetic diversity by protecting diverse populations and genetic material across the afroalpine and subafroalpine ecosystems. Such efforts may include identifying areas for seed collection along the altitudinal gradients and across the ranges of target species and micro-ecosystems within the afroalpine and subafroalpine ecosystems.

14. Initiate and support efforts to quantify the benefits of ecological services and natural systems at risk from climate change in the afroalpine and subafroalpine ecosystems.

15. Develop programs to engage citizens in monitoring impacts of climate change on afroalpine and subafroalpine ecosystems.

16. Coordinate development and maintenance of integrated long-term, large-scale monitoring of early-warning indicators of species responses in the afroalpine and subafroalpine ecosystems, including range shifts, population status, and changes in ecological systems functions and processes. Reconsider monitoring approaches to ensure that indicators track changes associated with climate change.

Mitigations

Mitigation potential of afroalpine and subafroalpine ecosystems to climate change are not as such researched or documented so far. Therefore, this is considered as a major research gap.

Information, data gaps and research needs

Vegetation (Information and gaps)

Generally intensive researches on impact, mitigation, and adaptation of the alpine and subafroalpine ecosystems are lacking. Therefore, there is a huge gap in terms of data available for any mitigation and adaptation actions to take in order to save the afroalpine and subafroalpine ecosystems in Ethiopia.

Although intensive researches are missing from the Ethiopian Afroalpine and Sub-afroalpine regions, these ecosystems are well explored and documented for their floral and faunal compositions; particularly the Bale Mountains are relatively well described than the Simien Mountains. Unfortunately vegetation of the afroalpine and subafroalpine of Arsi Mountains (Mount Kaka and Chillalo) in the south eastern parts of Ethiopia and some mountains in the central highlands of Ethiopia and in the north have not been studied for their floral and faunal resources.

A number of authors have contributed a lot in describing both the afroalpine and subafroalpine of Ethiopian, and in this document in the introduction section it has been tried to list out most of the authors and authorities, who had contributed for the science of the afroalpine and subafroalpine ecosystems of Ethiopia. However, most of the studies so far are site and species-specific, and thus researches on long term changes in vegetation composition and structure at a landscape-level in relation to variations in the environmental parameters and climate change drivers are considered to be a major gap. After identifying and reviewing the gaps, some recommendations or research needs are forwarded in the following paragraphs.

Vegetation: landscape-level change (Research needs)

1. Determine status of, and long-term changes in, the distribution of alpine ecosystems at the landscape scale.

2. Determine changes in the structure (density, age/size class distribution) of trees, tree islands, and/or shrubs in the subalpine-alpine ecotones.

3. Estimate rates of woody species encroachment into subalpine meadows and/or alpine ecosystems.

4. Studies of the phylogeography of afroalpine and subafroalpine species may identify relict populations and/or variation in genetic structure that are of relevance to population- and community-scale monitoring, and that can be tied to landscape-scale studies. Inventories that document species composition across a range of alpine environments, and studies linking community composition to environmental gradients, are likewise needed.

Population/Community and ecosystem-level change (Research needs)

1. Determine status of, and variability and ***long-term trends*** in species composition in selected alpine ecosystems (e.g., dry meadow, wet meadow, snow bed, fell-field).

2. Determine whether species composition (richness, diversity, species' presence/absence) is changing through time.

3. Climate-induced changes in flowering phenology may cascade into insect assemblages and ultimately into bird populations. Thus it is necessary to document variability in phonological metrics (e.g., emergence, flowering, fruiting) of selected species.

4. Relate variation in species composition to variation in environmental variables.

5. Studies of inter annual variation in community or population-level parameters are necessary to identify indicator species particularly sensitive to environmental variation.

6. Analyze whether species establishment is limited by dispersal or other factors. Such analyses may be particularly relevant to issues of invisibility.

7. Experiments designed to test the effects of environmental variables (e.g., variation in snow depth and duration, soil temperature, soil moisture, and atmospheric loading) and/or biotic interactions (e.g., herbivory, biological invasions) on community and ecosystem-scale processes are needed in a range of afroalpine and subafroalpine environments.

Wildlife and Avian communities

Information and gaps:

Although there are very few researches on avian structure and compositions, the research works of Antenneh Shimeles (2014) on bird community dynamics, distribution, abundance and diversity of the Bale afro-mountains is worth mentioning. There is also an effort from IBA, EWCA and EWNHS to undertake regular annual monitoring of birds in some of the Ethiopian IBA sites. However, findings of these researches are limited to specific habitats, and target only a few species of the country. Bird monitoring and researches on a larger landscape-level, which focuses on long term changes in relation to variations in environmental and climate change drivers are lacking and are thus considered to be a major gap in the afroalpine and subafroalpine regions. Recommendations in regards to research needs and actions to fill the gaps are discussed in the following section.

Research needs

1. Detect long-term changes in the composition of avian communities in the afroalpine and subafroalpine regions within a larger landscapelevel sample design.

2. Determine trends in distribution, relative abundance, and diversity of breeding birds.

3. Where site access permits frequent revisits, determine trends in avian annual productivity and survivorship.

4. For species of conservation concern, document changes in demographic parameters for selected populations.

5. Relate variation in species composition and/or population status to variation in habitat and environmental parameters.

6. Basic research on the biology of species that nest and breed in the alpine (e.g., habitat, diet requirements, distribution, migratory patterns, variation in clutch size, laying dates) will likely be necessary.

Invertebrate communities

Information and research data from other countries indicate that insects are useful as vital signs due to their abundance importance in ecosystem function (Holloway 1980, Rosenberg et al. 1986), and sensitivity to disturbance. Ants have proven particularly valuable as an indicator group because of their wide distribution and diverse trophic interactions. They are easily sampled and identified, and are responsive to changing environmental conditions (Majer 1983, Erhardt and Thomas 1991).

Data gaps and Research needs

There is almost no intensive research so far done in monitoring the status of Invertebrates in the Ethiopian alpines. In regard to this, the following research needs are recommended:

1. Estimate variability and long-term trend in the diversity, distribution and abundance of invertebrates in selected afroalpine and subafroalpine environments.

2. Monitor trends in invertebrate species assemblages, secondary productivity and, where site access permits frequent revisits, phenology.

The following recommendations are also forwarded in regards to the research needs for keystone species, abiotic variables, and ecological interactions in the afroalpine and subafroalpine ecosystems.

Keystone species

1. Estimate variability and long-term trend in the distribution and abundance of keystone and/or indicator species in the afroalpine and subafroalpine environments.

2. For keystone species check and document insect infection/ infestation, the rate of infection, and associated mortality rates. Determine whether rates of infection and mortality in keystone species are changing over time.

3. For species of conservation concern, document changes in demographic parameters for selected populations.

Abiotic variables

1. Estimate variability and trend in air and soil temperatures in selected alpine environments.

2. Estimate variability and trend in the timing of maximum and minimum soil temperatures and soil freeze-thaw events (Solifluction and Frost formation).

3. Estimate variability and trend in the amount and timing of precipitation (rain, snow, hail), and depth and duration of snowpack.

4. Where applicable, estimate variability and trend in SWE.

5. Where applicable, estimate variability and trend in rates of snowmelt.

Ecology (Abiotic and Biotic relationships)

Inventories that document species composition across a range of alpine environments, and studies linking community composition to environmental gradients, are likewise lacking from afroalpine and subafroalpine ecosystems. Thus a thorough investigation in ecological interactions and functions has paramount importance in mitigating changes associated with climate changes.

Afroalpine Lakes and Systems

Catchment-scale intensive and extensive research conducted over the last decade shows that our understanding of the biogeochemical and hydrologic processes in subalpine and alpine basins is not yet sufficiently mature to model and predict how biogeochemical transformations and surface water quality will change in response to climatic or human-driven changes in energy, water, and chemicals. A better understanding of these processes is needed for input to decision-making regulatory agencies and federal land managers. In recognition of this problem the *National Research Council* [1998] has identified as a critical research need an improved understanding of how global change will affect biogeochemical interactions with the hydrologic cycle and biogeochemical controls over the transport of water, nutrients, and materials from land to freshwater ecosystems. Improved knowledge of alpine and subalpine ecosystems is particularly important since high-elevation catchments are very sensitive to small changes in the flux of energy, chemicals, and water. Furthermore, alpine ecosystems may act as early warning indicators for ecosystem changes at lower elevations.

Policy Implications and recommendations

Policy Implications

Although all of the Ethiopian afroalpine and subafroalpine ecosystems are not well protected, some of these ecosystems are dedicated to the production of unique wildlife and rich plant diversity resources. It is of paramount importance that these fragile ecosystems obtained equal conservation status and legitimacy like any other land uses before it is too late and they lose their essential and critical ecosystem services. In short, the management of these conservation areas must be recognized and founded on legal grounds. In order to maximize the various national and global benefits from the afroalpine and subafroalpine ecosystems of Ethiopia, the necessary policy and legal instruments and tools should be in place.

Policy recommendations

1. Collaborate with local governments in the afroalpine and subafroalpine ecosystems to reduce and reverse habitat fragmentation and loss through comprehensive land use policies, zoning regulations, critical area ordinances, and other regulatory and non-regulatory approaches.

2. Use and improve existing regulatory and enforcement programs to build the resilience of natural systems to climate change in afroalpine and subafroalpine ecosystems.

3. Define priorities for land management in afroalpine and subafroalpine ecosystems important to biodiversity to emphasize resilience to fire and decrease the likelihood of severe fires.

4. Incorporate climate change considerations for species, habitats, and ecosystem processes into planning and regulatory activities related to implementation of the Growth and Transformation Plan (GTP), Management Act, Watershed Management Act, State Environmental Policy Act, and other state goals and policies.

5. Update natural resource protection plans, land use plans, and water resources management plans to address climate change considerations for species and ecosystems in the afroalpine and subafroalpine ecosystems.

6. Integrate programs and actions necessary to mitigate climate related changes in the afroalpine and subafroalpine ecosystems into educational policy and programs.

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Annex 1. Drivers, Impacts, Vulnerability and Risks to Afro-alpine ecosystems

Drivers	Impacts/Climate influences	Vulnerability/ Observed Changes	Risks/ Future Projections
1. Increased temperatures 2. Change in precipitation pattern 3. Increased summer drought stress 4. Increased fire frequency. 5. Increase incidence to disease & insect infestation. 6. Extent of frost formation & snow cover	1. Species Composition & Distribution – Soil quality & moisture – Seed dispersal & germination - Vegetation i. Composition: richness, diversity, structure ii. Distribution iii. Growth	– Up-elevation movement of tree-line. – Decline in habitat area with elevation. **– Depends on microclimates and structure of afroalpine /subalpine communities.**	–Upward shift of afroalpine /subalpine communities –Decline in afroalpine/ subalpine vegetation, Evidence/e.g.

	2. Productivity **–Expected to increase with rising temperatures Wildfires** **–Expect a change in species composition & distribution.**	**–Would favor species that can survive or regenerate quickly after fire (adaptation to fire increases) under moderate fire conditions**	**–Vulnerable species go to extinction.** **–Loss of endemic spp.**
	Insects & Disease **Disease outbreaks and insect infestations become rampant and triggered by changes in the environment or climate.**	**- Increased climatic suitability for disease outbreaks.** **- Increased climatic suitability for native plants.** **–Increased damage from invasive species.**	**–Local and regional extinction of species.** **–Reduced availability of seeds for dispersal.**

Climate Change Impacts, Adaptation and Vulnerability : Forest Ecosystems

Background

Forest is a complex ecosystem consisting predominantly of trees that shield earth and support numerous life forms. Not all forests are similar in terms of species composition, structure and physiognomy. In any geographical region, environmental factors such as climate, soil types, topography and elevation determine the types of forests (Stadtmüller, 1987; Friis, 1992; Bubb et al., 2004). In other words, local environmental factors determine which individual species can grow in a place and which different species can grow together. We recognize and classify forest types based on the distinct associations of different forest communities within the broader region due to the variations in environmental factors. Hence, forests can be classified in diverse ways and to different degrees of specificity such as coniferous forests, temperate forests, tropical forests, montane forests, etc.

Forests in Ethiopia show a variety of structure and composition resulting from the interplay between a great variety of environmental conditions (i.e. altitude, climate and soil), and human interactions. Many scholars have attempted to categorize the forest vegetation in Ethiopia (Logan 1946; Chaffey 1979; Friis 1986; Friis and Tadesse, 1990; Friis 1992).Most classifications are based on climate, physiognomy and species composition. The classification by Friis (1992) employed a combination of floristic and physiognomic forest classification and recognized seven forest types. These include: lowland dry peripheral semi-deciduous Guineo-Congolian forest; transitional rainforest; Afromontane rainforest; dry Afromontane forest of the Ethiopian Highlands; and riverine forest. A detailed account of each forest can be screened in Friis (1992).

Out of these aforementioned forest types, Afromontane rainforest including transitional rainforest is the largest forest cover in the country at the moment. According to Friis (1992) and Friis et al. (2010) Afromontane rainforest occurs between 1500 and 2600 m above sea level and transitional rain forest occurs between 450 and 1500 m above sea level. In southwestern moist Afromontane forest, the mean annual temperature ranges from 15-20 0C and annual rainfall from 1000 to 2500 mm. The Ethiopian Afromontane rainforests have recently been designated as part of the Eastern Afromontane Biodiversity Hotspot which is one of the globally important sites for biodiversity conservation (Mittermeier et al. 2004). The tree canopies of moist Afromontane forest are characteristically made of a mixture of *Podocarpus falcatus* and broad-leaved species. *Podocarpus* predominates in the southeast and gradually becomes rare towards the southwest. On the contrary, *Pouteria adolfifriederici* becomes more prominent in southwest. The dominant tree species include: *Pouteria adolfifriederici, Croton macrostachyus, Schefflera abyssinica, Apodytes dimidiata, Ficus spp*, *Syzygium guineense, Allophyllus abyssinicus, Cordia africana, Millettia ferruginea, Sapium ellipticum, Albizia spp, Acacia abyssinica* and *Olea welwitschii* (Friis et al. 2010). A segment of the Ethiopian Afromontane rainforests are also known as the centre of origin and diversity of wild population of Arabica coffee (Coffea arabica), which grows as a forest understory shrub (Woldemariam 2003; Senbeta 2006; Hundera et al. 2013). These rainforests with wild coffee occurrence are usually named as "coffee forest". During the past decades, however, large parts of the Ethiopian Afromontane rainforests with wild coffee have become increasingly disturbed and fragmented due to forest conversion to settlements and agricultural land, and forest modification by timber extraction and wild coffee management interventions (Reusing 2000; Senbeta & Denich 2006; Schmitt et al. 2009). This destruction threatens not only the wild coffee populations, and thus coffee genetic diversity, but has also endangered the exceptional floristic diversity of these forests. The Afromontane rainforests are of high conservation importance (because of high genetic diversity of coffee gene pools and plant diversity) and are highly valued for their economic (as sources of spice, coffee, and honey) and ecological services like protection of several river basins. The dependency of the local community on these forests for timber and non-timber forest products has contributed, to certain extent, to the maintenance of higher forest cover in Sheko areas where cultural resource management rules and religious taboos and values remained relatively intact among Mejengir people (Senbeta 2006; Senbeta et al. 2013). Nevertheless, human pressure on the Afromontane rainforests including coffee forests is immense, mainly because of unsustainable resource use and deforestation for agriculture, settlement and establishment of plantations (Gole et al., 2008). Apart from this, intensive management of coffee plants has considerably altered species diversity, structure and regeneration potential of moist Afromontane forests (Senbeta and Denich 2006; Aerts et al. 2011; Hundera et al. 2013).

The dry Afromontane forest of the Ethiopian Highlands is the other forest vegetation type occurring within an altitudinal range of between 1500-3200 (-3400) m above sea level; with average annual temperature and rainfall of 14-25^{0}C and 700-1100 mm, respectively (Friis 1992; Kelbessa and Girma, 2011). Tree canopies of this forest are characterized by the presence of Juniperous procera, Podocarpus falcatus, Olea europaea ssp. Cuspidata, and Prunus africana. Studies have shown that originally large parts of northern, central and southeastern highlands of Ethiopia was covered by dry Afromontane forest; but has considerably reduced and is situated on some isolated mountain chains. Importantly, this dry Afromontane forest region has been generally colonized by the majority of the Ethiopian population for long and represents a zone of sedentary cereal-based mixed agriculture; which has enhanced their degradation.

The lowland dry peripheral semi-deciduous Guineo-Congolian forestis found in the lower elevation (usually between 450-600 m a. s. l.) and represents a rare and fragile forest ecosystem. This forest was named differently by different authors: lowland forest (Chaffey, 1979), Lowland evergreen forest (Mesfin Tadesse, 1992), lowland dry peripheral semi-deciduous Guineo-Congolian forest (Friis, 1992), lowland tropical forest and lowland semi-evergreen tropical forest (Friis et al. 2010). As portrayed by many, the lowland dry peripheral semi-deciduous Guineo-Congolian forest is restricted to southwestern corner of the country, and covers only a small portion of Gambella Regional State. Importantly, it possesses restricted plant species (e.g., *Baphia abyssinica*, *Antiaris toxicaria*, *Alstonia boonei*, *Celtis integrifolia, Milicia excelsa*, and *Pouteria alnifolia*)) and is recognized as part of Ethiopian biodiversity hotspot. However, the lowland dry peripheral semi-deciduous Guineo-Congolian forest is among the most threatened habitats in the country due to rapid clearance for various kinds of agricultural practices. This means that virtually all these unique habitats and associated biodiversity are facing significant threats due to both natural (e.g., fire) and anthropogenic factors. At present , the country has lost the largest portion of the lowland dry peripheral semi-deciduous Guineo-Congolian forest. A diverse range of social, economic and ecological information about the forest is necessary to design suitable conservation and sustainable use approaches.

The subsequent discussion in relation to climate change impacts, adaptation and vulnerability refers to the types of forest vegetation mentioned above.

Drivers of forest change

Introduction

Global forest biodiversity is changing at an unprecedented rate; and the most important drivers are land conversion, climate change, pollution, unsustainable harvesting of natural resources and the introduction of exotic species (Laurance et al. 2011; Schmitt et al. 2012; Ango et al. 2014). Understanding drivers of deforestation and degradation is fundamental for the development of policies and measures that aim to alter current trends in forest activities toward a more climate and biodiversity friendly outcome. Parties to the United Nations Framework Convention on Climate Change (UNFCCC) are developing a mechanism for reducing emissions from deforestation and forest degradation, enhancing forest carbon stocks, sustainable management and conservation of forests (UNFCCC 2010). In addition to the discussion on policy incentives and modalities for measurements, reporting and verification (MRV), the issue of identifying drivers and activities causing forest carbon change on the national level for REDD+ monitoring and implementation has received increasing attention in the REDD+ debate (Bendorfet al.,2007, UNFCCC 2010). The UNFCCC negotiations (UNFCCC 2009, 2010) have encouraged developing countries to identify land use, land use change and forestry activities, in particular those that are linked to the drivers of deforestation and forest degradation, and to assess their potential contribution to the mitigation of climate change. Understanding is needed for assessing not only how much forests are changing but also how to define proper policies, and national REDD+ strategies and implementation plans (Boucher, 2011, Rudorff et al., 2011). Land-use change due to deforestation in the tropics was the major contributor to CO2 emissions in the 1990s, andaveraged between 0.5 and 2.7 gigatons of carbon (GtC) per year (UNFCCC, 2007).These changes alter ecosystem services and affect the ability of biological systems to support human needs, and also determine, in part, the vulnerability of environments and the community to climatic, economic and socio-political perturbations (Lambin & Geist, 2006).

There is a need for identifying forest change drivers at local, national and global level. In Ethiopia, drivers of forest cover change can be direct/proximate and indirect/underlying causes. Each of these drivers is described as follows.

Direct /proximate drivers

These are human activities or immediate actions that directly impact forest cover and loss of carbon. The two main direct drivers of deforestation and forest degradation are agricultural land (crop land) expansion and unsustainable fuel wood consumption (Senbeta and Denich 2006; Lemenih et al., 2008; Tadesse et al. 2008).Conversion of forests to agricultural land is the most prominent deforestation driver, as agriculture is more attractive than forestry (Tadesse et al 2008). Traditionally, land use in Ethiopia was exclusively limited to primitive field cropping and extensive cattle grazing expanding to forests (Lemenih et al., 2008; Tadesse et al. 2008). (ref.). The expansion of the two land uses was due to the fact that forests were considered as free virgin land that had highly productive soils for cultivation of cash crops and sedentary agriculture (von Breitenbach and Koukol 1962). Subsistence agriculture that forms the backbone of Ethiopian economy relied on extensification rather than intensification in which forest ecosystems have been providing productive crop lands for millennia (Lemenih et al., 2008). The same forests, when unconverted to crop lands, served as natural range lands for one of the largest livestock population in sub-Saharan Africa. In a 'business as usual' scenario, the impact of this deforestation driver would be expected to increase, as agricultural land requirements will increase by an estimated 19 million ha by 2030, spurred by strong governmental support to develop agriculture and sustained demographic growth of 2-3 % per year (CRGE, 2011). Forest land conversion has caused the emission of an estimated 40 mega tones of CO2 from deforestation in 2010 (MOA, 2013). Its impact is bound to increase up to 65 mega tones per year in 2030, as development of agriculture continues to accelerate (MOA, 2013). Under a business as usual growth path, requirement for agricultural land will increase by 19 million ha by 2030, from 15 million ha in 2008 to meet the increasing demand (CRGE, 2011). This will mostly be taken from forest land. According to WBISPP

(2004), 80% of new agricultural land developed between 2000 and 2008 was converted from forests, woodlands or shrub lands.

The second most prominent driver, with most of its impact focused on forest degradation, is unsustainable fuel wood consumption. Ethiopia's energy consumption is predominately based on biomass energy sources (94%). The biomass energy sources include traditional energy sources such as fuel wood, charcoal, branches, leaves and twigs. The current needs largely exceed the level of sustainable production (e.g. from dead wood and plantations), leading to massive degradations of the biomass (WBISPP 2004). Between 2000 and 2010, degradation due to fuel wood consumption claimed an estimated 135 million tons of woody biomass (indicate in % also if possible) from the total woody biomass existing in 2000 (MOA, 2013). As the evolution of fuel wood consumption is strongly correlated to population growth, its impact on degradation is expected to reach, in a business as usual scenario, 22 mega tones of CO2 per year by 2030 as the Ethiopian population reaches 130 million people (CRGE, 2011). The other drivers with limited role in deforestation and forest degradation in Ethiopia are logging, clearing to convert to pastureland, infrastructures expansion and fire use to clear forest land and invigorate grass growth. Conversion to pastureland was identified as a potential threat, as livestock population is expected to increase in Ethiopia, to meet the demand of a growing population reaching middle income level by 2020-2025 (CRGE, 2011).

Indirect/Underlying drivers

Indirect drivers are complex interplays of many social, economic, political, cultural and technological processes (Tadesse et al. 2008). These indirect drivers are strengthening direct causes. They are deficiencies in the regulatory and institutional environment: unclear user rights, weak law enforcement, lack of incentives for sustainable forest management at local levels and absence of benefit-sharing mechanisms that encourage an open access mentality and conversion to agriculture. Many regulatory policies regarding forest use have been un-implementable because of either lack of resources (i.e. financial, human and institutional capacity) or inherent deficiency of the forest regulatory instrument, and have resulted in widespread illegal/uncontrolled use of the forest. Besides the policy issues, resettlement and immigration, changes in farming systems, population growth and tenure insecurity have been driving deforestation and forest degradation particularly in the Afromontane forests of southwestern Ethiopia. Case studies have shown that forest cover in southwest Ethiopia has been reduced from 71% to 48% between 1973 and 2005 making overall forest cover loss of 30% (90127 ha) induced by these drivers (Woldemariam et al., 2008). This, combined with irregularities and inconsistencies in the implementation of bans on forest products, created a disincentive for forest-dependent people to invest in forest management/protection because of lack of security over future returns.

Impact, vulnerability and risks

Introduction

Climate change is expected to significantly alter global forest biodiversity as species struggle to adapt to changing conditions (Lovett et al., 2005). Historically, climate change has resulted in dramatic shifts in the geographical distributions of species and ecosystems and current rates of migration of species will have to be much higher than rates during post-glacial periods in order for species to adapt (Malcolm et al., 2002). Species that have the capability to keep up with climate shifts may survive; others that cannot respond will likely suffer. The projected rapid rise in temperature combined with other stresses, such as the destruction of habitats from land use change, could easily disrupt the connectedness among species, transforming existing communities, and showing variable movements of species through ecosystems, which could lead to numerous localized extinctions. If some plant species are not able to respond to climate change, the result could be increased vulnerability of ecosystems to natural and anthropogenic disturbance, resulting in species diversity reductions (Malcolm et al., 2002). Globally, forest ecosystems have also experienced various threats due to the impacts of climate change (FAO 2010; Laurance et al. 2011; Davies et al. 2012.). These threats vary with regions, but are generally reflected through changes in growth rates, species composition and density and shifting of ecosystems. Expected impacts for example in Africa include the loss of biodiversity and vegetation cover as well as the degradation of soil productive capacity. The various manifestations of the impacts have been attributed to factors like recurrent droughts and climate variability. Human factors such as deforestation have for long been identified as catalytic factors to climate change in contributing to accelerating the impacts of climate change on forest ecosystems. FAO (2010) statistics show that about 3.4 million ha of forests in Africa are lost every year due to various factors among which are climate change and variability and human intervention. Such forest loss is seriously impacting on people's livelihood as well as incomes of various nations and the environment (Larwanou et al. 2011). The regional climates of Ethiopia are known to show large variations in precipitation patterns and temperatures due to the highly heterogeneous topography with rugged mountains and undulating landscapes. Recent studies predict increasing temperatures for the tropical montane regions of Ethiopia as well as changes in precipitation patterns, which cannot easily be modelled (Christensen *et al.* 2007; Zelazowski *et al.* 2011). The predicted increase in temperature for the Ethiopian highlands due to climate change is likely to affect the distribution of the endemic montane species. It is thus likely that the pronounced climate variations will have a strong impact on the regional distribution of plant species and forest communities in the Ethiopian forests.

Impacts

According to IPCC (2007) and Fischlin *et al.* (2009), roughly 20–30% of vascular plants and higher animals on the planet are estimated to be at an increasingly high risk of extinction as temperatures increase by 2–3°C above pre-industrial levels. Changes in climate could also affect phenological events (such as flowering and fruiting) that may escalate into major impacts on forest biodiversity. Impacts of climate variability and change have already been observed in tropical forests, for instance, on forest composition, structure, function and carbon stock (Root et al. 2003). Climate variability and associated events, such as the El Niño Southern Oscillation, have caused drought and increased the frequency of fire in humid tropical forests in Indonesia and Brazil (Barlow and Peres 2004, Murdiyarso and Lebel 2007). As a result, some species extinctions linked to climate change have already been reported for tropical forests. Further, it is expected to cause significant shifts in the distribution of tropical rainforests and disturbance patterns.

Although major impacts of climate change on ecosystems will be felt when temperature is increase is greatest, most likely towards the higher latitudes (Laurance *et al.* 2011; Schmitt et al. 2012).Markham (1996) suggested that changes may be influenced more by the change in rainfall distribution within and between years, extreme events such as tropical storms and fires, shifts in seasonality and human land-use feedbacks. The tropical forest regions provide such an example where temperature changes may be small but other climate related impacts may have very deleterious effects. For example, changes in seasonal precipitation, length of seasons and frequency and intensity of extreme events may be highly disruptive of biological diversity in tropical seasonal forests (Lambin and Geist 2006; Christensen et al. 20107). The vertebrate fauna of these forests can be extremely sensitive to changes in the abundance of food resources during different stages of the annual cycle. Unusual weather conditions can cause severe population declines amongst many species of birds and mammals. Forests are currently under considerable pressure from human use and are also impacted by climate change, that interest is increasing in their potential to contribute to climate change mitigation and adaptation strategies. Tropical forests, as a whole, are among ecosystems expected to be most affected by climate change (IPCC 2007). Climate changes may have profound impact forest composition, structure and function that will have far reaching, mostly adverse, consequences on the livelihoods of forest-dependent communities, particularly in Africa. It is important, therefore, that the vulnerabilities and resilience of African moist forests, and their peoples, to climate change be better understood than at present, in order to facilitate the design of effective and timely response measures. Furthermore, since tropical forests are increasingly being considered as critical components of strategies for addressing climate change, it is important that the status of African moist forests, in terms of their size, productivity and resilience to climatic and non-climatic pressures, among other characteristics, be well understood, for effective use of the forests in addressing climate change. IPCC (2007) concluded that with climate change, forests are likely to undergo species range shift and changes in tree productivity, and that a large proportion of species may be threatened or endangered in the future.

Vulnerability and risks

Human disturbance and climate change are major driving forces that shape forest ecosystems (Laurence et al. 2011). General circulation models indicate that as the global temperature increases as a result of the GHG emissions, global precipitation also increases (Christensen et al. 2007) There could be substantial changes towards drier conditions certainly leading to upward ecological shifts, and thus shrinking the size of habitat suitable for high value highland plant and animal species (Laurance et al. 2011; Christensen et al. 2007). Such ecological shift and shrinkage of habitats is another risk related to climate change in forest ecosystems. For example, the moist montane forest is predicted to shrink from 23.11% under current climate to 22.38% under changing climate (Mamo, 2001). Similarly, dry evergreen montane forest is predicted to shrink from 9.01% under current climate to 1.72% under changing climate (Schmitt et al. 2012). The shrinkage will lead to species restrictedness to narrow ecological niches increasing the risk of extinction (Davis et al. 2012)

In the southern parts of Ethiopia, series of sediment records analyzed for fossilized pollen and charcoal showed temporal shifts in types of forest vegetation as a result of natural climate change and human disturbance (Eshetu, 2013).Analysis of charcoal sediment from northern Ethiopia provided evidence of two phases of climate: cooler during early Holocene and drier since mid-Holocene in the uplands of northern Ethiopia (Gebru et al, 2009). The generally drier environmental conditions led to the expansion of acacia savanna woodlands as indicated by an increase of C4 grass and Acacia species dominated charcoals. The cooler environmental condition was characterized by increased C3 forest vegetation dominated by charcoals derived from a mix of tree species during the Iron Age. These vegetation shifts and subsequent changes in local climatic conditions may be associated with development of human society's ability to use iron tools to permit high agricultural production since 2500 BC. If the current increasing trend of atmospheric warming and GHGs emissions continues, it would force species to spatially migrate or become extinct (Eshetu, 2013). Nkomo et al. (2006) predicted that up to 75% of Ethiopian species could migrate, if not become extinct due to climate change. For example, influence of climate change on indigenous populations of Arabica coffee is predicted to result in significant reduction in the number of existing bioclimatically suitable spaces by 2080 and this would place the population in peril leading to severe stress and high risk of extinction (Davis et al., 2012).

The immediate impact of climate change could be manifested by a decline in the health of the forests and their productivity as well as crop yields. The global warming-induced changes in hydrology, rainfall patterns, frequency and intensity of storms, fires, pest and diseases may have far reaching consequences through their impacts on the phenology, productivity, and regeneration of trees (Eshetu, 2013). The increase in temperature has increased incidence and frequency of fire. Increasing incidences of pests/ diseases is also a risk factor in forest ecosystems. Ayinekulu et al., (2011) reported high dieback of trees in a dry Afromontane forest following elevated temperatures during extreme drought condition.

Adaptation, mitigation and managing risks

Introduction

Adaptation to climate changes refers to adjustments in ecological, social, and economic systems in response to the effects of changes in climate (Spittlehouse and Stewart 2003).Forests do have the potential to contribute to national adaptation strategies. For instance the practices of tree planting and sustainable management of forests protect soil and land against detrimental impacts of flooding. In addition, rehabilitation of degraded land through afforestation and reforestation programs could maintain water quality by trapping sediments, taking up nutrients, and immobilizing toxic substances. Sustainable forest management can also contribute to food security, poverty alleviation, economic development, and sustainable land use, in the wider context of sustainable development. Forest management can both maximize forests' contribution to climate change mitigation and help forests and forest-dependent people adapt to new conditions caused by climate change. Thus, adaptation strategies that promote sustainable forest management have the potential to not only protect land and people from the harmful effects of rising global temperatures, but also to provide opportunities for greater, more sustainable rural development and poverty alleviation through income generation and employment opportunities. Because of this facts forest management is becoming increasingly recognized by governments and forest managers. Improved forest management practices for climate change mitigation and adaptation should be planned and implemented on continues base.

Like elsewhere, the forest of Ethiopia is vulnerable to climate change-related disturbance and other drivers of change. Hence, there is a need to implement adaptation strategies to safeguard forest and their biodiversity loss.

Adaptation measures

Several adaptation measures have been proposed for forests (Spittlehouse and Stewart, 2003; Millar et al., 2007; Guariguata et al., 2008). In most cases, adaptation measures are classified into: institutional and social measures, technological measures and ecosystem-based adaptation measures. On the other hand, Smithers and Smit (1997) identified two broad kinds of adaptation measures: measures that aim to buffer a system from disturbances by increasing its resistance and resilience to change, and measures that facilitate a shift or an evolution of the system towards a new state that meets altered conditions.

Buffering measures focus on preventing perturbations, such as fire (managing fuel, suppressing or controlling fires), control and management of invasive species, insects and diseases management, and managing the forest actively after a disturbance by using adapted and acceptable species. Measures that facilitate a shift or evolution of a system do not aim to resist changes, but rather to ease and manage natural adaptation processes. The resilience of the ecosystem is crucial, not necessarily to keep the ecosystem in the same state after a disturbance, but to help it evolve towards a state that is acceptable for the society. An example of facilitating measures is the reduction of landscape fragmentation. This is because connectivity between habitats eases species migration; corridors established in the direction of the climate or environmental gradient could help forests to adapt (Noss, 2001). As genetic diversity is a key element of the adaptive capacity of an ecosystem, some authors propose measures for maintaining or enhancing it in managed forests (Guariguata et al., 2008). For forest plantations, management can be modified to adapt to climate change, for example, by adopting species and genotypes that are adapted to future climates, planting mixed species and uneven age structure, or by changing rotation length.

Measures that reduce non-climatic pressures, such as forest conversion, fragmentation, and degradation, can contribute to both buffering and facilitating (Noss, 2001; Malhi et al., 2008). Climate change adds to other stresses, some of which are currently more pressing than the climate; for example, forest conversion. If non-climatic threats are not addressed, adaptation to climate change may be irrelevant or purely academic (Markham, 1996). In places where threats to forest sustainability are mostly non-climatic (e.g., land use conversion, overharvesting), implementing sustainable forest management is essential for reducing the vulnerability of forests and is an important first step towards forest adaptation. The application of community-based forest management that aimed at promoting afforestation and the conservation of land, water and timber resources is being practiced in many parts of the country (personal observation). Sustainable Forest Management is also quoted as a method of increasing the resilience of forests to climate change (Innes et al. 2009; Larwanou et al. 2011).Changes in forest management, such as harvesting and planting dates, and utilization of thinning are reported as further possible methods of adapting to climate change (Glück et al. 2009).

Although adaptation is about managing local problems, it is also a national issue and so requires collaboration at multiple levels and across sectors. Local adaptation is affected by institutions that operate on a regional, national, or global level. The adaptive capacity of a local system can be weakened by inappropriate policies and programs, policy-makers at different levels need to develop mechanisms that allow people to adapt their own systems more effectively as the climate changes. Overall, the adaptation options focus on reducing the anthropogenic stresses on forests through the use of regulatory, economic and informational instruments (Dang et al. 2003). Additionally, capacity building through the dissemination of information (via training, research, projects, etc.) regarding future risks and potential solutions is highly relevant. However, there is insufficient data for baseline information regarding forests. As a consequence, the establishment of monitoring programmes to determine the current situation of forests and further research into future projections of climate change, including extreme events, are important to note. The need for the incorporation of climate change into short- to long-term planning at all levels of decision-making, from forest-management plans to the long-term policy-making process, is also necessary.

The future adaptation measures of forests to climate change in Ethiopia may include but are not limited to :

- Afforestation, reforestation, and forest restoration with species suited to the future climate, and short rotation species and management practices that enhance forest resilience or with fast-growing tree species resistant to possible disturbances, such as insect, disease, and fire.
- Changes in forest species and composition and promoting mixed species forests for plantation forest.
- Community-based forest management and forestation.
- Forest conservation in the form of Sustainable Forest Management and formal protection areas and the establishment of forest corridors. .
- Establishment of biosphere reserve or forest nature reserve.
- Genetic management: seed selection or maintenance of genetic diversity.
- Monitoring and management of disturbances: fires, land use change, settlements, pests, and diseases.
- Mapping and risk assessment as an important aspect of adapting to climate change.

Mitigation measures

The term mitigation refers to all activities that are aimed at reducing greenhouse gas emissions and/or removal of CO2 from the atmosphere to stabilize CO2 concentrations (Guariguata et al. 2008). Some of the actions that can be taken in the forest sector to promote climate change mitigation include:

- managing forests with high carbon uptake potential, and expanding such forests through reforestation and afforestation,
- reducing deforestation and reversing the loss of forest cover,
- providing an enabling environment for investments and market access to sustainable forest-based products, and

– increasing the use of forest-based products such as bio-energy and durable wood products, and substituting these for less eco-efficient materials.

Forest-related mitigation activities often have a cost advantage over other mitigation strategies. They can also be designed to support other national development and poverty alleviation priorities since forests provide multiple benefits. IPCC (2007) estimates that about 65% of the total mitigation potential in the forest sector is located in the tropics and about 50% of this total could be achieved by reducing deforestation. In other words, because tropical forests have the greatest potential for carbon uptake and storage, the most cost effective way of reducing carbon concentrations in the atmosphere, is to reduce deforestation of tropical forests and allow for forest cover expansion.

Modern bio-energy can also contribute substantially to mitigation by providing an alternate source of renewable energy. Using fuels such as bio-diesel made from wood products is carbon neutral because trees harvested for use as fuel are continually replanted. In addition, forestation and bio-energy plantations can lead to restoration of land that has been degraded by over-extensive agriculture, manage water runoff, retain soil carbon and benefit rural economies by providing employment and income. However, if such plantations are not designed properly, they do have the potential to compete with land for food production and may be negative for biodiversity. Additionally, ecosystem-based adaptation measures based on the protection and restoration of natural forest ecosystems are seen as no- or low-regret options, irrespective of the future of climate change (Cheong et al., 2013).

Forest Adaptation: Challenges and Opportunities

There is a growing recognition of the potential co-benefits and new opportunities that can be achieved by mainstreaming adaptation with existing local to national goals and priorities. However, using forests for adaptation brings opportunities as well as new challenges. A challenge comes from the need to understand and value the role of forest ecosystem services in the adaptation of society. This can be achieved by incorporating ecosystems and the users of ecosystem services into vulnerability assessments in order to achieve a deeper understanding of linkages and better targeting of adaptation responses.

Forest adaptation practices and policies should jointly consider the vulnerability of society and forests. Decision-making on adaptation can be integrative by combining forests and society, inclusive across scales and sectors, and participatory by incorporating different views and experiences (Folke et al. 2005). Another challenge lies in the need to design cross-sectoral adaptation that considers sustainable forest management as an adaptation option in addition to technical and socioeconomic actions within one specific sector. For instance, Ethiopia is developing several hydropower plants and a drinking water facility that may face problems of siltation or low water quality. The forestry sector could participate in managing upstream forests instead of investing in technical filtration or treatment solutions. This means that adaptation strategies must be prioritized based on their effectiveness and efficiency, and their cross-sectoral effects. Adaptation strategies that consider forests benefit both the forest and many other sectors. This, however, poses another challenge in assessing adaptation strategies because economic valuations of Ecosystem-Based Adaptation are lacking.

Forests for adaptation will modify the costs and benefits of forest management. If the objective of providing ecosystem services to vulnerable sectors is added to the objectives of forest management, forest managers may face higher costs or lower benefits, while other sectors may receive benefits from ecosystem services (Markham 1996; Spittlehouse and Stewart, 2003; Millar et al. 2007; Glück et al. 2009). It means that Ecosystem-Based Adaptation must include financial transfers from sectors benefiting from forests ecosystem services to sectors managing the forests. These financial transfers may help remove the financial barriers to Sustainable Forest Management and forest adaptation in a cross-sectorial way.

The integration of forests in adaptation plans for other sectors could represent an opportunity for forest conservation because the role of ecosystem services would be recognized and, possibly, be rewarded by those who get benefit from the forest sector. So far, the importance of forests for the adaptation of society has not been adequately reflected in current policies in Ethiopia. Even though there is growing awareness of the value of forest ecosystem services, adaptation policies and proposed projects tend to apply sectorial approaches; few decision-making processes incorporate forests into adaptation in Ethiopia (personal observation).

Generally, Ecosystem-Based Adaptation represents an opportunity for achieving the dual purpose of better managing forests and facilitating sustainable processes of societal adaptation. Ecosystem-Based Adaptation requires new modes of local and national governance that include multi-sectorial processes, stakeholder participation, and flexible institutions, such as policy networks (Noss 2001; Malhiet al. 2008; Glück et al. 2009). Ecosystem-Based Adaptation can also be facilitated by a better integration of international policies related to forests, climate change mitigation and adaptation, and biodiversity. For instance, a global mitigation mechanism such as REDD (Reduction of Emissions from Deforestation and Forest Degradation) has the potential to contribute to adaptation by improving local livelihoods, strengthening local institutions, and conserving ecosystem services. But REDD can also have negative effects on the adaptive capacity of local forest people by reducing their access to land and forest resources through blocking individual use right dual (Larwanou et al. 2011). . Therefore, a better integration of policies for adaptation and mitigation in forests is necessary at the local, national, and international levels.

Synergies and Trade-offs between Mitigation and Adaptation

An understanding of the synergies and trade-offs between adaptation and mitigation could underpin discussions on mainstreaming both adaptation and mitigation into climate change policies. Forests play an important role in both adaptation and mitigation, as they provide local ecosystem services relevant for adaptation as well as the global ecosystem service of carbon sequestration, relevant for mitigation. Consequently, just as there are synergies and trade-offs between global and local ecosystem services, there are synergies and trade-offs between mitigation and adaptation in forestry projects: mitigation projects can facilitate or hinder local people‘s efforts to adapt to climate change, and adaptation projects can affect ecosystems and their potential to sequester carbon (Locatelli et al., 2011). Ecosystem-based adaptation projects aim to achieve better management of forest ecosystems, thus helping to increase or maintain carbon stocks which directly benefits climate change mitigation efforts (Pramova et al., 2012). The synergies between ecosystem services reflect the synergies between adaptation and mitigation; for example, mangroves simultaneously help protect coastal areas and store carbon. However, there may be trade-offs depending on local needs; for example, an adaptation project may prioritize the conservation of water services over carbon storage (Locatelli, 2011). An adaptation project could also contribute to mitigation indirectly. For example, if an agricultural adaptation project boosts the productivity of crops, there will be less pressure on forests for agricultural expansion.

Klein et al. (2007) defined trade-offs as the balancing of adaptation and mitigation when it is not possible to carry out both activities fully at the same time due to financial or other constraints. Successful adaptive forest management of climate risks will involve assessing and minimizing potential trade-offs with other non-climate policy goals (e.g., economic development, timber production) and interactions between adaptation and mitigation.

Adaptation will be the predominant approach to reducing climate risks to the local communities, populations, resources and activities. Still, positive synergies and complementarities between mitigation and adaptation in the forestry sector are required. The need for integration of mitigation and adaptation strategies to promote sustainable development is presented in Klein et al. (2007). The analysis has shown the complimentarily or synergy between many of the adaptation options and mitigation (Dang et al., 2003). Promotion of synergy between mitigation and adaptation will also advance sustainable development, since mitigation activities could contribute to reducing the vulnerability of natural ecosystems and socioeconomic systems (Ravindranath, 2007). Currently, there are very few ongoing studies on the interaction between mitigation, adaptation and sustainable development (Wilbanks, 2003; Dang et al., 2003; Innes et al., 2009).The possibility of incorporating adaptation practices into mitigation projects to reduce vulnerability needs to be explored. Thus, guidelines may be necessary for promoting synergy in mitigation as well as adaptation programmes and projects as well as emerging mechanisms. Integrating adaptation practices in such mitigation projects would maximize the utility of the investment flow and contribute to enhancing the institutional capacity to cope with risks associated with climate change (Dang et al., 2003).

Critical gaps in knowledge, research and data needs for climate change on forest ecosystems

Deforestation (through the conversion of forest lands to other land uses) has been the second major source of greenhouse gas emissions, after fossil fuel combustion (IPCC 2007). There has been a global decline in deforestation rate except in Sub-Saharan Africa where it has increased (FAO 2010). The huge implication of this in terms of climate change is not just carbon emissions; more importantly, it is increasing the vulnerability of forest ecosystems and forest -dependent communities. Incorporating climate change adaptation and mitigation into forest policy (or vice-versa) in Ethiopia requires information and scientific knowledge. Consequently, there is a need to study climate change impacts and their implications in forest ecosystem. It is also important to understand the adaptation strategies that have been developed over time. The natural resource base affected by climate change needs to be evaluated in order to plan for the special adaptation needs. Planning climate change response would be very challenging without adequate information and knowledge although it is absolutely fundamental and urgently required. Planning national climate change adaptation involves the integration of scientific knowledge and monitoring, and estimating future scenarios in order to formulate policy (Fischlin et al. 2009).

Understanding and adapting to the impacts of climate change on forest ecosystems and their services present important challenges for natural resource managers and policy makers. Currently available and future observations of forest ecosystems are important to addressing these intertwined challenges. Among the numerous gaps in our scientific understanding of how ecosystem services will respond to climate change some stand out as critical to answer in the next 5-10 years if society is to be able to reduce the human and economic costs of the climate change we are already observing. Research on Climate Change and Forests need to address the following issues:

- Assessment of the impact of climate change on forest ecosystem services and human wellbeing over the next years
- Assessment of adaptation strategies
- Green House Gas inventory for land-use sectors

- – Carbon stock changes and mitigation potential of forest sector Developing and implementing appropriate forest policies; (afforestation and reforestation, CDM, Carbon stocks, REDD projects)
- – Macro-economic implications of climate change impacts, vulnerability, adaptation and mitigation on forest ecosystems
- – Establishing long term monitoring plots to study vegetation response to climate change
- – Enhancing modeling capacity on climate change
- – Generate database for forestry climate change related analysis and projects
- – Developing pilot adaptation projects

Data required

- Climatic information (temperature, rainfall, cloudiness, humidity, etc)
- Forest types
- Species composition/dominance
- Physiological and phenological indicators
- Net Primary Productivity
- Forest fires
- Pests and diseases
- Invasive species
- Recruitment and mortality rates and regeneration patterns
- Level of exploitation
- Land use/land cover change
- Deforestation rate

Policy implications and recommendations

There are already a number of existing national policy initiatives, sectoral policies, programs and strategies that may directly or indirectly address climate change adaptation in Ethiopia. Accordingly, the most important policy and program documents that have relevance to climate change adaptation include Climate-Resilient Green Economy Strategy (CRGE, 2011), Plan for Accelerated and Sustainable Development to end Poverty (PASDEP), Environmental Policy of Ethiopia, Agriculture and Rural Development Policy and Strategy, Water Resources Management Policy, Health Sector Development Policy and Program, National Policy on Disaster Prevention and Preparedness, National Policy on Biodiversity Conservation and Research, Science and Technology Policy, Population Policy and National Agricultural Research Policy and Strategy.

The priorities of the national policies, sector strategies and programmes of the government of Ethiopia are primarily targeted at promoting rural and agricultural development and poverty reduction. As a result, climate change and adaptation issues are often treated indirectly in sector specific policies and programmes since climate impacts are considered as a sub-component of the overall development goal particularly in relation to natural resources and environmental protection. Moreover, climate change and adaptation issues are crosscutting issues like poverty, which should be addressed in a holistic approach through ensuring the participation of all the relevant sectors.

From the policy perspective, the ultimate goal is to reduce climate change impacts through development programmes and projects that contribute towards the alleviation of the worsening natural resource depletion and environmental deterioration. Therefore, programmes that address climate change impacts (drought, famine, etc), vulnerability and adaptation measures should be treated as an integral component of the overall development programmes that involve all the relevant sectors including forestry through short and long-term programmes particularly in the areas of forest management, utilization, development and conservation.

Thus, considering the nature of climate change as a crosscutting issue, it will be useful to incorporate some of the climate change/adaptation interventions into the on-going national programmes like poverty reduction as a sub-component. In addition to poverty reduction programmes, climate change and adaptation issues could be addressed along with two other national programmes; namely, food security and disaster prevention and management. In general, crosscutting issues like poverty, food security and others are aspects that should be considered when planning interventions that address climate change and adaptation.

Climate change is an inter-disciplinary science and a long term multi-institutional, rather than individual; approach to the study would ensure continuity of the research. Hence, a coordinated effort on Forests and Climate Change is of utmost necessity. Experiences that exist elsewhere can be used as starting point to undertake the initiative. The key proposed actions to address will be to identify a core set of widely recognized, policy-relevant questions about impacts on forest biodiversity and ecosystem services; establish a broader forest ecosystem assessment process and framework; align monitoring, modeling, and assessment activities for climate with those for forest biodiversity and ecosystem services; and identify and convey clear connections between forest biodiversity loss, reduced ecosystem services, and societal benefits.

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Woodlands and Dryland Ecosystems

Background

Over 65% of the total land surface of Ethiopia qualifies the definition of drylands; areas with the aridity index (P/ETP) of less than 0.65 (UNESCO, 1979) or length of growing period (LGP) of 1-179 days (FAO, 2000). The drylands in Ethiopia are found in the low lying areas circumscribing the highlands. The Great Rift Valley, which cuts diagonally from northeast to southwest through the highlands, is also a major part of the dryland ecosystems in the country. Drylands are sub-divided broadly as hyper-arid, arid, semi-raid and dry sub-humid (Table 1). Each sub-category further comprising diverse ecosystems**.**

The vast drylands in Ethiopia encompass diverse ecosystems: woodlands, grasslands, shrublands, bush tickets, wetlands, agro-ecosystems, forests and aquatic ecosystems (Table 1). These ecosystems harbor rich biodiversity, some of which are the world's most valuable and rarest flora and fauna resources. Wetland ecosystems such as those in Gambella regional state are fascinatingly huge and rich with biodiversity. Rift Valley lakes and their associated wetlands are also among biodiversity-rich and unique dryland ecosystems in the world (seems a source is needed)

With respect to vegetation ecosystems, several types are recognized from the drylands of Ethiopia. The most recent work of Friis et al. (2010) recognized 12 major vegetation types in the country, and 7 of these can be considered as typical of dryland areas. These vegetation types are:

- Desert and semi-desert scrubland;
- *Acacia-Commiphora* woodlands and bushlands;
- Wooded grasslands of the Western Gambella region;
- *Combretum-Terminalia* woodland and wooded grassland;
- Dry evergreen Afromontane forest and grassland complex;
- Freshwater lakes, lakeshores, marshes, swamps (wetlands) and floodplains vegetation, and
- Salt-water lakes, lake shores, salt marshes and pan vegetation.

Among these vegetation ecosystems, the two most dominant are woodlands (both the *Combratum-Terminalia* broadleaved deciduous and *Acacia-commiphora* small leaved deciduous) and shrublands. The term woodland in this paper refers to vegetation types with a continuous stand of trees with a crown density of between 20 - 80%, with the mature trees usually single storied, although there may be layered under-stories of immature trees, and of bushes, shrubs and grasses/forbs, and with maximum height of generally not more than 20 meters, with tree densities of between 150 and 400 stems per hectare (WBISPP, 2004). Shrublands are also defined as areas of land covered with a continuous stand of shrubs (a multi-stemmed woody plant) with a crown density of between 20 -100 %. There may be scattered individual trees with a crown cover of less than 20% or scattered clumps (i.e. less than 0.5 hectare) of trees. Although drylands of Ethiopia comprise several ecosystems, due to paucity of data on most of them, this report is biased towards woodland ecosystems, which are relatively better studied.

Table 1. Some typical attributes of drylands in Ethiopia (Source: modified from Kidane Georgis, 2011).

Dryland category	**Area coverage** **(10^6 sq. km)**	**Distribution in the country**	**Major eco-systems, farming system, crop/livestock species, typical constraints**
Arid	300-310	Afar, Somalia, parts of east Shewa and southern most parts of Borena	**Major eco-systems**: shrublands, bushlands, irrigated agro-ecosystem, salt marsh, riverian woodlands, desert and semi-desert scrubs and desert; **Farming Systems**: pastoral and agro-pastoralism; livestock species: sheep, goats, camel, donkeys; major crops: cotton, sesame, millet, tobacco, and sorghum; **Major constraints**: water stress, salinity, shallow soil, desertification, wind erosion, poor infrastructure and services, poor market integration; **Potential**: livestock production, irrigated agriculture, wildlife and other (eco)tourism, salt mining, forestry (incense production, sustainable charcoal);

Semi-arid	207-250	Western Tigray, Western Amhara, Benishangul-Gumuz, Lake Koka in eastern Shewa, South Omo and pocket areas in Borena area, fringes of Central Rift Valley lakes	**Major ecosystems:** woodlands, shrublands, wetlands and marshes, riverian forests, grass savanna, agro-ecosystems, low land forest(e.g. in Gambella), aquatic ecosystems; **Farming systems**: livestock-crop mixed farming. Livestock species: sheep, goats, camel, donkeys; Major crops: cotton, maize, sesame, millet, tef, sorghum, horticulture crops, tobacco, sorghum, haricot bean and other pulses; **Constraints**: open overgrazing, low input agriculture, land degradation, intense and erratic rainfall, water stress, low soil fertility, deforestation, salinity, wind erosion.
Dry sub-humid	300	Highlands of north Shewa, south and north Wello, Wag Hemera, north and south Gonder; eastern, parts of western and central Tigray; East and western Hararghe, east Shewa	**Major ecosystems**: dry forests, woodland savanna, wetlands, riverian forest; **Farming systems**: crop-livestock mixed farming. Livestock species same as above; Crops: highly diversified and major types include maize, sorghum, tef, barley, wheat, millet, haricot beans, chickpea, faba bean, field pea, sunflower and several horticultural crops; **Constraints**: low soil fertility and loss of organic matter, open grazing, land degradation, deforestation

Hyper arid	53-55	Northeastern lowlands of Afar, Southeastern Ogaden and other pockets	**Major eco-systems**: desert scrubs, desert, salt marshes, salt lakes; **Farming systems**: livestock (camel, goat and donkey) **Constraints**: salinity, water stress, high temperature (heat stress)
Total area	**860 – 915**		

Economic significance of drylands

Drylands have huge yet unrealized potentials. Vast areas of drylands in Ethiopia have significant non-agricultural and agricultural use potentials including tourism, commercial non-timber forest products production, and high-intensity agricultural production (e.g. high value crops for export, like Sesame and cotton in the western drylands of Ethiopia, cotton, sugar cane and horticulture, and livestock production). These potentials can drive national economy growth and ensure better rural livelihoods if properly taped. In general, four categories of potentials are recognized for drylands of Ethiopia. These are briefly presented as follows:

Crop production

The agronomic potential of the drylands is more than what their name might imply. Drylands offer vast and fertile lands where most commercial crops do well. They are also places where most irrigation potentials exist. They are known centre of crop diversity and origin for important food crops such as sorghum, millet, tef, field peas, chickpea, cowpea, cotton, safflower, castor bean, sesame and other crops. Most of the semi-arid and dry sub-humid areas are highly suitable for high value and commercial crops such as sesame and cotton. Among oil seeds, sesame seed is the major oilseed export product in terms of both export quantity and value (Haile Abera, 2009). For instance, in 2007/8 more than 500,000 smallholder farmers are reported to have been engaged in sesame farming and cultivated 185,912 ha. Ethiopia is the third African producer after Sudan and Uganda, and the country has excellent potential for higher production than observed today (Haile Abera, 2009). They are also highly suitable for large scale sugar cane plantations, horticulture (Mango, citrus, avocado, Papaya and passion fruit) and vegetable farming. These agriculture sub-sectors are the backbone of the country's economy, and if sustainably implemented, there is huge yet unutilized potential to lift the agriculture sector economy of the country.

Although erratic rainfall and climate change induced weather patterns may affect rain-fed agricultural system, the drylands are endowed with rich underground and surface water resources for supplemental irrigation development; many such developments are currently on-going. The 12 major river basins of the country comprise vast drylands and their rivers (Blue Nile, Awash, Wabeshebele, Web, Genale, Dawa, Baro, Omo, Tekeze, etc.), though emerge in the highlands, traverse mostly through the vast irrigable plains of the dryland areas. In fact the relative low population density, large water resources together with vast land area offer huge medium- and large-scale irrigation development opportunities in the dry lands. An estimated three million hectares can be irrigated in Ethiopia (EPA, 1998), and most of these are actually in the drylands. However, irrigation developments require carefully crafted policy, proper land use planning and implementation to avoid risks of land degradation and salinization. Experiences from across the world such as from the Middle East (e.g. Israel) and in Asia (e.g. India) can be learned on how to sustainably tap into the potential of drylands for agriculture.

Due to this potential, there is a growing interest from the private sector (domestic and international) to invest in commercial agriculture in the drylands. Areas like Gambella, Benishangul-Gumuz, western Amhara and Tigray and central Rift Valley are hotspots of commercial agriculture investment.

Livestock production

Livelihoods in rural Ethiopia involve mixed crop-livestock-forest farming system. Livestock production based on free grazing is an integral component of Ethiopian agricultural system.

The sub-sector contributes 12 and 33% of the total and agricultural Gross Domestic Product (GDP), respectively, and provides livelihood for 65% of the population (Ayele Solomon et al., 2003). The same source indicates that the share of livestock income at household level can account for 37–87% in different parts of the country; the higher share is mainly in dryland area pastoral and agro-pastoral areas. Estimates of feed supply for Ethiopian livestock from natural rangelands range between 80-90 per cent, and for the pastoral region this is almost 100%. Ethiopia’s drylands, particularly those in the semi-arid and arid eco-regions, hosts the country’s pastoralist and agro-pastoralist communities, which are estimated to be about 27% of the country’s human population and support 40% of the livestock population of the country (Sara and Mike, 2009). These drylands are also the centre of livestock genetic diversity; for example the distinct Borena and Jijiga cattle breeds, the black headed Ogaden sheep, the Afar goat, the Somali goat and the camel resources are worth mentioning. These are important economic resources that the dryland ecosystems of Ethiopia are offering. Through proper management the potentials can be enhanced for the benefit of the national and local economies.

Forest based economy

The drylands also host important vegetation resources among which the *Combretum-Terminalia* and *Acacia – Commiphora* are two prominent types from forest based economic importance. These woodlands and shrublands host several plant species providing commercial products such as gums, alloys and incense. Gums and incense are exported in large quantity; hence are source of foreign currency at the national scale, and employment and cash income for the producing households. Between 1998 and 2007 about 25,192 tons, approximately 2,519 tons per year, of natural gums and resins were exported from Ethiopia. This is worth 307,248,000 Birr (34,138,670 USD) (Mulugeta Lemenih and Habtemariam Kassa, 2010). Domestic sales during the same period were estimated at 750 tons per annum. The export volume has also been increasing on average by 12% a year over the past 10 years. There are over 40 import destinations (countries) for gum and resin products from Ethiopia. The bulk of the products are destined, among others, to China (29%), Germany (13%), Persian Gulf (9.5%), Tunisia (8.6%) and United Arab Emirates (7.3%) (Mulugeta Lemenih and Habtemariam Kassa, 2010). If extracted and managed properly, these products would provide investment opportunity and foreign currency earnings. Important lessons can be learnt from Sudan as to how to develop and benefit from the sub-sector.

The contribution of dryland forests to the energy sector through charcoal and firewood production is also immense. The *Acacia*-dominated dry-woodland and shrub-land areas are the largest source of wood for the bulk of charcoal coming to urban centres in the country. Charcoal and firewood of acacia species are much preferred over other species due to their excellent energy properties; hence the bulk of charcoal is made from acacia species, the main species constituting the dryland woodlands of the country. The various acacia species which are most popular trees for charcoal making in the country include: *Acacia tortilis*, *A. mellifera*, *A. nilotica*, *A. senegal* and *A. seyal*. If produced from sustainably managed woodlands these energy sources are clean – they are carbon neutral, hence can also help the country achieve its CRGE goals.

Contribution of dryland forests to household economy is also considerable. They play a safety net, income diversification and food security roles. In Liben in Somali Region, the income contribution to the household subsistence from collection and sale of oleo-gum resins is 33%, an income estimated to cover one-third of the annual subsistence and is the second livelihood activity next to livestock production (Mulugeta Lemenih et al., 2003). In Borena, the average annual contribution from collection and sale of various types of gum-resins is found to be 2670 and 2400 birr per household at Arero and Yabello Weredas, respectively (Adefires Worku 2006). In Tigray, income from woodlands and forests contribute 27% of total household annual income, the second largest source of household income, only next to income from crop production (Bedru Babulo et al. 2008).

A large number of wild plant species (ca. 450 trees and shrubs) have been recorded as having traditional food values in Ethiopia, most of which belongs to dryland plants. *Moringa stenopetala*, for example, provides edible and nutrient- and vitamin-rich leaves and shoots, which also have medicinal values. Moringa is widely used as a source of food to households in the semi-arid regions of southern Ethiopia, particularly in Konso (Menfes Tadesse, 2010). Fruits of *Cordia africana*, *Balanites aegyptiaca*, *Dovyalis abyssinica* and *Ficus spp*. are commonly used plants in drylands of Ethiopia. Fruits of *Opuntia ficus-indica* and *Borassus aethiopum* are consumed and traded in the markets for cash generation in Tigray and Afar. Many more species are also utilized as health care for humans and livestock. These, if accounted properly, can reveal how considerable contribution dryland ecosystems make to the national and local economy.

Wildlife, national parks and ecotourism

The savanna, woodlands and dry forests of Ethiopia host a vast diversity of big and small mammals -common and endemic species, birds and other tourist attractions. Many of the national parks of the country such as Awash, Abijata-Shalla, Nech Sar, Mago, Omo, Maze, Chebera-Churchura, Kafeta-Sheraro, Alatish, Geralle and Gameblla are located in the dryland regions. Many of the wildlife sanctuaries such as Yabello, Babile Elephant, Senkile Swayne's Hartebeest, and wildlife reserves namely Mille-Sardo, Gewane, Alledeghi, Awash west, Chew-Bahr and Tama are all found within the dryland ecosystems.

The Rift Valley lakes and their surrounding wetlands serve as breeding grounds for endemic and migratory birds. Most of the wildlife protected areas (National Parks, Wildlife Sanctuaries, Wildlife Reserves and Wildlife Controlled Hunting Areas) of Ethiopia are situated in the dry lands. These areas could contribute to community development in a variety of ways. Wildlife based tourism such as sport hunting, spot fishing, bird watching, game photographing, and intensive wildlife utilization schemes such as crocodile and ostrich farming civet musk production are some of the options to utilize natural resources in the dry lands. Tourism in Ethiopia is growing and involves features of ecotourism. The wildlife resources of the country are one of the bases for the expansion of ecotourism in Ethiopia. According to the reports of the Ethiopian Tourism Commission, during the past Ethiopian Fiscal Year, some 180,000 tourists visited Ethiopia and the country earned US $80 million. Major eco-tourism attractions are the Rift Valley lakes and, especially, the Omo valley and Afar depression.

The society in drylands is also culturally diverse. Together with other potentials, such as the Denakil depression, the Rift Valley lakes, the landscape scenery, etc the (eco)-tourism potential of Ethiopia's drylands is immense.

Drivers of change in dryland ecosystems

Dryland ecosystems in Ethiopia are under increasing pressure, particularly since recent decades. In the past drylands were generally avoided for human habitation and were considered unfavorable for settlement due to their notorious tropical human and livestock diseases such as malaria, Tsetse fly and others. These diseases have kept both human and livestock populations at lowest density; hence with little pressure on the dryland ecosystems. Native occupants of some of the drylands, like those in the western lowlands where Tsetse fly prevalence was high, have even developed a non-animal mode of living (Wolde-Selassie Abutte 2004). Until recently, inhabitants of the western lowlands practicedsporadic shifting cultivation with simple hand tools for livelihoods supplemented with hunting and gathering. Those in the southeastern, eastern and northern drylands also practiced nomadic pastoralism. These practices were also regulated by strong traditional institutions, for instance, the Gada system in the Borana drylands. Consequently, earlier land uses and practices exerted no significant negative environmental impacts. However, over years the traditional NRM systems have weakened and degradation of dryland ecosystems is looming (Mulugeta Lemenih et al, 2012a). Major change drivers in drylands are: i) demographic pressure, ii) climate change, iii) changing culture and traditional NRM system, and iii) development policies.

Demographic pressure

Human and livestock populations are rapidly increasing in the drylands of Ethiopia. Estimates show that population natural growth in the drylands is about 2.7% (Sandford and Yohannes Habtu, 2002). However, more than the natural growth, spontaneous and planned human migration (settlement or resettlement) to the drylands is a major problem. As land access in the highlands is growing scarce and those available are degraded, many are migrating to lowlands where there exists relatively unpopulated land. In addition, series of government resettlement programs have targeted these areas, causing a rapidly building up of human and livestock population in the drylands of the country. Between 2000 and 2004 alone, about 440,000 household heads or 2.2 million people were formally resettled in four regional states of Ethiopia, namely Amhara, Oromiya, SNNPR and Tigray, and the majority of these resettlements took place in dryland areas (Mulugeta Lemenih et al., 2012b). Considering the wood demand for construction and fuelwood, as well as land for crop cultivation and settlement, moving such large number of people could lead to the clearance of an estimated 1.7 million ha during the same period (Mulugeta Lemenih and Habtemariam Kassa 2010). In fact, clearance for subsistence agriculture is the leading cause of deforestation in the dryland forests in Ethiopia (Mulugeta Lemenih *et al.*, 2007), causing the loss of 91,400 ha of woodlands and 76,400 ha of shrublands annually (WBISPP, 2004).

Demographic buildup is perhaps the most important challenge to afflict the drylands. Because, too often, the inevitable result of increasing population is land degradation. Higher population implies increasing demand for forest products, space for settlement, grazing and farming areas (Mulugeta Lemenih and Habtemariam Kassa, 2010).

Changing traditional systems of NRM, culture and norms

A range of traditional institutions and management arrangements have been and still are employed to determine access to, use and manage dryland ecosystems, particularly rangelands, forests and water resources. Borena is a good example in this respect. The Borena people own a strong indigenous institution called *Gada* with well recognized role in managing the rangelands and water resources in the entire Borana drylands. The sophistication and roles in sustainable natural resources management of the *Gada* institution have been well described by many scholars (Asmerom Legesse 1973, 2000; Coppock, 1994; Watson, 2003; Homann *et al.*, 2008). This egalitarian Borena institution is very popular and is often cited as a model of sustainable pastoralism in sub-Saharan Africa (e.g. Hogg, 1997; Coppock, 1994; Watson, 2003; Homann et al., 2008). The G*ada* system is all about regulating the use of the Borena natural resources, maintaining peace among the multitudes of users, and protecting them and their cattle from external invasion (Coppock 1994; Watson, 2003). The system comprises decentralized social organization to govern resource use. The structure begins from a village level unit at micro level in the social organization through *Kora Olla* (village council), *Kora ardaa* (area/county council) and *Kora Gossa* (clan council) to *Gumi gayyo* (the pan Borena assembly). A consensus on important community issues - such as redefinition and enforcement of rules, regulations, and norms is reached through open, participatory discussions in assemblies beginning from the village council and terminating at the macro (*Gumi gayyo*) level. *Gumi gayyo* (an assembly of all Borena people and/or their representatives) is held every eight years to discuss issues such as resource conflicts and cardinal rules, including those that have been violated, and to collectively devise the future of the Borena society. *Gada* used to play a lead role in managing dryland resources, at least for a few hundred years.

Unfortunately, changing biophysical, socio-economic and political conditions in recent decades are threatening the role and the strengths of traditional institutions and practices including the *Gada* (Mulugeta Lemenih, unpublished). Traditional norms are increasingly violated. The lack of adherence to cultures and norms originates from multi-dimensional changes taking place in dryland area that include:

- expanding urbanization and its 'modern culture' which clashes sharply with traditional way of life, where the latter is often considered as 'backward',
- growing individualistic thinking rather than communal way of life as a result of increasing resource constraints;
- changing livelihood strategies from pure pastoralism towards agro-pastoralism and petty trade;
- growing influence over the *Gada* rulers either through corruption or political interferences and subsequent lack of trust by communities;
- resource scarcity, particularly pasture and water due to recurring drought;
- population pressure, regionalism (ethnicism) that curtailed pastoral mobility,
- cultural mixes as a result of continued migration of highlands into lowland drylands; and
- exogenous interventions (state and NGOs) to modernize pastoral communities through assistance and introduction of new way of sedentary mode of life.

Immigration is in fact one of the major drivers in changing traditional NRM system in the drylands. This is because with immigration new culture, and socio-economic systems uncommon in drylands are introduced, spoiling long standing and biophysically adaptive land uses and cultural practices. For instance, with immigration, the oxen driven intensive farming system, a common highland practice, is introduced in the drylands of Amhara and Benesgangul gumuz, causing large scale deforestation and conversion of woodlands into crop farming (Wolde-Selassie Abutte 2004; Mulugeta Lemenih et al., 2012). The oxen-driven relatively advanced farming system with permanent settlement is gradually replacing the sporadic and shifting cultivation based on stick and hoe system of cultivation traditional used in the western dryland areas.

Climatic variability and climate change

At a country level, Ethiopia is already experiencing signs of climate change. In the last 50 years the annual average minimum and maximum temperatures over the country have been increasing by about 0.25 and 0.1 ^{0}C respectively, every decade (INCE-2001), a change that is also perceived by local people (e.g. Temesgen Deressa et al., 2008; Kassahun Dessalegn, 2012). The country is also experiencing unusual frequency and extensive droughts since recent decades (Kassahun Dessalegn, 2008). Dry lands of Ethiopia in particular are exposed to climatic change and its variability, a problem that is affecting many sectors including biodiversity (flora and fauna), agriculture, human health and water. Climate change coupling with other factors such as conflict, insecurity and higher than average food prices in the Horn of Africa have resulted in considerable number of food insecure people. In Ethiopia, increase in the erratic nature of rainfall and poor crop production, coupled with rising cereal prices, made nearly 5 million people to become dependent on emergency food aid, over and above the 7.2 million Productive Safety Net Program beneficiaries (Cullis, 2009), most of which were in the drylands. As a coping mechanism, most households revert to natural resources such as forests and harvest wood and non-wood products for subsistence and to augment family income.

Development policies

There are several policy designs that are intended for good cause but have ended up with significant ecologically negative consequences in dryland ecosystems. These policy agenda include: resettlement program, investment policy and the crop-focused rural development strategies. State-sponsored resettlement program, which was meant to ensure food security of highland food insecure households, has relocated millions of such households to dryland woodlands. In fact such a strategy has been used by successive governments of Ethiopia since the 1960s including the present one (Belay Kassa, 2004, Hammond, 2008). The relocation of such large number of household corresponds with clearance of large dryland woodlands to give space for settlement as well as farm and grazing lands. This resettlement policy measure of the government of Ethiopia is a major change driver, particularly in terms of deforestation, loss of biodiversity and land degradation in many lowland drylands of the country, particularly those in the western lowland drylands. Similarly investment policy that encourages big commercial agriculture is driving significant dryland woodland degradation. Between 2009 and 2011 a total of 350,099 ha land, which are mostly in the drylands have been leased for agriculture-oriented investment (Bossio et al., 2012).

Threats/impacts (effects)

The various change drivers described above are inflicting a number of threats on dryland ecosystems. Dryland ecosystems and their natural resources are fast degrading, livelihoods and food security are threatened and biodiversities are lost. These changes are developing a usual vicious cycle of degradation-poverty-degradation. Climate change and improper policies are also blamed for the cause of one of the major threats in drylands – bush encroachment and invasion of alien species.

Deforestation, degradation and loss of habitat

Deforestation, degradation and land cover/land use changes are perhaps the number one threat to dryland ecosystems today in Ethiopia. These processes result in native habitat loss for the rich biodiversity of the dryland ecosystems, both flora and fauna. Studies conducted in various dryland areas (Table 2) reveal a rapid decline in natural ecosystems and expansion of settlements and agricultural lands. Following such conversion, many fauna and flora species are threatened. Two of the critically affected species in dryland ecosystems as a result of deforestation and degradation are *Boswellia papayrifera* (frankincense tree) and lowland bamboo (*Oxytenanthera abyssinica*). A study in Pawe by Behailu Kebede (2006) showed that 18365.8 ha of lowland bamboo forest was lost following (re)settlement and woodland conversion and unsustainable use to the extent that settlers could not anymore and easily access bamboo products for construction in their vicinity.

Table 2. Example of deforestation and conversion of dryland ecosystems in several dryland areas of the country (Source: Work Zewdie and Mengistie Kindu 2011)

Site	Period assessed	Decline in woodland (%)	Increase in agro-ecosys-tem (%)	Major driver
Humera	2001-2006	-41.7	+20.8	Agricultural land expansion due to resettlement and investment
Metam	2001-2006	-43.7	+44.6	Resettlement/ settlement and agricultural land expansion
Gambella woredas	1987-2000	-57.8	+244	Agricultural expansion due to investment
Pawe	1990-2005	-49.5	+18.3%	Resettlement
Didessa catchment	2001-2006 -42.4 +42.4			Resettlement

Similarly, deforestation is clearing large areas of *B. papyrifera* woodland in western lowlands of Ahmara, Tigray and Beneshagul –Gumu threatening the very existence of the species and the sustainable production of frankincense (Figure 1).

Figure 1. Expansion of agricultural fields by clearing *B. papyrifera* forest in Metema district (Photo: Mulugeta L.).

Deforestation is a threat not only to dryland ecosystems but also as a contributor to climate change. Through deforestation and conversion huge volume of GHG is emitted. In fact, deforestation and forest degradation is the major GHG emission sources in Ethiopia accounting for close to 40% of total annual emission in the country (CRGE, 2011).

Decreasing seedling viability, poor recruitment and risk of local extinction

Anthropogenic pressure driving dryland degradation is also threatening many species to local extinction. Several studies have observed increasing threat to some of the economically important tree species in the drylands of Ethiopia. These threats are related to one of several of the following facts:

i. Reduced quality and quantity of seeds: Several studies revealed some economically important species like *B. paprifera*, the major source of frankincense product, is producing fewer and lower-quality seeds and seedlings following human effect through such practices as tapping, and livestock grazing in its woodlands (Mulugeta Lemenih and Habtemariam Kassa, 2010; Abeje Eshete, 2011). This leads to low germination and regeneration rates. For instance, Abeje Eshete et al. (2012) shows that untapped trees yield significantly higher numbers of viable (germinable) seeds than continuously tapped trees. The same study shows that the effect of tapping is more pronounced in older trees than in younger ones. Tapped stands also produce seeds with a higher incidence of insect attack and a higher proportion of unfilled seeds than untapped stands. Therefore, tapping, by interfering with tree physiology, results in the production of a high proportion of unfilled seeds and seeds that are vulnerable to opportunistic predators. These seeds fail to produce seedlings, leading to insufficient natural regeneration.

ii. Poor recruitment and high adult mortality: Population structures of several species including *B. papyrifera* are increasingly showing clear gaps (Figure 1a). There are limited number of seedlings growing to saplings and then to adult trees. Increasing fire and grazing intensities are affecting regeneration/ recruitment and also driving large scale adult mortality. Population modeling and projections are showing a possible close to 90% decline in adult trees of *B. papyrifera*, for instance, over the coming 40 years (Mulugeta Lemenih et al., 2014; Abeje, Eshete, 2011) (See also figure 2b). Consequently, frankincense yield is projected to be halved in ca. 15 years. Mortality rate of juveniles and adults is estimated as 7% of standing stock (Abeje Eshete, 2011). Therefore, in addition to the conversion and loss of habitat, poor recruitment and high adult mortality are causing rapid decline in the population of some of economically important species of dryland ecosystems like *B. papyrifera*.

Overriding disturbances by fire, climate change and grazing are blamed for these declines.

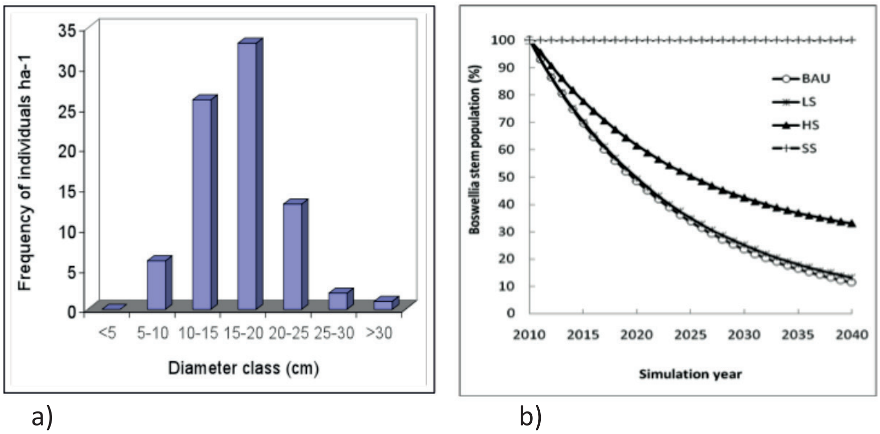

Figure 2. Population structure of *B. papyrifera* species showing clear gap (a) and modeled projection of the same species showing a considerable decline in standing tree stock over the coming four decades (b).

iii. Damage by fire: Fire, which kills seedlings and affects adult trees, is another threat to dryland ecosystems. Fire intensity and frequency have increased in most dryland areas because of population growth, which means fire wreaks more damage than under natural conditions. Traditional savannah and woodland management by cattle herders and pastoralists involve fire. The vegetation of these areas is also evolved under cyclic fire regime. However, most of the species also need some fire-free years to allow enough regeneration and the development of seedlings into saplings to maintain a viable population. However, in recent years, woodland ecosystems are being exposed to annual and intense burning that is badly affecting not only juveniles but also mature trees; hence threatening the species composition and population structure.

Bush encroachment and invasion by alien species

In recent decades bush encroachment and invasion by alien species are emerging as one of the several threats facing dryland ecosystems: natural and agro-ecosystems alike. Bush encroachment is alleged to have expanded due to both climate change and human effects. The latter is associated with policy restrictions on traditional way of rangeland management (for example banning of rangeland burning) (Oba et al., 2000; Birhanu Terefe et al., 2011), introduction of species for reforestation and afforestation (e.g. *Prosopis juliflora*) (Farm Africa, 2008) and food importation through aid (for some of the alien invader weeds) (Taye Tessema et al., 2007).

About six major invasive species have been recognized in the drylands of Ethiopia. These are *Prosopis juliflora, Parthenium hysterophorus, Lantana camara, Eicchornia crasipes* and *Straiga* species. The most notorious alien invasive species is *Prosopis juliflora*. Common bush encroachers are mainly *Acacia* species such as *A. drepanolobium*, *A. melifera* and *A. oerfota* (Gemedo Dalle, 2004).

The most affected areas are woodlands in Afar and Borena drylands. Both bush encroachment and invasion by alien species are threatening local livelihoods by altering several ecosystem processes and native biodiversity – particularly affecting availability of animal feed. For instance, Adefires Worku et al. (2008) reported 76 species from non-infested plots compared to only 31 species in the *P. juliflora* infested site in Afar Region, implying the adverse impact on native biodiversity. A study in Borena showed that because of excessive bushland encroachment, the community is forced to shift from a grazer- based livestock production system to a browser-type, which is also changing the long standing cultural fabrics of the community (e.g. Ayana Angessa and Oba, 2007; Berhanu Terefe et al., 2011). Bushland cover dominantly by encroacher species increased from 51 % in 1986 to 53.8% in 2002 and continued increasing to about 57% of the rangeland in 2010 (Table 3). A number of similar studies have documented similar patterns and problem. In the early 1980s the Borena rangelands was affected by 40% due to bush encroachment (Coppock, 1993), which was reported to have increased to 52% in early 1990s (Gemedo Dalle *et al.,* 2006). Ayana Angassa (2007) also estimated the further increase of bush encroached lands in the 2000s.

Table 3. Extent of land cover changes in 24 years (1986-2010) in Borana woodland area.

Land cover type	Unchanged area		Cover decrease area		No change		Cover increment area		Total area
	Ha	%	Ha	%	Ha	%	Ha	%	
Forest	18954	0.9	15699	0.7	2060452	97.7	13323	0.6	2108428
Bushland	800280	40	278508	13.2	634680	30.1	394961	18.7	2108428
Bare land	199336	9.5	359992	17.1	1232743	58.5	316358	15.0	2108428
Grass-land	135746	6.4	307316	14.6	1428496	67.8	235871	11.2	2108428

(Source: Daniel Jalata 2010**)**

Pastoralists are now facing multiple problems because of encroachment and invasion. It is decreasing the production of pastor land, which means reduction of livelihoods. It is also imposing changes in livestock composition, from grazers to browsers. It also causes fragmentation of communal rangelands, emergence of family range enclosures, a new form of management (Ayana Angassa and Oba, 2007). The overall impact was forage scarcity, and livestock productivity; hence greater vulnerability of stock during drought years and families to food insecurity.

Desertification encroachment/desert expansion:

Dryland vegetations play significant role acting as a buffer ecosystems between the highland and arid environments and have limited capacity to endure intense human interference (Birhanu, 2007). Rehabilitation works either through area exclosures, plantation development and other forms are uncommon in drylands of Ethiopia, and establishing trees is also a challenging activity. Degradation coupled with poor regeneration, low attention to woodland conservation and unwise utilization will result in expansion of deserts or desert like conditions.

Vulnerability and risks

Dryland ecosystems are vulnerable to the effects of climate change. Increase in temperature and aridity coupled with human population growth is increasing risk of forest fire. Fire incidences, mostly human caused, are increasing in frequency and intensity. Moreover, increasing incidences of disease/pest is another risk factor in dryland ecosystems. Most serious of all is the ecological shifts observed in various ecosystems: shrinkage of some and expansion of others. These risk factors are increasing vulnerability of flora and fauna of dryland ecosystems.

i) Risks of increasing pest/disease attacks

Climate change coupling with other stressors such as anthropogenic interferences in dryland ecosystems are blamed for increasing disease and pest incidences (Aklilu Negussie 2008; Abreham Abiyu *et al.* 2010). For instance, continuous tapping of *B. papyrifera* trees for incense production is found to weaken the trees and predispose them to a variety of diseases and insect attacks. The occurrence of symptoms of infection is associated with wound made during tapping (Alemu Gezahegn et al., 2013). Wounds meant for incense production are also gateway for insects to attack the trees. Moreover, infestation by parasitic plants is also on the raise in many dryland woodlands. As large as 37.6% infestation of *Boswellia* trees by a parasitic plant called *Tapinanthus globiferus* has been reported (Abraham Yirgu et al.,2013).

Figure 3. Parasitic plants infesting some of dryland plants (Photo: Abraham Yirgu *et al.*, 2013).

ii) Drought intensity and fire

Drought, which is the dominant climate-related natural hazard in drylands, is a factor that can also affect regeneration. It can also cause phonological changes, plant productivity reduction, and affect seed production and viabilities (Cleland et al. 2007). However, empirical evidences under Ethiopian context on this are still lacking. Furthermore, the increasing severity of drought has increased and is likely to continue increasing fire incidence, as witnessed by the increasing severity and frequency of forest fire in recent decade. Forest fire is affecting over 200,000 ha forest every year in recent decades. In 2008, the FAO reported 51550 incidences of fire in Ethiopia, many of which were located in forested areas; particularly dryland woodlands (see Figure 4).

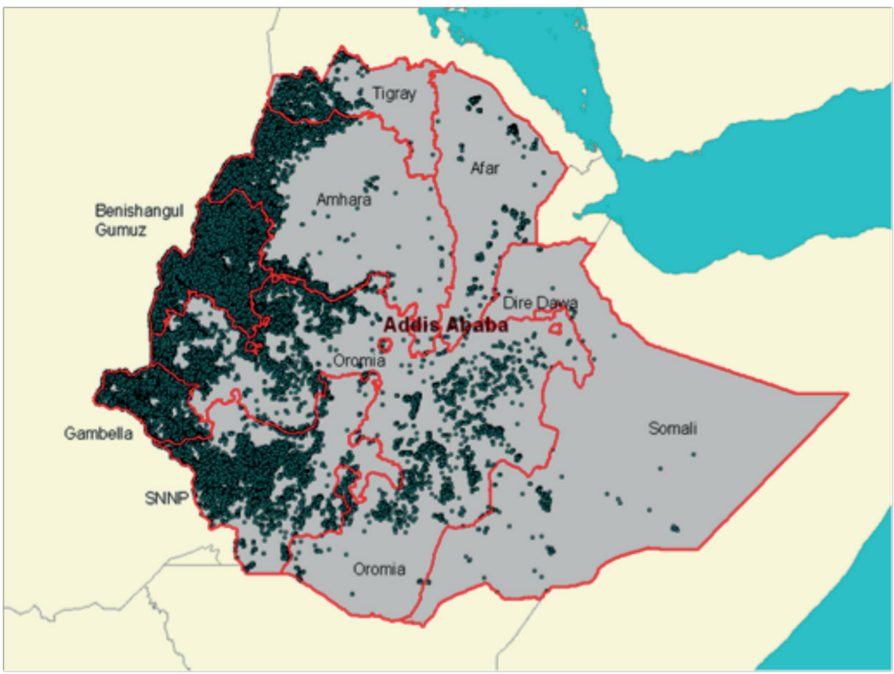

Figure 4. Incidences of fire in Ethiopia in 2008 (note that most happened in western lowland woodlands and grass savanna areas) (source: J.S. Latham, Dept. of Nat. Res., FAO)

iii) Ecological shifts and shrinking-expansion of ecosystems:

One of the major risks related to climate change in drylands is the possible shift in altitude distribution, thereby shrinking of some of the ecosystems and expansion of others. In the case of Ethiopia, dry evergreen montane forest is predicted to shrink from 9.01% under current climate to 1.72%

under changing climate (Table 1). This shrinkage means some species will be restricted to very narrow ecological niches which will increase the risk of extinction. On the other hand, *Combretiun-Terminalia* woodland will expand from 44.9% under current climate to 51.29%, and desert and semi-desert scrub lands will expand from 17.09% under current to 21.33% under future climate (Table 4).

Table 4. Potential effect of climate change on vegetation distribution of Ethiopia (Source: Negash Mamo, 2000)

No	Holdridge life zones	Current climate		Climate change (GFDL)	
		Area (ha)	%	Area	%
1	Nival (Afroalpine)	1,890,755	1.64	945,377	0.82
2	Alpine (Afroalpine)	960,924	0.84	660,228	0.57
3	Subalpine (Subalpine Zone)	1,161,111	1.01	1,320,460	1.15
4	Montane moist (Moist evergreen forest)	3,793,630	3.3	2,971,032	2.58
5	Montane wet (Moist evergreen forest)	360,341	0.31		
6	Lower montane dry (moist evergreen montane forest)	6,085,819	5.29	3,237,176	2.87
7	Lower montane moist (Dry evergreen montane forest and grassland)	10,359,911	9.01	1,980,688	1.72
8	Lower montane wet (Moist evergreen montane forest)	850,814	0.74	--------------	-------
9	Subtropical desert (desert and semidesert scrubland)	1,801,627	1.57	360362	0.31
10	Subtropical desert scrub (desert and Semidesert scrubland)	2,742,618	2.38		
11	Subtropical thorn woodland (Combretum-Terminalia woodland savanna)	10,289,845	8.95	5,591,948	4.87
12	Subtropical dry forest (Combretum-Terminalia woodland and savanna)	28,026,807	24.37	23,838,291	20.73
13	Subtropical moist forest (Moist evergreen montane forest)	13,873,266	12.06	18,816,543	16.36
14	Subtropical wet forest (Moist evergreen montane forest)	1,631,562	1.41	660,228	0.57
15	Tropical desert (Desert semidesert scrubland)	151303	0.13	151303	0.13
16	Tropical desert scrub(Desert semidesert scrubland)	7,206,897	6.27	9,073,156	7.89
17	Tropical thorn woodland (Desert semidesert scrubland)	10,490,032	9.12	14,945,200	13
18	Tropical very dry forest (Combretum-Terminalia woodland and savanna)	9,729,306	8.46	16,786,316	14.6
19	Tropical dry forest (Combretum-Terminalia woodland and savanna)	3,593,432	3.12	12,754,192	11.09
20	Tropical moist forest			907500	0.79
	Total	**115,000,000**	**100**	**115,000,000**	**100**

(**Note**: The names in the bracket were given based on the simplified vegetation map of Ethiopia from Conservation Strategy of Ethiopia (CSE), 1997)

Adaptation, mitigation and managing risks

Adaptation

Given the threats, vulnerability and risks dryland ecosystems are exposed to, adapting them is urgently needed. Unfortunately, while plans such as NAPA exist, actual actions to adapt them are hardly observed in Ethiopia. Some official government documents such as National Action Plan for Combating Desertification (NAPCD), National Adaptation Plan of Action (NAPA), Climate Resilient Green Economy (CRGE) strategy and also the pan Africa initiative called Great Green Wall Sahel and Sahara Initiative (GGWSSI) of Ethiopia have included elements that target dry forest management and acknowledge the potential and actual impacts of climate change on dryland ecosystems.

Ethiopia prepared its NAPCD in 1998. The NAP priority areas relevant to dryland ecosystems include:

- Promoting Peoples participation in sustainable development and natural resource management;
- Improving knowledge on drought and desertification;
- Managing natural resources leading to sustainable development;
- Improving the socio economic environment;
- Improving basic infrastructure;
- Promoting alternative livelihood;
- Intensifying agriculture;
- Promoting awareness;
- Improving institutional organization and capacity; and
- Empowering women.

However, compared to the recognition of the role of forests and natural ecosystems in climate change adaptation and mitigation, the reverse, adapting forests to climate change is less targeted. For instance, the NAPA document mentions the role of forest in climate adaptation of local communities. Nearly half of the national adaptation options in the NAPA are directly forestry related, and those relevant to dryland ecosystems include:

- Community Based Development and Commercialization of Non-timber Forest Products (Gum Arabic, Myrhh and Frank Incense);
- Community Based Rehabilitation of Degraded Eco-Systems in Selected Parts of Ethiopia
- Establishment of Centre for Propagation and Commercialization of Traditional Herbal Medicinal Plants
- Establishment of Acacia Woodland Nature Reserve in the Ethiopian Rift Valley System
- Community Based Carbon Sequestration Project in the Rift Valley System of Ethiopia
- Development of an Incentive Scheme for Farmers (Hill-farming communities) to Reforest Hill Areas in the Northern Parts of Ethiopia
- Participatory Approach to Rehabilitate Degraded Hills/Ecosystem in Northern Ethiopia
- Reclamation of Bush Encroached Rangelands
- Promotion of on farm and homestead forestry and agroforestry practices in arid, semi-arid and dry-sub humid parts of Ethiopia
- Commercial level uses of some indigenous, wild edible fruits in selected arid and semi arid areas of Ethiopia, and
- Improving/enhancing the rangeland resources management practices in the pastoral areas of Ethiopia.

However, the corresponding attraction given to adapt woodlands and other ecosystems to climate is negligible. Perhaps, the current CRGE, particularly the resilience component under development, may provide some policy directions and actions towards adapting dryland ecosystems to climate change. The draft forest sector resilience strategy outlined a number of actions that can help adapt the forest resources and their ecosystems in the country to the likely changing climate. Some of the forest adaptation objectives priorities for Ethiopia include:

a) Improving conservation and management of remnant forests for their NTFPs and environmental services, including promotion of natural regeneration on degraded forest lands through area closure

b) Developing national and regional forest inventory, monitoring and surveillance system

c) Promoting agro-forestry with tree species that better adapt to current and future climate scenarios (to reduce dependence on natural forests)

d) Expanding plantation forests (Afforestation/Reforestation) with species tolerant to high temperature and extended droughts, and

e) Improving forest protection against fire and pest/disease for natural and planted forests of the country.

Mitigation of climate change

Dryland ecosystems hold considerable stock of carbon (Biniyam Alemu et al., 2013), although on a per hectare basis their biomass and carbon stock is smaller than high forests (WBISPP, 2004). Given their vast area coverage, the total carbon stock in dryland ecosystems is considerable. Some studies have attempted to assess carbon stock in the woodland ecosystems of Ethiopia (e.g. Biniyam Alemu et al., 2013). These studies calculated the mean aboveground tree biomass carbon stock in *Combretum-Terminalia* broadleaved woodlands of Kafta Humera, Metema and Sherkole in western and northwestern Ethiopia to be equal to 18, 27.3, and 25.9 ton c/ha, respectively (Table 5). The highest carbon stock was stored in the soil organic matter with values of 36, 46.2, and 37 ton / ha for Kafta Hufta Humera, Metema and Sherkole, respectively (table 5).

Table 5. Carbon stocks of different pools in the three study sites (tons /ha) (Source: Biniyam Alemu et al., 2013)

Carbon pools	**Kafta Humera**	**Metema**	**Sherkole**
ABG Tree biomass C	18	27.3	25.9
BGB Tree biomass C	4.5	6.8	6.5
Dead wood C	1.7	1.6	0.8
Herb C	0.4	0.3	1.2
Litter C	0.0	0.5	0.7
Soil C	36	46.2	37
Total C stock in ecosystem	**60.6**	**82.8**	**71.3**

A similar estimate for *Acacia-Commiphora* woodlands from Awash national park and Omo national parks shows 10.6 ton/ha and 1.49 ton/ha for above ground biomass, respectively. The mean below ground carbon stock was 2.5 and 0.36, respectively.

Taking the average of the above estimates and scaling it out to a national figure using the area estimates of WBISPP (2004) for woodlands and shrublands shows a considerable carbon stock; hence climate mitigation potential of these resources (Table 6).

Table 6. Total carbon stock in woodlands and shrublands mainly located in the dryland ecosystems of the country

Ecosystem	Area estimate (ha, from WBISPP)	Average C stock in ecosystem (ton/ha)	Average C stock (tCO_2e/ha)	Total C stock (tCO_2e)
Woodlands	29,242,949	71.6	262.4	7,673,674,739
Shrublands	26,400,200	7.5	24.4	723,585,482

Moreover, the study of WBISPP (2004) showed an annual incremental yield of 0.317 and 0.312 tons/ha/yr for woodlands and shrublands. Based on this estimate a carbon enhancement potential of the woodland and shrubland resources is estimated and presented in Table 7 below.

Table 7. Carbon enhancement potential in dryland woodland and shrublands for 20 years

Ecosystem	Total area	Annual yield (increment) (tons/ha/yr)	Annual Co2e sequestration (tons/ha/yr)	Total annual C enhancement (tCO_2e)	Total tCO_2e enhancement for 20 years (tCO_2e)
Woodlands	29,242,949	0.317*	1.16325	34016860	680,337,208
Shrublands	26,400,200	0.3124*	1.145467	30240549	604,810,982

* is average of annual yield estimated for woodlands/shrublands with 20-50% canopy cover and > 50% canopy cover as provided in the terminal report of WBISPP, 2004

These carbon potentials in drylands are without including stock of carbon in wetlands, grasslands, shrublands and semi-desert and desert scrubs. If carbon in all ecosystems, particularly in the wetlands is included, the mitigation potential of dryland ecosystems would be huge. Therefore, reducing deforestation and degradation of dryland ecosystems and improving their management can offer large opportunities for C-sequestration in both the soil and biome.

Managing risk

Dryland ecosystem is increasingly prone to fire, anthropogenic fire. There is increasing frequency of forest fire in drylands following increasing human population pressure. The carbon stock in the ecosystems can be emitted and released to the atmosphere if fire is not well managed. Increasing level of deforestation and forest degradation as a result of expanding farmland and unsustainable fuel wood harvest is another major risk factor related to carbon stock in dryland forest ecosystems. There is no system, institutional and technical, to manage these risks so far.

Information and/or data gaps and research needs

Compared to the highland and moist ecosystems, dryland ecosystems in Ethiopia are under researched. Until recently, they were largely considered as marginal and little contributor to the national economy and hence were grossly ignored. Potentials in their ecosystems and natural resources for development, adaptation and mitigation were little explored in depth. It is only recently that research and development attentions is being paid to dry land systems in general. The most important information or data gap in dryland ecosystems is paucity of long terms climatic records; hence precise information to analyze climate pattern is difficult. The network of weather stations are limited and the existing ones are not properly distributed to provide socio-economic and ecological representation. This is the very reason why many scholars provide conflicting scenarios of trends and impacts from global climate change on dry lands. Some technologies (agronomic and NRM) suitable for drylands that have been generated through research, have not reached farmers due to poor extension of the technologies to the farmers.

Second priority for research in the dry land ecosystems is on bush encroachment and invasive alien species. There is little conclusive study that shows why indigenous species turn to be encroachers, and what drives invasion by some of the exotic invasive species. Moreover, research on how to make productive elimination or control of invasion and encroachment is rarely met. There must be a coordinated research on this issue.

Gender aspects of dryland ecosystem change

Drylands, excluding the dry sub-humid, are home to one third of Ethiopia's population. At least fifty per cent of this population are women (CSA, 2007). The continued degradation of dryland ecosystems coupled with climate change and variability are increasing livelihood stresses; hence affecting women and men. Poverty and food insecurity further induces poor women and men to increase the pressure on dryland ecosystem resources such as woodlands and to exploit the natural resource base in ways that are not sustainable resulting a common vicious cycle of poverty-degradation-poverty. However, the challenges faced by women and men from degrading drylands are different because of differential gender roles, relationships, responsibilities, uneven access and control of resources, and different opportunities and constraints. Climate change and variability that affects access to water for domestic and livestock affects women more negatively than men. For women is responsibility to provide family with water, the drying out of streams and wells would mean more distance walking to fetch water. Similarly the less water is available for livestock, the less milk available. This can force women to depend more on charcoaling and firewood production and sale to ensure household wellbeing. They often carry big loads of firewood and travel long distances to deliver firewood to markets.

The worst impact of climate change and land degradation in drylands on women is through its action as a push factor for men to migrate out in search of incomes. This increases women's workloads as they have to assume even more responsibility to fully ensure wellbeing of their household members and livestock.

Policy implications and recommendations

a) Enhancing the economic role of natural resources through improved management, production and marketing:

Potentials of drylands are hardly recognized. Where recognized, agriculture potential is the only one that has attracted policy attention. Consequently, dryland ecosystems are often considered as candidate sites where large scale agriculture and settlement/resettlement schemes are targeted. This in turn is driving large scale deforestation and degradation of dryland ecosystem. If dryland ecosystems are to be managed well, their non-agricultural potential should be recognized and enhanced, such as proper commercialization of gum and incense resources through sustainable production.

b) Strengthening NRM capacity: institution and human resources:

Lack of stable and fully capacitated institution for the forest sector has been identified as one of the major challenges for improved management of natural ecosystems in Ethiopia. This challenge is even more a problem for dryland woodlands and ecosystems. There seems no formal recognition of dryland ecosystems either as forest ecosystems or agricultural land (e.g. as rangelands). Institutional mandates to manage dryland ecosystems in general have remained undefined territory. Academic institutes training specialists in Ethiopia in dryland ecosystem are limited. These challenges of dryland ecosystems and their needs should be recognized by policy makers.

c) Establishing a representative in-situ conservation area for each of the dryland ecosystems:

Conservation efforts in Ethiopia focused mostly on highlands. Conservation of dryland ecosystems, whether through *in-situ* or *ex-situ* schemes are always overlooked except for the few national parks established for the conservation and protection of common wildlife populations. There is a need to establish conservation areas targeting protection of genetic resources of dryland flora resources.

d) Re-thinking about policy frameworks affecting drylands:

The driving forces for dryland ecosystem degradation come mainly from improperly designed and/or implemented policies such as investment and food security policies (see previous section). The negative impacts of these policy directions should be recognized and corrective actions need to be taken.

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Wetland and Aquatic Ecosystems

1. Drivers

The situation of people and the resources at their disposal around the world are changing and changing very fast given the rise in population and their desire for quality of life in all its forms. There is unprecedented desire to access information given the current advancements in communication technologies. The interaction of all these factors are demanding today that man stops for a while and re-visits the impacts of his own actions on the environment in general, and that of the climate in particular. It is therefore important to point out what the drivers are to get man to re-consider his position in the context of changing climate, population increase, increasing demand for quality by the same and dwindling natural resources; in this case, those of wetland and aquatic ecosystems. These points are discussed below.

1.1. Natural resources, in this context, wetland biodiversity and fresh waters are under severe pressure as human livelihoods have become so intensive and fast.

1.2. Climate change has increasingly become real causing droughts, floods and in general extreme variabilities that has left billions of people, particularly those in the South, guessing and vulnerable to all sorts of related disadvantages.

1.3. The continuous degradation of the environment (deforestation, emissions, alterations of wetlands and their landscape through unsustainable development endeavors) has left the world with ever increasing temperature and warm conditions.

1.4. The impact of the above changes has resulted in increasing UV radiations that have exposed biodiversity to undesirable and unpredictable genetic alterations.

1.5. Again the above factors (human, emissions, precipitation changes, warming, UV radiations, etc.) have led to development of invasive organisms and diseases in wetlands that are favored by the new environmental changes (Karvonen *et al.* 2010).

1.6. It is global that development efforts cannot any more continue in the conventional economic development patterns of exploitation of natural resources as experienced in the North.

1.7. The competition for wetland resources has increased dramatically in light of global warming and rainfall variabilities extending into frequent drought periods.

1.8. Overhauling the economic development paths and finding sustainable ways with the intention of green economic development should be sought imperatively.

1.9. Information exchange and engagement of stakeholders for the common sustainable development should be approached with urgent purpose.

1.10. Platforms for knowledge and technology exchange and adapting them to local conditions should be developed to mitigate such problems of humanity in general and those of developing people like Africa in particular.

2. Impact, vulnerability and risks

Global warming has significantly influenced physical and biological processes at global and regional scales (Allison *et al.* 2009). As the planet's climate changes, so too will populations, species and ecosystems (Hall-Spencer *et al.* 2008). As a result of this change, many countries have become vulnerable to the effects of these changes, of which the world's least developed countries, whose inhabitants are among the world's poorest, are the most affected (Allison *et al.* 2009). According to Funk et al. (2005) the majority of this crisis is expressed in tendencies of drought over the past couple of decades occurring in the equatorial and subtropical eastern Africa (ESEA) located at 23^0N/S, 21-52^0E. Although as a globe the world is experiencing increase in rainfall, the subtropical regions that include ESEA will experience spells of drought and sporadic showers that do not match the regular patterns of farming and fisheries practices (Gitay *et al.* 2002). As a result populations of the region are challenged and seem to be at a loss, for they do not know what causes this incompatibility between the traditions of farming and fishing they inherited from their fathers and grandfathers and the climate pattern they grew up in.

One does not have to go to great lengths to find living examples. Up until the 1980s Lake Alemaya (Haramaya) (eastern Ethiopia) was such a thriving lake with fishery practices, irrigation, municipal water supply source and instrument of waste assimilation of the people in the watershed. By the turn of the millennium (in 2005), it completely dried out and turned into a terrestrial environment, where livestock graze in the field (Figs. 1 and 2).

Fig. 1: Upper images show Lake Alemaya (Haramaya) back in 1985/86 and lower images show the status of the same lake in 2005 as terrestrial environment where livestock graze and boreholes are dug for groundwater abstraction. The images on the left are satellite images from a South African Environmental Authority and the images on the right are ground images taken at about the same time as the satellite images (From Brook Lemma 2011).

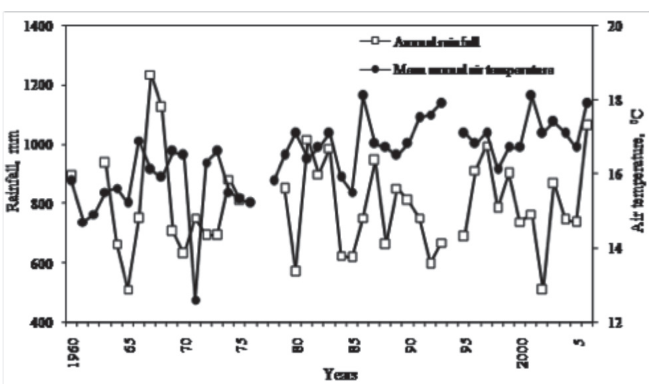

Fig. 2: Changes in air temperature in lake Alemaya (Haramaya area), with precipitation (open boxes) (from 1960 to 2006) (Brook Lemma 2002 and 2003a and b).

Ethiopia, being one of the ESEA countries, faces the largest food insecurity.

For the past ten years, it has seen declines in rainfall and an average annual increase of about 0.5 million people needing food aid or an additional 1.5-2 million individuals per year who are born without food, in a country where less than 8% of the population uses any form of family planning (Funk *et al.* 2003, 2005). This is coupled with declining health conditions with outbreaks of malaria, tuberculosis, Rift Valley fever, various forms of flu and dysenteries that have taken away lives of particularly children, and limited the productivity of people and livestock, leading to severe food shortage, and limited livestock exports, both in terms of numbers and quality (Funk *et al.* 2005).

The parts of Ethiopia, such as the Great Rift Valley to which the Lake Zwai watershed belongs, is exposed to increasing warming and declining rainfall leading to increasing demands for wetland, water and irrigated agriculture (Handisyde *et al.* 2006), pushing people to the lake in search of fresh water for irrigation, in-doors flower farming and direct fishing exercises with free-access-to-all policy. The Zwai area is specifically identified as one that is exposed to declining rainfall, increasing warming and hence designated as one of the highly populated areas of the country with high risk as impacted upon by climate change (Allison *et al.* 2009).

Lake Zwai that provides about 70% of the fish supply of the country (Dawit Taye 2004) has been reported as a case where the fishery was closed for some time in the 1980s, when individual length and total catch of Nile-tilapia failed drastically (Zinabu GebreMariam 1998). After about 14 years, over-fishing reappeared in Lakes Zwai and Langano, where fishing was banned as of August 26, 2004 (Dawit Taye 2004). Today the problem has persisted and fillet sizes of *Oreochromis niloticus* (Nile-tilapia) collected from Lake Zwai are much smaller and cheaper than those collected from Lakes Chamo and Tana, as documeneted from markets in Addis Ababa today (personal observation). It has however increasingly become clear that declining fish catches and sizes of individual fishes is not a matter of overfishing alone, but also another face of the impacts of climate change on freshwater ecosystems (Allison *et al.* 2009). In the deeper Rift Valley lakes, such as Lake Tanganyika, climate change has been associated with increases in surface water temperature, reduced primary productivity and fish catch rate over the last century (Ficke *et al.* 2005). Such lakes as Lake Chad in Central Africa have faced increasing shrinkage due to excessive evaporation and evapotranspiration which pushed people to converge on the narrowing and continuously shallow lakes (Sarch and Birkett 2000, Béné *et al.* 2009). At the same time, the quality of the water chemistry and fish has deteriorated so much with the additional pain of losing so many species forever (Sarch and Birkett 2000, Béné et al. 2009). The fate of another lake called Alemaya in the eastern part of Ethiopia is an outstanding example of the effects of climate change and the increasing demands for fresh water by increasing populations. In Lake Alemaya which has gone to the extremes of changing from once thriving freshwater supplying municipal water to over 100 000 people of the region, fishes, animal watering source, bathing and recreation, and turned from freshwater to completely terrestrial environment (See Brook Lemma 1991, 1995, 2002, 2003b and the web after the names of the lake and the author).

The effects of climate change on freshwater systems such as Lakes Tanganyika or Zwai or any other lakes and wetlands in the tropics and subtropics have been expressed in terms of:

2.1. Increased epilimnetic water temperature that has resulted in prolonged stratification (De Silva and Sota 2009, Jeppesen and Kronvang 2009),

2.2. The same impact in turn hinders the uplifting of nutrients to upper illuminated and widening epilimnetic layers (Gitay *et al.* 2002, Sharp 2003),

2.3. Increased incidences of red tides, frequent algal blooms with *Cyanobacteria* and associated fish, animals and human poisoning (Michael 2001, Patz *et al.* 2006),

2.4. Decrease in the amount of dissolved oxygen in contrast to high biological activity due to increased temperature (Daw *et al.* 2009),

2.5. Narrowing of migration spaces as lakes shrink (Gitay *et al.* 2002),

2.6. Increase in human numbers and their demand for fresh water (Michael 2001, Funk *et al.* 2005, Allison *et al.* 2009)

2.7. Overfishing as human needs for fish and fishery products increase by the day

2.8. Collateral damage by fishing gears (e.g. nets) to non-fish vertebrates such as amphibians, reptiles, aquatic birds and mammals.

2.9. Habitat destruction has lead to disappearance of aquatic biodiversity that have limited adaptive capacities, such as changes in temperatures, level of turbidity, dissolved oxygen, selectivity in food type, etc.

2.10. Hunting of non-fish vertebrates for commercial purposes or just to remove them from fishing grounds as they may be considered nuisance to fishing practices.

2.11. Lack of ownership of wetlands and their biodiversity as all these are government properties (at least in Ethiopia) with open access to all who have fishing gears or pumps who would take fresh water for any purpose, etc.

2.12. Lack of awareness of wetland resources (e.g. grasses, wetland trees, fresh water, fishes) by local populations who consider them inexhaustible.

3. Gender and water

Firstly, wetlands are not all similar and that they produce different benefits depending on their characteristics and how they have been altered; and that communities are not all uniform. Secondly differentiation of communities, in terms of gender, socio-economic status, age and other personal characteristics, means that wetlands have stakeholders with different sets of interests, needs, rights and power or influence (Wood 2003).

However, most development issues cannot be addressed from a single professional perspective or without the participation of the beneficiaries. Cognizant of this, there is wide agreement among researchers and development research managers about the value and importance of interdisciplinary and participatory approaches to the initiation, design, implementation, monitoring and evaluation of research for development projects and programs. However, looking at the existing scenarios of research for development, one finds that such research undertakings often tend to be sectoral and “researchers-driven”, with little participation by users of the research results (*Flintan and Shibru Tedla, 2000).*

Often, it was difficult to include women in the research—because of cultural constraints that prevented contact, or because the women were too busy (with household issues keeping them away from public and interactive platforms), or perhaps because they did not have sufficient interest to attend necessary meetings or fill out questionnaires (because mostly women are the most illiterate section of society and hence shy away from such encounters) *(Flintan and Shibru Tedla, 2000 with original insertions in brackets)*. Gawler (2000) agrees that the concept of gender is still not well understood by policy and decision makers, planners, researchers and natural resource managers.

3.1. Issues that need to be addressed for gender integrated actions

Matiza (1993) has outlined the key issues that need to be addressed for gender to be fully integrated into wetland conservation and management by stating the following preconditions. These are:

3.1.1. Correct gender perceptions, and increase gender awareness.

3.1.2. Promote gender roles research in wetland conservation and management.

3.1.3. Review traditional stereotypes in wetlands resource allocation and utilization.

3.1.4. Anticipate potential conflicts between traditional culture and gender roles empowerment.

3.1.5. Train policy makers, planners, and wetlands resource managers in gender roles analysis.

3.1.6. Integrate gender issues into national wetlands policies and into wetland projects and program at the planning, monitoring, and evaluation stages.

3.1.7. Organise courses specifically for women, in response to an unfavourable gender imbalance in the participation in our wetland management training courses.

3.1.8. In many community-based wetland management projects it is necessary to work with or through local women associations.

3.1.9. Provide funding to local women associations for investing in alternative livelihood activities, which has proven very successful (measured by profits and continued investment capacity).

3.1.10. Support projects of local women’s groups to restore a number of coastal wetlands as part of local/village based development strategies.

3.1.11. Reward any gender-based positive activities that prove to be promoting the role of women in decision-making and their empowerment in natural resource use and sustainable management.

To consolidate the above key issues for addressing gender inequality, the following basic principles may be important considerations to enhance sustainable management of natural resources.

3.2. Basic principles for community-based resource management

According to Addun and Muzones (1997), there are five basic principles that are required for community-based resource management:

3.2.1. **Empowerment**: The actual transfer of economic and political power from the few to the impoverished many, and the issue of putting into action community management and control system.

Females make the majority of the impoverished sector of society, although they remain hidden in the domains of their families. This has been told many times over in the Ethiopian condition that men are holders of property denying females the right in decision making in family matters. Females thus need to be supported in microeconomic systems to empower them economically but ensure that is harmonized with their family matters, particularly in getting the man in the family onboard.

3.2.2. **Equity**: Communities as a whole, rather than a few individuals, benefit.

Many cultural practices of various nationalities and religions put the man of the family accountable to social, religious and economic matters, without the knowledge of the women. Bringing both family heads (man and women) to equal levels adds value to the gains of the whole family. Although hard to cross that barrier, men as heads of families need to learn equity in the family is an attribute that adds value to the gains of the family.

3.2.3. **Sustainability**: Inter-generational equity, based on the carrying and assimilative capacity of the ecosystem.

Any sustainable management plan that addresses natural resources requires the active and responsible participation of the women. As females are setters of cultural practices in their children, any awareness about sustainable use of natural resources can very easily be passed over to children, ensuring inter-generational transfer of new knowledge and practices that contribute to the wise use of resources.

3.2.4. Systems orientation: The community functions in the context of other communities and stakeholders, just as resources are ecologically linked to wider ecosystems.

Experience sharing is vital between communities. In the world today life has become easier with the advantages gained from the development of information technology that transfers knowledge instantly. Best practices in one community, including gender equity, can be communicated to others in real time.

3.2.5. Gender-fair (balance): Women are involved in the control and management of community resources, and their practical and strategic needs are addressed.

There are certain natural resources in Ethiopia where women are mostly or wholly involved. These include collection of water, washing cloths and bathing the kids in rivers and lake shores, collecting firewood and grass for sale in the market and so on. Wetland management planned without the involvement of females therefore destined to fail.

3.2.6. Establishment of responsible public institution: Cognizant of the age-old and deeply rooted nature of the gender imbalance in Ethiopia and cognizant of the fact that formation of Gender-based associations in Ethiopia is not enough, the government of Ethiopia has established the Ministry of Women, Children and Youth Affairs (MWCYA) that works relentlessly in the realization of a nation where the role of women in the development of the country is captured in the Growth and Transformation Plan I and II and legislations are now in place to implement the GTP regarding gender balance to the ground level. This was further strengthened where the MWCYA has formulated its implementation strategy document entitled the National Action Plan for Gender Equity (NAP-GE) 0f 2006-10. These actions are reflected in whatever imbalance happens in the use and conservation of wetland resources whenever societies go about earning their livelihoods.

4. Adaptation, mitigation and managing risks

4.1. Adaptation strategies: Although there is a growing consensus on several general adaptation principles, capacity for taking action continues to lag, adaptation strategies and solutions are generally very specific to a region, limiting widespread application(Staudinger, *et al.* 2012). Twentieth-century water planning was based in part on the idea that climatic conditions of the past would be representative of those in the future; but this model is much less useful in the twenty-first century (Udall 2013). Further, adaptation is also constrained by numerous non-climate factors, such as, un-integrated development plans, free access to water and aquatic biodiversity (e.g. any person with a fishing gear can scoop out any fish of any size and number and make some income).

Despite the above backdrop, the following adaptation strategies are suggested:

4.1.1. Develop wetland and aquatic ecosystems sustaining policy, strategy and action plans in collaboration with all stakeholders, including local populations.

4.1.2. Build implementation procedures for the same, sufficiently empowering and making accountable local populations, whose livelihoods are directly intertwined with their lives.

4.1.3. Invest heavily in climate-change studies relating to water resources and their sustainable development and application of such data and knowledge for impact assessment and adaptation.

4.1.4. Identify and minimize greenhouse gas emissions and seek for alternative adaptation mechanisms to cut back on emitting actions.

4.1.5. Developing successful human response strategies to climate change which would include adopting approaches that benefit biodiversity and enhance the ability of its elements to adapt to change (Klein, *et al.* 2007).

4.1.6. Climate change adaptation seeks to reduce key vulnerabilities of natural and human systems against actual or expected climate change effects, and when possible, take advantage of beneficial opportunities (Klein, *et al.* 2007)

4.1.7. Conserving populations with higher genetic diversity or more plastic behaviors or morphologies

4.1.8. Changing seed sources for re-planting to introduce species or ecotypes that are better suited for future climates

3.1.9. Assisted migration to help move species and populations from current locations to those areas expected to become more suitable in the future, and 5) ex-situ conservation such as seed banking and captive breeding.

4.1.10. Support and improvement of governance for climate change adaptation

4.1.11. Build livelihood resilience to climate change

4.1.12. Develop targeted approaches for conservation and sustainable management of biodiversity

4.1.13. Identify, support and application of innovative technologies

4.1.14. Improved disaster risk management

4.2. Mitigation strategies: The following mitigation strategies for wetland and aquatic ecosystems are adapted from FAO:

4.2.1. Strengthen agriculture, forestry and other land-based sectors in climate change negotiations and international agreements

4.2.2. Develop integrated and accessible knowledge database for mitigation

4.2.3. Seek for various methods and technologies that are used elsewhere and develop modalities of contextualizing them for mitigation to local conditions

4.2.4. Develop policies that are participatory for all stakeholders and that allow good governance for climate change mitigation actions

4.2.5. Reduce emissions from fishing operations which tend to increase long distance travels due to overfishing, as this is now the case in most countries. Mitigations in this regard could be use of fuel efficient engines, safer fuels (e.g. alcohol, chargeable batteries driven engines, manual operations when possible).

4.2.6. Reduce emissions during the processing and transport of fish and fishery products along the value chain.

4.2.7. Reduce emissions from waste products from fish processing (offal), which either lays around to decompose and release GHGs into the atmosphere or during handling to change it into animal feed or fertilizer. In all cases, organic wastes should be handled in a way they can be changed into biofuels.

4.2.8. The above procedure can be used as mitigation procedure to cut back on the use of conventional fuels.

4.2.9. Attempt to convert wetlands into systems of carbon sequestration and set up policy actions for such mitigation actions. These solutions require innovative approaches such as the recent inclusion of mangrove conservation as eligible for Reducing Emissions from Deforestation and Forest Degradation (REDD) funding which demonstrates the potential for catchment forest protection under REDD.

4.2.10. Developing low-carbon aquaculture production systems.

4.3. Managing risks and hazards

Prioritizing and implementing the above adaptation and mitigation strategies within the framework of the contextual limits of a community is imperative. Despite such real efforts there are always unforeseen risks and hazards the may occur as a result of sudden climatic changes. As mentioned above, these changes have not been experienced in the past and they may not be part of the strategic models developed.

This therefore suggests a whole series of preparedness procedures for any sudden climatic impacts or generally natural hazards that may bring about unexpected damage or loss to wetland and aquatic ecosystems, thereby affecting human livelihood systems. It is common to find that sudden floods, hurricanes, landslides, and generally natural disasters cause destructions and complete alterations of peoples 'lives. The following procedures of risk management may be considered (developed here with some adaptations from Schmitt (2010).

4.3.1. Conserve seeds of all wetland plants in gene banks

4.3.2. Make regular consultations with meteorology information centers to get predictions on upcoming weather conditions

4.3.3. Check out with flood control structures if they are up to standard for any sudden hazards.

4.3.4. Check out for any and all early warning and alarm systems are in place and functioning properly to mobilize communities at times of emergency. In other words, improve monitoring, forecasting, and early warning systems for storm or other sudden natural disaster events.

4.3.5. Arrange for alternative sources of supplies of basic needs (food, water, medicine, etc.) for times of disaster and risks.

4.3.6. Establish alternative communication systems for times of sudden risks, hazards or disasters.

4.3.7. Develop networked information and experience sharing mechanisms with various communities to work proactively against times of emergency.

4.3.8. Require and establish contacts with army corporations, red cross-red crescent societies and federal and regional offices for any emergency actions

4.3.9. Develop insurance and loan systems to re-establish communities immediately after a sudden natural disaster.

4.3.10. Reduce stormwater runoff speed by developing structure to slow down flow and allow infiltration into the ground. In other words, preserve and restore wetlands, flood plains, dunes, and other natural barriers to reduce impacts of storms.

4.3.11. Create incentive mechanisms for those who are working on risk reduction procedures and their maintenance of time.

5. Information, data gaps and research needs

5.1. Information

This section attempts to give readers some highlights on the wetland and aquatic ecosystems that Ethiopia has and the life forms they support. These information may not be exhaustive, but they are important indicators as to what to expect in the Ethiopian waters.

(a) Some Ethiopian wetlands in images

Fig. 3: Seneati Wetlands at about 4300 m above sea-level at the peak of Bale Mountains, Bale Mountain National Park

Fig. 4: Dinsho Wetlands at Bale Mountain National Park

Fig. 5: Another view of the Dinsho wetlands with male and female Mountain Nyalas

Fig. 6: Lake Hawassa shore steaming with active fishing landing site

Fig. 7: Lakes Shalla (left) and Abijata (right corner) seen from the View Point of the Shalla-Abijata National Park: Note the difference in the altitude differences of the surfaces of the two waters.

Fig. 8: Hot springs adding more water, chemicals and heat into the waters of Lake Shalla.

Fig. 9: Lake Chitu along with Lakes Abijata and Shalla are highly saline-alkaline water devoid of and shoreline vegetation and filled with almost monoculture set of algae such as *Arthrospira* sp. (syn. *Spirulina* sp.)

Fig. 10: Lake Zwai with a fisherman standing on a raft and its aquatic grasses which are partly harvested

Fig. 11: River Kulfo enters Lake Chamo, providing services to communities on its way

Fig. 12: Lake Abaya with its turbid waters and invaded with water hyacinth

Fig. 13: Wetlands of NechSar National Park through which numerous springs flow and covered with dense wetland forests. On the right is Lake Chamo and on the left is Lake Abaya, separated by a hilly isthmus

Fig. 14: River Kulfo crossing the NechSar Wetland forest to join Lake Chamo

Fig. 15: River Kulfo provides the last refuge to hundreds of crocodiles commonly known as “Crocodile Market” by wardens of the NechSar National Park to imply an open market filled with people (a common scene in developing countries)

Fig. 16: Part of River Baro close to the town of Itang, Gambella.

Fig. 17: Tata wetlands with rich fishery resources, which is being challenged with water hyacinth

Fig. 18: Dallol wetlands in Afar at an altitude of 110 m below sea-level, which are refuges for killifishes (*Aphanius dispar*)

(b)Biodiversity in wetland and aquatic ecosystems of Ethiopia

The following information provides baseline data on biodiversity to readers of this report.

5.1.1. Phytoplankton: As discussed above, with increase in salinity-alkalinity the diversity of phytoplankton changes to a few tolerant species, as it will be seen in the cases of lakes Abijata and Chitui (Wood and Talling 1988, Zinabu GebreMariam and Taylor 1997, Elizabeth Kebede and Willen 1998).

Table 1: List of most common phytoplankton recorded in a salinity-alkalinity series of Ethiopian rift Valley lakes (after Elizabeth Kebede and Willen 1998, Tudorancea and Taylor 2002, Brook Lemma 2008a).

Phytoplankton	**Lakes in Salinity Alkalinity Series**							
	Zwai	**Hawassa**	**Abaya**	**Chamo**	**Langano**	**Shala**	**Abijata**	**Chitu**
Cyanophyceae								
Aphanocapsa elachista				✓				
Aphanocapsa elachista v. plancronica		✓						
Merismopedia punctata		✓						
Microcystis aeruginosa	✓	✓	✓	✓	✓			
Microcystis wesenbergii		✓						
Myxobactron sp.	✓							
Radiocystis geminata	✓	✓						
Synechococcus elegans		✓						
Anabaena aphanizomendiodes	✓			✓				
Anabaena compacta				✓				
Anabaenopsis abijatae							✓	
Anabaenopsis elenkinii				✓				

Phytoplankton	**Lakes in Salinity Alkalinity Series**							
	Zwai	**Hawassa**	**Abaya**	**Chamo**	**Langano**	**Shala**	**Abijata**	**Chitu**
Arthrospira fusiformis							✓	✓
Cylindrospermopsis africana	✓	✓						
Limnothrix planctonica				✓				
Planktolyngbya limnetica	✓	✓						
Planktolyngbya nyassae	✓	✓						
Planktolyngbya tallyingii	✓	✓						
Pseudanabaena limnetica			✓					
Pseudanabaena moniliformis			✓					
Raphidiopsis curvata				✓				
Spirulina laxissima		✓						
Cryptophceae								
Gymnodinium spp.	✓	✓			✓			
Peridinium umbonatum					✓			
Chrysophyceae								
Mallomonas sp.					✓			
Diatomophyceae								

Phytoplankton	Lakes in Salinity Alkalinity Series							
	Zwai	Hawassa	Abaya	Chamo	Langano	Shala	Abijata	Chitu
Aulacoseira granulata	✓							
Cyclotella sp.				✓				
Stephanodiscus sp.	✓							
Thalassiosira rudolfi					✓	✓		
Navicula spp.	✓	✓						
Nitzschia subacicularis						✓		
Charophyceae								
Cosmarium contractum		✓						
Cosmarium variolatum				✓				
Staurastrum tetracerum	✓	✓						
Chlorophyceae								
Botryococcus braunii	✓							
Monoraphidium sp.				✓				
Oocystis spp.		✓		✓			✓	
Pediastrum borynum	✓							
Pediastrum duplex	✓	✓						
Pediastrum tetras				✓				
Scenedesmus spp.	✓	✓		✓				
Tetraedron minimum		✓						

Phytoplankton	Lakes in Salinity Alkalinity Series							
	Zwai	**Hawassa**	**Abaya**	**Chamo**	**Langano**	**Shala**	**Abijata**	**Chitu**
Coccoids	✓							
Dunaliella sp.							✓	
Euglenophyceae								
Phacus spp.	✓	✓	✓	✓	✓			
Euglena spp.	✓	✓	✓	✓	✓			
Flagellata spp.	✓							

5.1.2. Zooplankton

The diversity and composition of zooplankton in tropical Africa is also a reflection of the salinity-alkalinity series of lakes, the impact of predation by fishes and climatic conditions that keep lakes open to predation effect the year round (Nilssen 1984, Green and Seyoum Mengistu 1991, Fernando 1994 and Brook Lemma 2001). As indicated in Fig. 19, below, the impact of fish predation on zooplankton is limited by low fish biomass and that is restricted to the months of spring and summer when temperatures are high. At other times as in winter and most of autumn when water temperature approaches freezing point, fish activity is reduced to limit predation. There is also low level of fishes that directly graze on phytoplankton.

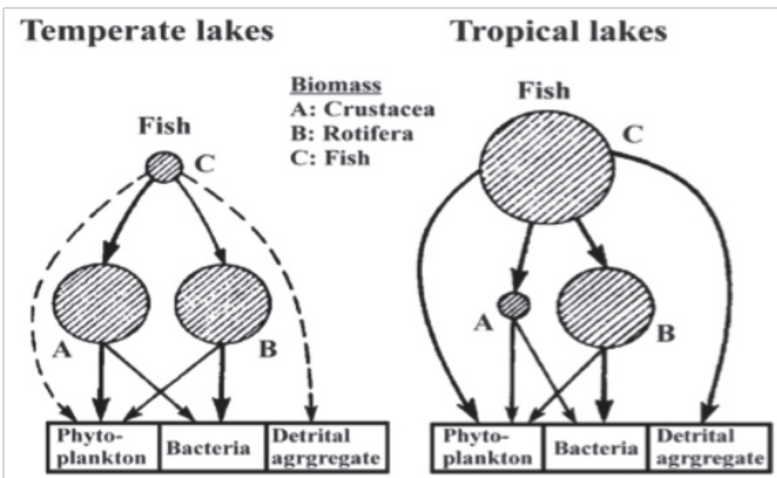

Fig. 19. The comparative relations of phytoplankton, zooplankton and fishes in temperate and tropical lakes (Nilssen 1984 and Fernando 1994)

In the tropics, including the Ethiopian rift valley lakes, where water temperature is always high, fish predation activity on zooplankton is high throughout the year. When macrozooplankton (e.g. *D. Barbata*) are removed by fish, grazing pressure of zooplankton on phytoplankton becomes low. The elimination of macrozooplankton results in increase of phytoplankton biomass and diversity, which is assisted by nutrient inputs from extensive uncontrolled fertilizer use in the watersheds (Elhigzi *et al.* 1995, Tudorancea and Taylor 2002, Brook Lemma 2001).

As a result of combinations of the above factors in waters of the Ethiopian Rift Valley lakes:

5.1.2.1. Cladocerans are generally absent in saline lakes (Shala, Abijata and Chitu) (Green and Seyoum Mengistu 1991).

5.1.2.2. Rotifers are generally abundant if the Ethiopian Rift Valley lakes as a response to year-round predation by fishes on macrozooplankton (Brook Lemma 2007). They exhibit a marked deduction in species in salinity over 2 gL^{-1} (Shala, Abijata and Chitu) (Green and Seyoum Mengistu 1991).

5.1.2.3. Cladocerans *Bosmina*, *Ceriodaphnia*, *Diaphanosoma* and *Moina* (Green and Seyoum Mengistu 1991 and Brook Lemma current observations).

5.1.2.4. *Lovenula africana* (synonymous with *Paradiaptomus africanus*) (Tudorancea and Taylor 2002, Brook Lemma 2008b).

5.1.2.5. Small-bodied cyclopoids such as *Africocyclops*, *Thermocyclops*, *Eucyclops* and *paracyclops* are common in freshwater lakes (Defaye 1988).

Macroinvertebrates (benthic fauna)

Table 2: Most common benthic fauna recorded from the Ethiopian Rift valley lakes (Tudorancea *et al.* 1989, Tilahun Kibret and Harrison 1989, Eyualem Abebe and Coomans 1996a-d, Balemwal Atnafu and Russo 2004, Brook Lemma and Yared Tigabu 2011).

Invertebrates	Zwai	Hawassa	Abaya	Langano	Chamo	Shala	Abijata	Chitu
Nematoda								
Monhystera stagnalis	✓	✓	✓		✓			
Brevitobrilus graciloides	✓	✓			✓		✓	
Dorylaimus sp.	✓		✓	✓	✓			
Mesodorylaimus macrospiculum						✓	✓	
Ironus tenuicaudatus	✓		✓					
Oligochaeta								
Tubificidae	✓	✓	✓	✓	✓	✓	✓	
Gastropoda								
Melanoides tuberculata	✓				✓			
Ostracoda								
Limnocythere thomasi	✓							
L. borisi		✓	✓	✓		✓		
Gomphocythere angulata	✓	✓				✓		

Invertebrates	Zwai	Hawassa	Abaya	Langano	Chamo	Shala	Abijata	Chitu
Darwinula stevensoni	✓	✓	✓	✓	✓	✓		
Chironomidae	✓	✓	✓	✓	✓	✓	✓	
Tanypodinae	✓	✓	✓	✓	✓			
Chironominae	✓	✓	✓	✓	✓	✓	✓	
Stictochironomus caffraius	✓	✓	✓	✓	✓			
Nilodorum spp.	✓	✓		✓				
Kiefferulus disparilis				✓		✓	✓	
Cladotanytarsus pseudomancus	✓	✓		✓	✓	✓	✓	
Microchironomus deribae			✓	✓	✓	✓	✓	
Ephydridae								✓

5.1.4. Fishes

Table 3: Fish diversity in the Ethiopian Rift Valley lakes. ("**+**" sign indicates presence of fish species and "**e**" is for species that are endemic to that water body). (Tudorancea and Taylor 2002, Klemperer and Cash 2007, Redeat Habteselassie 2012, and Vijverberg *et al.* 2012, Brook Lemma and Hayal Desta 2014).

Fish species	Zwai	Hawassa	Langano	Abaya	Chamo	Shala	Abijata	Chitu
Famiy Mormyridae								

Fish species	Zwai	Hawassa	Langano	Abaya	Chamo	Shala	Abijata	Chitu
Mormyrus caschive				+	+			
Hyperopisus bebe				+				
Marcusenius cyprinoides				+				
Family Characidae								
Hydrocynus forskahlii				+	+			
Family Cyprinidae								
Barbus bynni				+	+			
Barbus ethiopicus	e							
Barbus intermidius	+	+	+	+	+			
Barbus kerstennii				+	+			
Barbus paludinosus	+	+	+					
Barbus stigmatopygus				+	+			
Carassius carassius	+							
Carassius auratus	+							
Cyprinus carpio	+	+	+	+	+			
Garra makiensis	e							

Fish species	Zwai	Hawassa	Langano	Abaya	Chamo	Shala	Abijata	Chitu
Garra hirticeps	+	+		+	+			
Garra quadrimaculata	+			+	+			
Garra dembecha	+							
Labeo cylindericus				+	+			
Labeo horie				+	+			
Labeo niloticus				+	+			
Labeo varicorhinus				+	+			
Family Bagridae								
Bagrus docmak				+	+			
Family Schilbeidae				+	+			
Schilbe intermidius				+				
Family Clariidae								
Clarius gariepinus	+	+	+	+	+			
Family Machokidae								
Synodontis schall				+	+			
Family Cyprinodontidae								

Fish species	Zwai	Hawassa	Langano	Abaya	Chamo	Shala	Abijata	Chitu
Aplheilichthys aninorii	+	+	+		+			
Lebias dispar	+							
Family Centropomidae								
Lates niloticus				+	+			
Family Cichlidae								
Oreochromis niloticus	+	+	+	+	+	+	+	
Tilapia zillii	+	+	+	+	+			
Family Poeciliidae								
Aplocheilichthyes antinorii						+		
Total native species (77)	**15**	**8**	**7**	**23**	**22**	**1**	**1**	**---**

5.1.5. Amphibians

Amphibians, organisms extremely dependant on wetness of the environment, are important indicators of the availability of moisture in the form of fresh water wherever they are found. Their abundance both in type and quantity indicates that fresh water is available both in terms of surface water or very shallow groundwater providing sufficient moisture to the ground surface above. This list of amphibian species found exclusively in Ethiopia is based on the species recognized in Amphibia Web as of 28 January 2013.

Afrixalus clarkei (Anura - Hyperoliidae) Clark's Banana Frog

Afrixalus enseticola (Anura - Hyperoliidae) Ethiopian Banana Frog

Altiphrynoides malcolmi (Anura - Bufonidae) Malcolm's Ethiopian Toad

Altiphrynoides osgoodi (Anura - Bufonidae) Osgood's Ethiopian Toad

Amietophrynus langanoensis (Anura - Bufonidae) Lake Langano Toad

Balebreviceps hillmani (Anura - Brevicipitidae) Ethiopian Short-headed Frog

Ericabatrachus baleensis (Anura - Pyxicephalidae) Bale Mountains Frog

Hemisus microscaphus (Anura - Hemisotidae) Ethiopian Snout-burrower

Leptopelis gramineus (Anura - Arthroleptidae) Badditu Forest Tree Frog

Leptopelis ragazzii (Anura - Arthroleptidae) Shoa Forest Tree Frog

Leptopelis susanae (Anura - Arthroleptidae) Susana's Forest Tree Frog

Leptopelis vannutellii (Anura - Arthroleptidae) Dime Forest Tree Frog

Leptopelis yaldeni (Anura - Arthroleptidae) Grassland Forest Tree Frog

Paracassina kounhiensis (Anura - Hyperoliidae) Kouni Valley Striped Frog

Paracassina obscura (Anura - Hyperoliidae) Ethiopia Striped Frog

Phrynobatrachus inexpectatus (Anura - Phrynobatrachidae) Bore River Frog

Phrynobatrachus minutus (Anura - Phrynobatrachidae) Tiny River Frog

Ptychadena cooperi (Anura - Ptychadenidae) Cooper's Grassland Frog

Ptychadena erlangeri (Anura - Ptychadenidae) Erlanger's Grassland Frog

Ptychadena filwoha (Anura - Ptychadenidae) Filwoha Grassland Frog

Ptychadena harenna (Anura - Ptychadenidae) Bale Grassland Frog

Ptychadena nana (Anura - Ptychadenidae) Arrussi Grassland Frog

Ptychadena neumanni (Anura - Ptychadenidae) Neumann's Grassland Frog

Ptychadena wadei (Anura - Ptychadenidae) Tisisat Grassland Frog

Sylvacaecilia grandisonae (Gymnophiona - Indotyphlidae) Aleku Caecilian

Xenopus largeni (Anura - Pipidae) Largen's Clawed Frog

5.1.6. Reptiles

The crocodile farm on the shores of Lake Abaya and Nile monitor (*Varanus niloticus*) are common in the rift lakes of Ethiopia and elsewhere in other lakes and rivers of Ethiopia. Other wetland reptiles particularly those that are endemic to highland areas as Bale Mountains include: *Chamaleo balebicornutus* (Bale Mountains two-horned chameleon), *C. harennae* (Bale Mountains heather chameleon), *Lamprophis erlangeri* (Ethiopian house snake) and *Bitis parviocula* (Ethiopian mountain adder).

5.1.7. Birds

This is given special coverage by other departments of this EPCC document write up.

5.1.8. Mammals

Among the mammals of wetlands, hippopotamus is very common in Ethiopian wetlands. Many other mammals visit wetlands by the day or make their living in grasslands or shrubs along the water systems. Such cases are very common in game parks and natural settings. For instance, the mammals of the Bale Mountain National Park such as Mountain Nyala, Minilik's Bushbuck, Warthogs and others are common sites while grazing in the wetlands around Dinsho, Headquarter of the Ethiopian Wildlife Conservation Authority (see images above). So, do also the predators, such as the Ethiopian wolf, hyenas, etc. which come at these centers for hunting and drinking water.

5.1.9. Plants

Diverse wetland plants are known in Ethiopian wetlands. These include the plants shown in Table 4, below.

Table 4: Wetland plants of Ethiopia identified so far (Yilma D. Abebe and Geheb 2003, Haileab Zegeye *et al.* 2006 and Girum Tamire and Seyoum Mengistou 2012)

Wetland plant species
Aeschynomene schimperi
Aeschynomene elaphroxylon
Arundo donax
Cyperus articulatus
Cyperus papyrus
Cyperus elegantulus
Cyperus flavescens
Cyperus latifolius
Cyperus mundtii
Cyperus platycaulis
Echinochloa colona
Echinochloa stagnina
Echinochloa ugandensis
Eragrostis botryodes
Fimbristylis dichotoma
Floscopa glomerata
Fuirena stricta
Hydrocotyle sibthorpioides
Impatiens ethiopica
Jussiaea abyssinica
Leersia hexandra
Ludwigia erecta
Ludwigia stolonifera
Nymphaea lotus
Nymphoides indica

Wetland plant species
Oldenlania goreensis
Oldenlandia lancifolia
Ottelia ulvifolia
Panicum hymeniochilum
Panicum subalbidum
Persicaria glabra
Persicaria senegalensis
Phyllanthus boehmii
Pistia stratiotes
Potamogeton schweinfurthii
Sacciolepis africana
Schenoplectus corymbosus
Sesbania dummeri
Smithia elliotii
Thelypteris confluens

The plants listed above are not exhaustive as there are some more wetlands that have not yet been surveyed. It should also be noted that the plants listed in Table 7, above, are limited to freshwater systems only. Such highly saline wetlands or shallow waters of Lakes Abijata, Shalla, Chitu or those found in Dallol (saline wetlands 110 m below sea-level) or those wetlands found in the Senatea Plains of Bale Mountains (4377 m above sea-level) do not harbour these plants due to exceptional aquatic environments they possess.

(c) Summary of water quality

The following data is available on some of the frequently visited water systems of the country. Further research in the area is needed and certainly a central database where users can easily access for information.

Table 5: Water chemistry of lakes and rivers in the Ethiopian Rift Valley (**nd**: No data and **bd**: below detection and data with * are in mgL^{-1}). (after Bauman et al. 1975, Wood and Talling 1988, Elizabeth Kebede *et al.* 1994, Haile Gashaw 1999, Zinabu GebreMariam 2002, Zinabu GebreMariam *et al.* 2002, Zinabu GebreMariam 2003, Zinabu GebreMariam and Pearce 2003 and Girum Tamere and Seyoum Mengistou 2012)

Lakes/ Rivers	Cond. (μScm^{-1})	pH	Salinity (gL^{-1})	Cations ($meqL^{-1}$)	Anions ($meqL^{-1}$)	Na^+ ($meqL^{-1}$)	K^+ ($meqL^{-1}$)	Ca^{++} ($meqL^{-1}$)	$HCO_3^-+CO_3^{2-}$ ($meqL^{-1}$)	Mg^{2+} ($meqL^{-1}$)	Alkalinity ($meqL^{-1}$)	Cl^- ($meqL^{-1}$)	SO_4^{2-} ($meqL^{-1}$)	NO_x^- (μgL^{-1})	NH_x^+ (μgL^{-1})	SRP (μgL^{-1})	SiO_2 (mgL^{-1})
L. Abaya	1000	8.8	0.833	10.695	10.788	9.344	0.397	0.621	9.37	0.333	8.655	1.736	0.397	47	32.3	187.9	18
L. Abijata	49100	9.9	19.049	328.08	320.392	326.442	7.484	0.092	325	0.024	231.551	83.404	5.437	9.5	36	1009.4	81.4
L. Chamo	1620	9.2	1.213	15.704	16.242	14.256	0.57	0.372	12	0.553	13.266	2.761	0.21	27.3	20.9	14.8	1.7
L. Chitu	50000	10.0	44.9	895	693	864	31.2	0.16	573	573	581	99	21.1	bd	35	2347	222
L. Hawassa	820	8.4	0.735	8.761	8.837	6.851	0.936	0.508	8.25	0.479	7.795	0.791	0.25	20.6	179.2	18.8	40.1
L. Langano	1750	9.3	1.461	17.267	17.449	16.284	0.535	0.251	12.5	0.197	12.249	4.792	0.409	64.8	8.5	16.4	30.7
L. Shala	23000	9.8	18.627	294.740	307.316	289.091	5.491	0.114	218	0.042	217.322	84.859	6.419	1.7	9.3	951.7	45.6
L. Zwai	400	9.0	0.375	4.514	4.61	2.745	0.277	0.802	4	0.69	4.098	0.387	0.124	13.6	297	59.1	22.9
R. Bilate	76	7.5	0.079	0.927	1.013	0.304	0.156	0.3	0.9	0.167	0.87	0.143	0	nd	nd	nd	nd
R. Bulbula	425	7.9	0.965	12.401	12.408	10.599	0.475	0.788	9.4	0.54	9.373	2.827	0.209	nd	nd	nd	nd
R. Horakelo	4462	9.1	2.323	35.52	38.933	34.3	0.778	0.269	27	0.174	27	9.244	1.048	nd	nd	nd	nd
R. Katar	203	7.9	nd	nd	nd	5*	4*	30*	nd	3.67*	nd	4.6*	nd	33.8	56.5	29.1	nd
R. Kulfo	85	7.7	0.089	1.25	1.11	0.23	0.05	0.55	nd	0.42	1.02	0.09	0	nd	nd	nd	nd
R. Meki	451	7.8	0.285	nd	nd	2.3	0.2	1	3.4	0.8		0.5	0.3	nd	nd	nd	nd
R. Tikur-wuha	743.2	7.2	0.46	6.81	7.066	5.405	0.506	0.586	6.1	0.312	6.077	0.733	0.204	nd	nd	nd	nd

Data gaps and research needs

There are major data gaps particularly in the form of lack of database where one accesses for information on wetlands and the biodiversity in them. These gaps and research needs can be summarized as follows.

5.2.1. There is lack of regular platforms where scientists, users and policy makers could meet to discuss and exchange views on current issues and future trends of use and conservation of wetland resources. In the past few years, the Ethiopian Fisheries and Aquatic Sciences Association has been regularly holding annual conferences and publishing outcomes of the same. The circulation of the same material to national and international stakeholders is limited.

5.2.2. Rapid development work, mostly without compatible conservation procedures, is being done in this country by international donor organizations in collaboration with national public and private organizations. A recent publication of the Ethiopian Academy of Sciences authored by Brook Lemma (2014) shows that there is limited communication between all these actors as shown in the redundancy of the work they do and the lack of integrated information supply to decision makers and users.

5.2.3. The absence of such organization as Ethiopian Panel for Climate Change (EPCC) and other related institutions causes further separation rather than integration of knowledge.

5.2.4. There may be sizable amount of scientific data locked up in academic and research institutes of the country. There is no mechanism to get these information into local languages to be usable by ordinary people and there are not any institutional systems that would transform knowledge into contextual practices.

5.2.5. Lack of collaborators, fund or lack of knowledge of both.

5.2.6. Climate change database to access information on when rain fails or flood comes or to obtain any weather data that may affect livelihoods and safety of the environment, such as landslide.

5.2.7. Inadequate use or lack of recognition to indigenous knowledge and ineffective or non-existent awareness creation mechanisms and lack of transferring whatever knowledge is created to the education system.

5.2.8. Given the opportunities of working with CRGE strategy in Ethiopia, the desire to build many dams that would create more wetland resources and hence improving the green cover of the national landscape. It is therefore imperative that:

5.2.8.1. Researchers seize the opportunity to engage users and decision makers in designing and implementing targeted research activities that would generate desirable and usable outcomes.

5.2.8.2. Researchers need to conduct collaborative research that would address overarching national problems like food security, sustainable use of natural resources, particularly, wetland biodiversity and fresh water.

Policy implications and recommendations

6.1. The understanding that could be learned from the above information inevitably leads to the suggestion that responsible decision makers should reach out to create open and transparent platforms where scenarios are discussed and knowledge databases have to be referred to and experts have to be consulted.

6.2. There does not seem to be any other alternative way other than engaging stakeholders and draw lines where each follows guidelines to sustainably use aquatic resources and ensure that they are passed to future generations.

6.3. Such effort will not be let alone without enforcing regulations and reaching consensuses with all stakeholders for the sake of sustainable outcomes in the use of natural resources. Decision makers and stakeholders at large need to put in place implementation procedures that make all users accountable for their actions while using aquatic resources.

6.4. The fact that Ethiopia is not signatory to the Ramsar Convention may give it the right to act unilaterally with regards to the management wetland in its own boarders. As these aquatic systems are influenced by numerous international conditions such as climate, migration of animals, etc., it would be worthwhile to revisit the signing of the Convention and reap the benefits of global opportunities.

6.5. The Ethiopian Constitution at Article 92 states that as Ethiopians have the right to live in a clean and healthy environment, they have also the obligation to safeguard it for sustainable use. As a result, numerous policies have been developed and put into action. These include the policies for environment protection, land use, forest use and development and so on. So far however, there is not any policy developed on the management of wetlands. This may be because sustainable management of wetlands is mentioned in all of the above policies and others such as the use and protection of Ethiopian fishery resources and others. It may be time to revisit and consider a wetland policy that is aligned with all other national policies and the Ramsar Convention for the management of wetlands.

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Crop Biodiversity: Climate Change Adaptation, Mitigation, Vulnerability and Risks

Crop biodiversity background

Crop biodiversity concept

The concept of biodiversity was proposed in 1992 in the Rio de Janeiro Convention on Biological Diversity. Hence, according to CBD (1992) definition, biological diversity is the variety and variability of all types of living organisms and of the ecological complexes they form part of; it includes the diversity within each species, among species and that of ecosystems. Agricultural biodiversity (or agrobiodivesity) refers to the biological diversity found in crop and domesticated livestock and aquatic systems, as distinct from that of wild species of plants and animals (Smale *et al*, 2002a; Sundar, 2011). Di Falco (2012), also defined agrobiodivesity as a component of biodiversity referring to all diversity within and among species found in crop and domesticated livestock systems including wild relative, interacting species of pollinators, pests, parasites and other organisms. Agricultural biodiversity in Ethiopia is the basic component of sustainable production and food security in marginal areas with remarkable adaptability to the changing conditions (Adugna Abdi, 2009). This is because the countryhas a wealth of genetically-diverse populations and species-rich agro-ecosystems which have great contribution for adaptation to climate change.

According to Brush (2002) , crop genetic resources are a natural asset comprised of the genes of domesticated plants, together with the dynamic human and ecological contexts and are indispensable to a crop's evolutionary system. Abundance and diversity of these resources are concentrated in locations where crops were originally domesticated and/or long evolved under heterogeneous conditions. These locations are known as "Vavilov's Centers" in honor of the Great Russian botanist Nikolai Vavilov, who pioneered the study of crop center of origin/domestication in the early 20th century. The Vavilov's Centers are located, virtually without exception, in developing countries, and within them, crop genetic resources are concentrated on the poorest farms (Nabhan,1985 and Brush, 2002).

Crop genetic resources are conventionally divided into two broad groups:

wild and weedy relatives of domesticated plants, and landraces or “primitive crop varieties” from farmers’ fields. The landraces have been inherited from previous generations, and undergo continuous natural and artificial (that is, conscious) selection. Crop diversity is distributed within and across localities. In theory, it is conceivable that each individual locality hosts a genetically distinct population of the crop. At the other extreme, different regions may be sown with the same crop population, that is, the same mix of varieties. In the first case, where diversity is found entirely between localities, genetic resources are easily connected to particular people and places. In the latter case, no single site can be identified with specific genetic resources because they are shared across many localities. The distribution of diversity is critical to claims of ownership or rights to private benefit from genetic diversity.

Several factors favor the distribution of diversity between rather than within localities, and hence a tendency toward a situation where each farming region is genetically distinct. Most prominent is the importance of local adaptation in agricultural systems that offer few other management tools to contend with risks such as drought, insect attack, or disease outbreaks. Classic definition of landraces stresses that these are crop populations in balance with their local environments. Adaptation to different micro-environments could be the major reason why there is so much diversity. Another factor favoring a high proportion of diversity between rather than within localities is the physical and social isolation of farming communities: mountainous terrain, cultural and linguistic heterogeneity, and the lack of integrating mechanisms, such as markets, pose barriers which help to protect local varieties.

Supporting the maintenance of diversity on-farms is one strategy for crop genetic diversity conservation. On-farm conservation is viewed as a complementary strategy to *ex-situ* conservation strategies. Through on-farm conservation not only are materials conserved, but so also are the processes of evolution and adaptation of crops to their environment (Smale *et al.*, 2002b). On-farm conservation is defined as the choice by farmers to continue cultivating diverse crops in their communities, in the agro-ecosystems where the crops have evolved historically through processes of human and natural selection.

Crops diversity and distribution in Ethiopia

Ethiopia is recognized as a center of agro-biodiversity and is designated as one of the eight Vavilovian Centers of crop origin/domestication and diversity and harbors crops of global importance including sorghum, millet, Arabica coffee, durum wheat and tef, among others (Fassil Kebebew, 2010). Fassil Kebebew (2010) also reported that Ethiopia harbors important gene pools of crop wild relatives for at least over 120 species of crops, including grains, pulses, oil seeds, vegetables, tubers, fruits, spices, stimulants, fibers, dyes and medicinal plants. In addition, several crops that were domesticated outside of East Africa exhibit high secondary diversification in Ethiopia, as evidenced in farmer varieties of wheat, barley, and several pulses. Agro-ecosystems are an important part of the earth system.

Chavas and Di Falco (2012) reported that about 40% of earth land is used for agricultural purposes and agro-ecosystem services help support economic livelihood everywhere, especially in developing countries where the agricultural sector constitutes a large part of the economy. In Ethiopia, out of the total agricultural land, about 97% is cultivated by small holders who produce more than 97% of the agricultural outputs (Wondimagegn Mesfin *et al.*, 2011). The principal mangers of crop genetic diversity in developing countries are farmers, particularly those living in marginal areas.

The study conducted by Wondimagegn Mesfin *et al.* (2011), in eastern Ethiopia showed that land allocation is an indicator of importance of the crop under consideration (Table 1). Crop portfolio composition of the study areas seems to contain significantly higher proportion of low- risk and low- return crops. To some extent, on the other hand, they contain low concentration of high value cash crops.

Table 1: Area allocation and diversification index for the 2004 -2009 production periods in eastern Ethiopia

Crops	2004	2005	2006	2007	2008	2009
Maize	0.183	0.183	0.182	0.189	0.182	0.188
Sorghum	0.139	0.138	0.139	0.166	0.146	0.154
Potato	0.049	0.063	0.0634	0.055	0.060	0.058
Onion	0.051	0.026	0.033	0.048	0.059	0.041
Beetroot	0.0057	0.0074	0.0079	0.012	0.015	0.0071
Cabbage	0.0056	0.0052	0.0057	0.012	0.0137	0.0094
Carrot	0.0050	0.0044	0.0057	0.013	0.016	0.0051
Diversity index	0.439	0.427	0.437	0.496	0.493	0.462

Source: Wondimagegn Mesfin *et al.*, 2011, pp,88.

From the data in Table 1, there appear similar trends of diversification in the study area for the six years of the assessment. This indicates that the crop diversification in the study area was nearly the average value the maximum diversification that takes the value of 1(one) and the maximum specialization that attain at the value of 0 (zero). The average values of the six years (0.459) could be attributed to farm size, age of the household head, household size, distance to market, level of extension service and climate variability. In general, stable crop diversification index value in the study area attributed to the increase in land fragmentation. Analyzing the trend in crop diversification may help to know risk-aversion behavior of smallholder farmers. Hence, increase in diversification index with time indicates the increase in risk aversion strategy of the farmers. Kebu Balemi (2011) also reported that 16 different crop species adapted to different agro ecological niches in southwestern Ethiopia lowland to highland altitudes (<1500-2300 masl). According to this study, within some of the major crops, a large varietal diversity was observed with distinct morphological, agronomic and gastronomic qualities and attribute. Tesema and Abebe (2002) also studied farmers' varieties distribution across the country (Table 2).

Table 2: Distribution of farmers' varieties accessions of four crops across the region

Region	Barely	Sorghum	Tef	Durum wheat
Arsi	134	5	21	31
Bale	108	6	23	31
Gamo-gofa	36	46	48	9
Gojam	9	12	54	34
Gonder	11	18	26	22
Harar	21	56	14	13
Illubabor	7	12	4	*
Keffa	*	17	18	*
Shewa	145	25	98	108
Sidamo	12	5	12	*
Tigray	164	12	130	62
Wollega	44	28	119	6
Wollo	80	25	37	43

**Regions where farmers' varieties of a crop wre not observed*

Source: Tesema and Abebe (2002), pp, 3.

From the data in Table 2, the plant materials used for the study were 771 accessions of farmers' varieties of barley, 359 accessions of farmers' varieties of wheat, accessions of 267 farmers' varieties of sorghum and 604 farmers' varieties accession of tef crops collected by the then Institute of Biodiversity Conservation and Research. From the data in the Table 2, Tigray has the largest frequency of distribution for barely and tef farmers variety accession. However, the highest frequency value for sorghum and durum wheat was found in Harar and Shewa respectively. On the other hand, Illubabor has the lowest distribution of farmers variety accessions of Barley and sorghum followed by Gojam for Barley and Sidamo for Tef. The variation in distribution could be attributed to Ethiopia as a center of origin for Sorghum and tef and center of diversity for barley and durum wheat.

Table 3: Distribution of farmers' varieties for the four crops across altitudinal ranges

Altitude range (m)	Barely	Sorghum	Tef	Durum wheat
500-1000	*	6	*	*
1001-1500	*	41	184	2
1501-2000	99	156	250	38
2001-2500	296	50	189	173
2501-3000	258	14	61	141
More than 3000	118	*	*	5

**Altitude ranges where farmers varieties of a crop were not observed.*

Source: Tesema and Abebe (2002), pp 5.

The distribution of the accessions of the farmers varieties showed that it is only sorghum that thrives in the lower altitude range and barley and some durum wheat accessions at the highest altitude (Table 3). This is attributed to the physiologically response of the crops to cooler and warmers climatic conditions. In the mid altitude range (1501-2000 masl), the highest distribution was recorded for sorghum and tef. Generally, the study could lead us to revisit the change and the shift that has occurred so far in adaptation capacity of the crops in the study area due to change in climate scenario thereafter. For coffee genetic resources distribution, Taye Kufa (2010) reported that there are about 21,407 coffee germplasm (10,573 arabica, 8,000 robusta, 1,282 mascaro and 1,552 arabica or robusta in Cameroon) in the different field gene banks of some African countries, of which around 89.85% is found in Ethiopia. Ethiopia alone possesses around 99.8% of total Arabica coffee genetic diversity.

Girma Megersa (2014) reported that the number of barely farmers varieties'(FVs) that are traditionally used by farmers were considerably higher in north Shewa zone of Oromiya regional state. According to this finding, all households involved in the survey (90 smallholder farmers) had grown FV's of barley before 1990s. Interviewed farmers reported that previously they were growing a wider diversity of FV's for various reasons and 65.6% of barley grown before a decade was dominantly FV's.

Table 4: Data on in situ collections from Ethiopian Biodiversity Institute community gene banks

s/n	Name of the community gene bank	Conserved crops type	Location/ Region	No of conserved crop types
1	Ancober	Faba bean and Barley	Amhara	2
2	Siadebre	Faba bean, Lentil, wheat, chick pea and grass pea	Amhara	5
3	Agarfa	Faba bean, wheat, Barley and Emmer wheat	Oromiya	4
4	Goro	Faba bean, lentil, chickpea,barley,Filed pea, Emmer wheat, fenugrek and Flax	Oromiya	8
5	Chena	Faba bean, barly and tef	SNNPR*	3
6	Decha	Faba bean, wheat, barley, field pea, teff	SNNPR	5
7	Hawuzen	Wheat, barley, tef, sorghum, maize and Millet	Tigray	6
8	Ganta Afeshum	Barley, wheat, tef, Lentil and grass pea	Tigray	5

Source: Delassa Agesa*, 2014.*

** SNNP Southern Nations Nationalities and People Region*

According to the report of Delassa Angassa (2014), the diversity of farmers variety is greater in Agarfa woreda of Oromiya Regional state and Hawuze woreda of Tigray regional state (Table 4). The distribution of the community gene banks is also representative in locations and agroecology of the country. Besides the community gene banks, the institute also established two field gene banks in Bedessa and Choche districts to conserve genetic resource of coffee, spice and root crops. According to the report of Delassa Angassa (2014), in Bedessa field gene bank, 832 coffee accessions were collected and conserved from eastern part of the country basically from eastern and western Harerghe, Dire Dewa and Somale region. On the other hand, in Choche field gene bank, 4592 coffee arabica accessions, 342 different spice crops accessions and 462 root and tuber crops accessions were also conserved. Accessions in Choche field gene bank represent most part of the country with major contribution and collections from southwestern part. There are also two additional field gene banks established by the contribution of mainstreaming agro-biodiversity conservation project of the institute. As a result, in the enset field gene bank in Angacha district, 84 enset accessions/ cultivars were conserved including one crop wild relative species with 100 planting materials. One field gene bank was also established in Yayo forest coffee biosphere reserve area with the target to conserve forest coffee genetic resources in the biosphere reserve.

Multiple benefits of crop biodiversity

The relevance of biodiversity in the provision of ecosystem services is highlighted by growing evidence that it can support system productivity and that its loss can have adverse effects on the functioning of ecosystems (Chavas and Di Falco, 2012). Crop genetic diversity is considered a source of continuing advances in yield, pest resistance and quality improvement. It is widely accepted that greater varietal and species diversity would enable agricultural systems to maintain productivity over a wide range of conditions. Genetic diversity has tangible values such as a source of agronomic traits for breeding, diversity to attain stable yield increases and adaptability to changing climates and environments (Adugna Abdi, 2009). The merit in making better use of neglected or underutilized crops for food and income security is also immense.

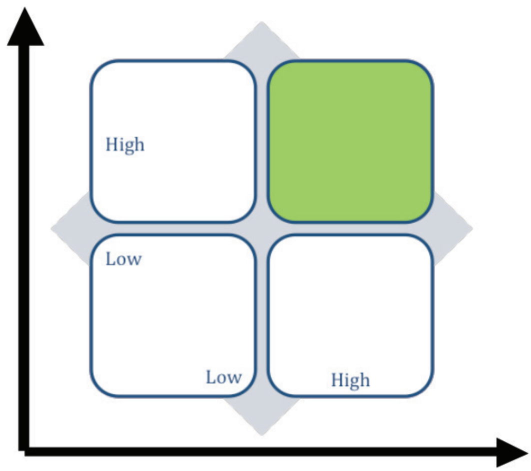
Landraces are the most important crop genetic resource for agricultural science in terms of their historic value in crop breeding, proportion of material collected and stored in conservation facilities, and relevance to political conflicts. For most crops, landraces are counted in the thousands, and for some in the tens of thousands.

This diversity embodies the collected wisdom and experience of the hundreds of generations of farmers who have selected and managed crop populations since the Neolithic Revolution, some 5000 to 8000 years ago. Currently, landraces represent 60% of the 1,300 collections and 6.1 million accessions in over 120 national and international gene banks; the remainders are in selected and bred varieties, breeding lines, and wild and weedy relatives. For Ethiopian context, data in Table 4 showed the progress towards conserving the crop biodiversity in community gene banks. Moreover, according to the annual report of Ethiopian Biodiversity Institute (Delassa Agesa, 2014), 67,856 accessions of different crops were conserved in the *ex situ* gene bank (cold room) of the institute. From the total accessions, 50988, 7838, 7855, 416,759 accessions were categorized under cereal, pulse, oil, horticultural and industrial crops respectively. From the total accessions conserved in the cold room, cereal crops have 75.1% share.

In terms of the role of agricultural biodiversity conservation in national development priorities, first, we need to know in which locations conserving agricultural biodiversity on farms costs least in terms of public investments that compete for scarce funds (Smale *et. al*., 2002a). In principle, this will occur in locations where both the public value of the resources is believed to be greatest (as in a biodiversity 'hotspot') and where the private net benefits farmers earn (monetary and non-monetary) through maintaining diverse crop genetic resources is high (Figure 1). Costs include the opportunity cost of growing these resources. Our premise is that it does not make economic sense to trade productivity for conservation or thwart the opportunities that farmers may have to choose to grow modern varieties rather than traditional varieties. Application of theoretical models of farm household decision-making in candidate sites can be used to develop a profile of least-cost sites and farmers to target (Figure 1).

Increasing farm diversity offers the opportunity to increase profits while decreasing production costs. Adding new crops that fit the climate, geography and management requirements can increase profits by providing the opportunity to exploit niche markets, expand marketing opportunities and offset commodity price swings.

1 Farmers utility (current private value)



Crop genetic diversity (public value)

Fig 1: Least-cost site for on-farm conservation (Adapted from Smale *et al*, 2002b, page 12)

In general, research should aim to identify policies that favor conservation without impeding the progress of economic development. The world's poor cannot be asked to shoulder the burden of conserving agricultural biodiversity unless they can benefit by doing so. Once these elements are understood in each specific context, feasible policy interventions can be proposed. These options can then be assessed using cost–benefit criteria based on environmental valuation methods.

Drives of climate change on crop biodiversity

Agriculture

Agricultural activities are significant emitters of global greenhouse gases (GHGs) and as such agricultural activity is a major driver of anthropogenic climate change.

Emissions from agricultural sources were 14% of global GHG emissions in 2000 with developing countries accounting for three quarters of agriculture emissions in the case of rice (Braimoh *et al.*, 2010). In Ethiopia, of the 150 Mt CO2e in 2010, more than 85% of GHG emissions came from the agricultural and forestry sectors (CRGE, 2011).The cultivation of crops contributes to the concentration of greenhouse gases mainly by requiring the use of fertilizer (~10 Mt CO2e) as well as by emitting N_2O from crop residues reintroduced into the ground (~3 Mt CO2e).

As forests are cleared in the region for agricultural purposes, crop residues are burnt, agriculture is intensified (e.g. through mechanization and increased fertilizer/agrochemical use) and livestock are raised, large quantities of GHGs such as CO2, CH4 and N2O are emitted. Apart from those primary agricultural activities, the associated land-use change also contributes significantly to CO2 emissions. This additional contribution from land-use conversion seems to further unbalance the annual net flow of CO2 between agricultural lands and the atmosphere. Not only are these emissions contributing to enhanced greenhouse effect, they also represent a loss of useful carbon and nitrogen which are potential energy sources for crop and plant production.

The greatest factor contributing to the loss of crop genetic diversity is the spread of high input, industrial agriculture and the displacement of more diverse, traditional agricultural systems (Sundar, 2011). The Green Revolution introduced high-yielding varieties of rice and wheat to the developing world, replacing farmer's traditional crop varieties and their wild relatives on a massive scale. According to report of Sundar (2011), in the Philippines, where small farmers once cultivated thousands of traditional rice varieties, just two Green Revolution varieties occupied 98% of the entire rice growing area in the mid-1980s.The same process continues today. New, uniform plant varieties are replacing farmer's traditional varieties and the traditional ones are becoming extinct. Genetic diversity in agriculture enables plants to adapt to new pests and diseases, changing environments and climates.

The ability of a certain variety to withstand drought, grow in poor soil, resist an insect or disease, give higher protein yields, or produce a better-tasting food are traits passed on naturally by the variety's genes. This genetic material constitutes the raw material that plant breeders use to breed new crop varieties. Without genetic diversity, options for long-term sustainability and agricultural self-reliance are lost. In recent years, agriculture has also witnessed several changes including shift from the mixed cropping and intercropping to mono cropping due to various consideration. Intensive agriculture has increased area under monoculture and at the cost of mixed cropping and intercropping and this has resulted in loss of species diversity. This trend needs to be reversed.

Climatic factors

Woldeamlek Bewket (2011) reported the annual and seasonal rainfall trend and variability in Amhara Regional state for the period 1975-2003 and showed negative trends in four, three and seven stations for annual, kiremt and belg, respectively (Table 5). Negative trend was the highest for belg season, in 58.3% stations with significant value in Dangela (Table 5). According to Woldeamelak Bewket (2011) report, of the 29 years of observation, 17 years (59%) recorded below the long-term average annual rainfall amount while 12 years recorded above average. This was supported by 0.12-0.23, 0.11-0.29 and 0.35-0.68 coefficient of variation (CV) for annual, kirmet and belg, respectively. Study of Defaru and Tuma (2013) in Gamo Gofa also showed significant variation of maximum temperature over 25 years. Seifu Admassu (2004) also reported the Belg rain in ten stations (all over the nation) shows that there is high variability; since CV is greater than 0.30 referring standard that indicate CV less than 0.20 is less variable, CV between 0.20 and 0.30 is moderately variable and CV greater than 0.30 is highly variable. Mintewab Bezabih *et al.*, (2011) reported the coefficient of variation for the annual rainfall from 8 stations, computed as the ratio of the mean to the variance of annual rainfall, is 0.972. This is also accompanied by a much lower spring (belg) and summer (kiremt) coefficient of variation, 0.27 and 0.49, respectively. The high annual coefficient variation represents the notoriously fluctuating rainfall across the years. However, the very low coefficient of variation of summer rainfall shows the relative stability of rains in the main rainy season.

Table 5: Annual and seasonal rainfall trend during 1975-2003.

Station	Annual		Kiremt		Belg	
	Trend	Rho	Trend	Rho	Trend	Rho
Bahir Dar	45	0.17	42	0.16	8	0.09
Changni	-24	-0.17	-12	-0.123	-4	-0.12
Combolcha	51	0.26	60	0.27	-15	-0.16
Dangela	-22	-0.03	12	0.36	-19	-0.56*
DebreBirhan	62	0.20	73	0.23	-23	-0.16
Dessie	128	0.62***	107	0.48***	2	-0.04
DebreMarkos	55	0.26	33	0.26	6	0.04
Debre Tabor	-103	-0.28	-101	-0.40*	25	0.23
Gonder	-36	-0.02	-29	-0.40	-19	-0.28
Gorgora	29	0.12	11	0.13	-10	-0.01
Kemissie	34	0.21	30	0.11	5	0.04
Lalibela	101	0.47**	104	0.45**	-19	0.09

Significant at 0.1 level; **Significant at 0.05 level; ***Significant at 0.01 level

Trend: in mm /10 years*Rho*: Spearman's *rho, Adapted from: Woldeamelak Bewket 2011, p,828.*

The rainfall variability (annual and seasonal) affects the correlation of the crops with the seasons and farmers preference and technology involvement to subsequently affect crop biodiversity of a given location. Adugna Abdi (2009) reported that farmers have been experiencing change in their farming strategies by shifting to more drought-resistant crops as well as to a shorter agricultural calendar as consequences of a loss of the spring rains since the last 20–30 years and as a shorter main summer wet period. According to personal communication with the farmers in Berke district of Oromiya Regional State, failure in Belg season has shifted farmers to sow oat, a previous livestock feed but currently cereal for human consumption.

Anthropogenic factors

Rich farmers owned more plots of farmland and maintained FV's than poor farmers (Girma Megersa, 2014). However, in order to obtain better yield and sustain their families, poor farmers used improved varieties, most of the time through seed exchange from their neighbors, which on the other hand is positively correlated to genetic erosion.

The diversity within and among crop varieties that is conferred by genes can be expressed and measured in many ways. Only some of these are visible to farmers in the traits of the crop varieties they grow. Although conservationists, plant breeders and society as a whole may be concerned about the genetic diversity that can be identified in laboratories, it is the choices that farmers make based on what they observe that will determine diversity.

There are several essential reasons why the diversity of crop genetic resources grown on farms is of economic importance. The first relates to aggregate crop productivity. The pattern of crop varieties and the genes they carry determines annual yields and the crop's vulnerability to disease and abiotic stress. Yield growth and yield instability have economic value, and maintaining diversity on farms may entail efficiency trade-offs in the short term.

A second concerns options for the future, which have economic value in the longer term. Crop varieties are not like endangered species, but if a farmer ceases to plant the seed of a traditional variety or abandons a breeding practice, the variety may be 'lost' to future generations. Even if this traditional variety were sampled for storage in a genebank, it would not serve as a perfect substitute because accessions sampled from that variety and regenerated under *ex situ* conditions tend to evolve differently.

A third reason is related to social equity. Many farmers in the developing world depend on the diversity of the varieties and crops they grow for their own consumption and wellbeing— particularly in production environments areas that are agro-ecologically heterogeneous or risky, where a commercial seed market has not developed because there are few opportunities for profit, or where economic opportunities are limited aside from labour migration.

In areas where crops have evolved over centuries, crop diversity is part of the cultural endowment. By contrast, in some advanced economies, there are niche markets for scarce traditional varieties and consumers may be willing to pay to conserve certain attributes of agriculture, such as its biodiversity.

Table 6: Trends in barley production at Degem woreda

Varieties in production	Varieties rarely in production	Varieties lost	Reasons for loss of the varieties
Magee	Karfe	Mugaa	Climate change
GarbuAdi	Hadhoo	Barsaddad	Degradation in soil fertility
GarbuGura-cha		Abichu	Introduction Improved varieties
DamoyAdi		Abiso	Replacement by other crops
DamoySayin-tee		Kasalee	Extension system focused on improved varieties
Filatama		Buttujii	
Tolase		Luqa'a	
Qaxee		Samareta	

Source: Girma Megersa, 2014, pp 284

According the report of Girma Megersa (2014, Table 6), among 18 farmers varieties managed by the farmers so far in the district, 44.4% were lost due to different reasons, 11.1% were rarely produced and only 44.4% were under the production system with different production scales. From the lost varieties, climate change and land degradation played major roles equivalent to the competitive effects of the extension systems in practice. This request calls for the requirement and practices of interdependent system for conservation of the farmers varieties at field level.

Impact, vulnerability and risks

Impacts of climate change on crop biodiversity

There is widespread recognition that climate change and biodiversity are linked and the impact of climate change on agro biodiversity in Ethiopia can be viewed in the context of the global climate change. Most obviously, by changing the environmental conditions within which species exist, climate change induces an adaptive response on the part of species (Perrings, 2010).

According to Perrings (2010), climate change is already inducing an adaptive response on the part of the world's biota. It includes changes in species distributions and abundance, changes in the timing of reproduction in plants, and changes in the frequency and severity of pest and disease outbreaks.

Agro-biodiversity is the basis for human survival. However, due to global climate change in most arid and semiarid regions, predominant losses have been underway. Semi-arid regions of Ethiopia are characterized by erratic rainfall pattern and recurrent drought occurrence. Although Ethiopia forms an agro-biodiversity hot spot, noticeable patterns of ecological change is increasingly felt due to climate change currently underway (Adugna Abdi,2009).An exposure to gradual climate change mainly temperature and precipitation and extreme climate changes such as drought and flood significantly impacted the performances of agro-biodiversity and the effectiveness of the traditional coping mechanisms on Ethiopian farmers. In the poorest countries, income growth is strongly correlated with increasing levels of threat to biodiversity (Perrings, 2010). According to Sundar (2011), genetic erosion and the reduction of diversity within and between species are global threats to agriculture and approximately 30% of the Earth's vegetation will experience a shift as a result of climate change. Hence, the greater the diversity of species within functional groups, the greater will be the capacity of the system to continue to produce valuable services under climate change.

Climate change has both direct and indirect impacts on biodiversity. The direct impacts are through changes in temperature and precipitation that affect individual organisms, populations, species distribution, and ecosystem compositions and functions. According to Perrings (2010), the direct impacts of climate change on plant biodiversity will occur through two antagonistic effects; warming and the reduction in water availability. Hassen and Aldosari (2014) reported that as the duration of the crop growth cycle is related to temperature, an increase in temperature will speed up crop growth and shorten the duration between sowing and harvesting. This shortening could have an adverse effect on productively of crops. Similarly, in line with reduction in water availability, Hassen and Aldosari (2014) also reported that there is greater water demand due to high evapotranspiration rate at elevated temperature. On the other hand, the biggest indirect impacts are also reported by Perrings (2010), as those deriving from edaphic changes,

changes in the fire regime and the rise in sea level. Interactions with other components of global change (land use changes, modification in atmospheric composition) constitute another important potential source of impacts for which evidence is now beginning to accumulate.

Vulnerability level of crop biodiversity

The agricultural sector in sub-Saharan Africa is expected to be especially vulnerable to climate change because the region already endures high heat and low precipitation, provides for the livelihoods of large segments of the population, and relies on relatively basic technologies, which limit its capacity to adapt (Fassil Kebebew, 2010). Fluctuation in mean monthly temperatures beyond and below the optimum requirement levels of crops increases vulnerability to reproductive development. For instance, pollen viability and production in maize requires less than 77 ^{o}F while in rice it needs less than 95 ^{o}F. On the other hand, kernel development in maize needs less than 86 ^{o}F temperature requirement. So, more crop choices mean more robust agricultural systems, more opportunities for farmers especially when faced with increasingly unpredictable climate which is similar to well-balanced financial portfolio.

Scientists predict that the build-up of greenhouse gases in the atmosphere will cause global temperatures to rise 1 to 3 degrees Centigrade during the next century; melting glaciers and thermal expansion of the ocean will bring an associated rise in sea level of 1-2 meters. Each one degree rise in temperature will displace the tolerance of terrestrial species some 125 km. towards the poles, or 150 meters in altitude (Sundar, 2011). In other words, global warming will wreak havoc on the world's living organisms. According to some literatures, approximately 30% of the Earth's vegetation will experience a shift as a result of climate change. But since climate will be changing faster than the migration rate of most species, experts predict a "drastic reduction" in global species diversity. However, those global evidences need national assessment and study for Ethiopia context.

Study results of Lane and Jarvis (2007) showed that the crops likely to suffer significant decreases in suitable areas for their cultivation are typically cold weather crops, including strawberry (32%), wheat (18%), rye (16%), apple

(12%) and oats (12%). With similar study, twenty-three crops are projected to suffer decreases in suitable area, on average, whilst some 20 crops gain suitable area. Overall, suitable area for crop cultivation is projected to increase. Lane and Jarvis (2007) also reported that the biggest gains are in areas suitable for pearl millet (31%), sunflower (18%), common millet (16%), chick pea (15%) and soya bean (14%), although many of the gains in suitable area occur in regions where these crops are currently not an integral component of food-security. For example, land area suitable for pearl millet is projected to increase by over 10% in Europe and the Caribbean, yet these levels of increases are not projected for Africa, where the crop is currently widely cultivated. Sub-Saharan Africa and the Caribbean are projected to suffer a decline in land area suitable for cultivation (-2.6% and -2.2%, respectively), although there is some disagreement on regional impacts (Lane and Jarvis, 2007).

Risks of climate change on crop biodiversity

Crop diversification is the most important risk management strategies. As genetic diversity erodes our capacity to maintain and enhance agricultural productivity decreases along with the ability to respond to ever-changing needs and conditions.

Crop failure, reduced diversity and reduced yield are the major critical risks due to climate change on crop biodiversity. Thus reduction of biodiversity in variety, species as well as ecosystem poses a serious threat to our food security. Success in any breeding programme depends largely on the extent of genetic variability present at different levels. Often it is observed that breeders only use a few varieties extensively in different breeding programmes for development of new varieties. Extensive use of a few genotype in breeding programme reduces the genetic diversity among the varieties cultivated and makes them vulnerable to various diseases and pests. Irish late blight, a disease of potato is an eye opener in this context. Thus, there is need to change our approach in breeding so that adequate genetic diversity can be maintained.

Adaptation, mitigation and managing risks

Adaptation

Adaptation is the term used to describe responses to the effects of climate change. The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as 'adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.' Adaptation can also be thought of as learning how to live with the consequences of climate change. Indigenous and underutilized crop species having adaptive traits with greatest genetic variability and evolutionary flexibility have been conserved in in-situ (Adugna Abdi, 2009). According to CBD (1992) definition, *ex-situ* conservation means the conservation of components of biological diversity outside their natural habitats. In-situ conditions' means «-conditions where genetic resources exist within ecosystems and natural habitats, and. in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties.

The *in situ* conservation of habitats and entire ecosystems is often considered the best method of adaptation to climate change through conserving species (CBD, 1992). Though there are potential problems with *ex situ* conservation in maintaining genetic variation, such measures can usefully assist in the temporary restoration of ecosystem service. According to Adugna Abdi (2009), community practices at farm level also aim at maximizing the genetic resources conserved with the highest possible benefit and with increased chances for resilience to environmental change.

Adapting crop varieties to local ecological conditions will reduce risk due to climate change (Lane and Jarvis, 2007; Campbell *et al.*, 2008). However, the authors reported that varieties improved for cultivation in one region could be adopted for cultivation elsewhere, where they would face the same abiotic and biotic stresses. For instance, Lane and Jarvis (2007) reported that rice varieties that were initially bred for resistance to chilling temperatures in Nepal, for example, were successfully adopted in Bangladesh. Diversity in species, varieties and practices has permitted agriculture to withstand moderate change in climate over the past 10,000 years (Lane and Jarvis, 2007). Similarly, according to Campbell *et al.* (2008), the most common adaptation strategies used by farmers in South Africa and Ethiopia include the use of different crop varieties in which crop diversification and mixed cropping is currently being used to increase chances that at least one crop will survive and produce a harvest.

Over centuries of observation and selective breeding, farmers' practices have given rise to traditional varieties that are well adapted to local environmental conditions. Farmers use indicators of abiotic stress tolerance that could assist selection of local breeding material to combine tolerance traits with relatively high yield and desirable market traits of modern varieties. Blending the resistance traits of traditional varieties through modern plant breeding will ensure that new varieties are bred to suit specific requirements of local conditions and communities (Lane and Jarvis, 2007). Generally, adaptation to climate change needs some strategies in crop biodiversity like switching crops or crop mixtures, continuous field testing of existing variability for adaptation traits, and evenness of crop diversity. More crop choices mean more robust agricultural systems.

Mitigation

Climate change mitigation is an anthropogenic intervention to reduce sources and enhance sink of greenhouse gases (Fantahun Ali, 2013). CRGE (2011) also stated that climate change mitigation as key issue to reach a green economy in Ethiopia. However, the role of preserving biodiversity was coined in general term in the strategic document as ecosystem-service function to sink carbon. Among the initiatives to limit soil based emission in CRGE (2011), introducing lower-emission agricultural techniques (ranging from the use of carbon and nitrogen-efficient crop cultivars to the promotion of organic fertilizer) were stated besides intensifying agriculture through residue management. Here, it important to identify the contribution of crop biodiversity in supplying the cultivars with carbon and nitrogen efficient characters. Fantahun Ali (2013) also reported that mitigation in agriculture sector to include efficient control and management of agricultural practices to reduce emission of gasses, promoting agro forestry to enhance removal of carbon and crop reside management to avoid emission. According to Defaru and Tuma (2013), many Sustainable land management practices can increase soil organic carbon, and reduce the need for coping measures, like changing crops and livelihoods, clearing new lands for agriculture and migration. Hence, the contribution of crop biodiversity for climate change mitigation can be analyzed in terms of applying the initiatives and practices of soil management. In general, the review of literatures showed that there is lack of evidence for the contribution of crop biodiversity for climate change mitigation.

Management of risks

According to the comparative advantage theory, diversification can reduce risks but at the expense of income. So, promotion of farm diversification is on-farm level risk management strategy. According to the report of Di Falco and Chavas (2009) from Tigray Regional State, maintaining a larger number of barley varieties supports productivity and reduces the risk of crop failure. They also documented how the skewness effect differs from the variance effect: biodiversity increases variance but reduces downside risk exposure (by increasing skewness).

They also found that the skewness effect dominates the variance effect. Thus, for farmers exhibiting both risk aversion and downside risk aversion, reducing the odds of crop failure can be more relevant than reducing yield variance. This indicates that the variance alone would not provide an accurate characterization of risk exposure. Conserving landraces in the field delivers important productive services and allows farmers to mitigate some of the negative effects of harsh weather and agroecological conditions. Therefore, *in situ* conservation of crop biological diversity is one of the strategies that can help improve Ethiopia's poor agricultural performance and alleviate food insecurity.

Gender and crop biodiversity

Household characteristics include those related to human capital, labor supply and the life-cycle stage of the household. Age of household head is expected to have a quadratic relationship with both inter and intra-specific diversity of crops, as younger households may be more willing to try out different crops and varieties, while older households may be more set in their production activities and less likely to try new crops and varieties

(Wondemagegn et al., 2011 and Benin *et al.*, 2003). However, according to Benin *et al.*, (2003) study, the direction of effect of the gender composition of the household is difficult to predict a priori, while household size is expected to have a positive effect on diversity through its effects on preferences and overall labor capacity. Three categorized independent variables: sex, level of education and class were also studied by Girma Megersa (2014) and showed positive association with trend on farmers' varieties of barley genetic erosion. The reason for this could be that male farmers were socially powerful on the discussion of farming activities, had access to adopt new technologies than female farmers. According to the report of Wondemagegn Mesfin *et al.* (2011), sex of the household head has positive effect on diversification due to the fact that there is skill or requirement for frequent and early ploughing. However, there are practices that show women increase crop biodiversity in home gardens especially in promoting fruit and vegetables production.

Information, data gaps and research needs

- ✓ One-quarter of undernourished people in the developing world live in so-called biodiversity hot spots areas that are rich in crop biodiversity (Chavas and Di Falco, 2012) and loss of biodiversity and the consequent reduction in ecosystem services (i.e., food production) are seen as a primary obstacle to the achievement of development goals. Ethiopia is a 'biodiversity hot spot': it is a recognized global center of genetic diversity of cereals. However, the productive value of crop biodiversity was not well documented in managed agricultural system in most part of the countries except some efforts in northern highlands of the nation with the existing climate change scenarios. On the other hand, Chavas and Di Falco (2012) reported the argument that stated "biodiversity benefits may be larger when agro-ecological conditions are more difficult". Pervasive land degradation and erratic rainfall was considered in Ethiopia to describe challenging agro-ecological conditions. This provides a strong motivation for importance of empirical analysis and its documentation of the productivity effects of crop biodiversity.

- ✓ According to the comparative advantage theory, diversification can reduce risks but at the expense of income (Wondimagegn Mesfin *et al*, 2011). Despite the significant role crop diversification plays in agriculture, there are only few empirical studies on the factors that determine diversification. However, crop biodiversity in Ethiopia coverage and distribution is not well documented and the share of farmers' varieties was also not well known. This should include the threshold level of the theory of diversification at the expense of income.

- ✓ Woldeamelak Bewket (2011) reported that negative trends and variability of rainfall in Amhara regional states for the period 1975-2003. Even most of the areas of the regional state became uni-modal rainfall distribution. But, there is limited assessment on the contribution of the rainfall variability for crop genetic erosion as the rainfall pattern concentrated to uni-modal distribution even with negative trend and variability.

- ✓ Sorghum exhibits the largest year-to-year variability in terms of area cultivated, total production and yield compared to the other cereals (Woldamelak Bewket, 2011). This high inter-annual variability is caused mainly by inter-annual variability in rainfall. As sorghum is cultivated in semiarid and arid parts of the region, it is particularly vulnerable to the vagaries of weather. So, relevant and periodical Central Statistics Authority data should be compiled in terms of crop area coverage trend in Ethiopia to evaluate the impacts of climate change on dominant crops. Generally, the correlation between rainy season and the crop is common but figure indicated annual base became poor predictor of yield and total outputs.

- ✓ Farmers have been experiencing change in their farming strategies by shifting to more drought-resistant crops as well as to a shorter agricultural calendar as consequences of a loss of the spring rains since the last 20–30 years and as a shorter main summer wet period (Adugna Abdi, 2009). On the other hand, traditional agricultural production which is highly diverse and is the main source of food for population has been contributing to adaptive strategies. However, comparative advantages of the coping strategies of the farmers are not well documented.

Policy implications and recommendations

- The country's strategy such as the National Biodiversity Strategy and Action Plan (NBSAP) has set the overall biodiversity goal of the country as "the establishment of effective systems provides for the equitable sharing of the costs and benefits arising there from, and that contribute to the well-being and security of the nation". The NBSAP (2005) identifies four strategic objectives (highest priorities of biodiversity conservation for Ethiopia), and 23 specific objectives which are followed by one or two actions for the achievement of the overall goal. One of the four strategic objectives is on agro-biodiversity, which aims to conserve the rich agro-biodiversity of the country through a mix of *in situ* and *ex situ* programmes (Fassil Kebebew, 2010; NBSAP, 2005).As a result of several studies cited by Fassil Kebebew (2010), agro-biodiversity will only be maintained if the country mainstreams agro-biodiversity conservation into production systems and landscapes through strategies that simultaneously promote food production and biodiversity conservation. However, there is a huge absence of mainstreaming initiatives in the country that ensure the conservation and sustainable use of Ethiopia's biodiversity in the face of changing climate circumstances.
- At the higher level, the Government of Ethiopia has signed and ratified all the Rio Conventions, namely the United Nations Framework Convention on Climate Change (UNFCCC), United Nations Convention on Biological Diversity (UNCBD) and the United Nations Convention to Combat Desertification (UNCCD). However, the magnitude and direction of climate change especially of increasing temperature has critical impact on Ethiopian agriculture and its biodiversity which requires policy implication worth thinking (Adugna Abdi, 2009). As a result, implementation and update of national policies for environmental protection and safeguards, genetic resources conservation and sustainable utilization and community knowledge management need to be strengthened in line with the changing climate scenarios.
- Reliance on few, poorly adapting crop varieties with no genetic variability within has led to seed production system not conducive to evolutionary flexibility. Improving evolutionary flexibility of species and varieties through adapting to ultimately evolve with climate change and prevent extinction should urgently come into action. Indigenous

crop species which have already developed adaptive traits with the greatest genetic variability and evolutionary flexibility should be conserved. Scaling up of conservation strategies across the nation is important, both *in-situ* and *ex-situ* conservation strategies.

- Farmers cared not only about the productivity of the crop varieties but also about environmental adaptability and yield stability. The extension system should not stick only to increasing productivity or profitability; risk reduction should be part and parcel of an extension system.
- Negative relation between diversification and extension contact urges that production under risk should be made part of farmers' training and extension programs brought in to improve the efficiency of the individual farm. So, the agricultural intensification policy should equally support the value of crop biodiversity in the farming systems including the attention of access to market information and linkage.

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Agro-Biodiversity (Livestock): Climate Change Adaptation, Mitigation, Vulnerability and Risks

Introduction

Agricultural production is highly affected by climate change and variability. Change in the level and distribution of rainfall, temperature, humidity can have serious implication on agricultural production including both crop and livestock. One major way to adapt to or mitigate the effect of climate change is making use of agro-biodiversity. Agro-biodiversity includes the diversity of plants, animals, fish, trees and microbes that are used directly or indirectly for food and agriculture (Rudebjer *et al.*, 2011). Crucially, agro-biodiversity concerns three levels of genetic diversity: agro-ecosystems, species (inter-specific diversity) and within-species (intra-specific diversity) (Rudebjer *et al.*, 2011). The diversity enables plant and animal species to adapt to different conditions since it encompasses the genes that will be needed to adapt varieties and species to the new conditions in any given future climate (Rudebjer *et al.*, 2009). Whether a particular population will survive or go extinct will depend on its potential to adapt to new environmental conditions (Pulido, 2007). However, the fast rate at which the change in climate takes place is beyond the ability of organisms to genetically adapt to the changes. As a result climate change now poses one of the principal threats to the biological diversity of the planet and it is one of the dominant drivers of biodiversity loss. This loss is occurring while it is still unknown which genotypes contain significant genetic diversity or specific genes that should be targeted for conservation and/or incorporation into breeding programmes (FAO, 2007). Actions to mitigate and adapt to the climate change is required to maintain agriculture in general and agro-biodiversity in particular. Since other components of agriculture and biodiversity are to be dealt in other sections, in this review, focus will be given to crops and livestock diversity in relation to climate change.

Livestock diversity and climate change

Background

Ethiopia has the largest population of livestock in Africa and is endowed with ample livestock diversity. Population wise there are about 55 million cattle, 28 million goats, 27 million sheep, 1.1 million camels, 2 million horses, 7 million donkeys and 51 million chickens (CSA, 2014). Except in chicken and cattle where exotic and their crosses contribute about 2.2 and 1.3 per cent of the population, respectively, the livestock population is almost entirely composed of indigenous animals (CSA, 2014). The country has served as gateway to Africa for livestock species from their center of domestication. In addition a recent study has indicated that Ethiopia is among the centers of domestication for donkey (Kefena Effa *et al.*, 2014). Due to presence of extensive variation in physico-geography and climate, further adaptive changes have taken place since the introduction and domestication of cattle, sheep, goats, camels, donkeys, horses and chickens. As a result of the adaptive changes, sizeable intra-species diversity has been created. In this review, the livestock diversity of the country has been assessed in relation to its implication to climate change adaptation and mitigation.

Objective

- To review existing literature pertaining to livestock diversity and climate change
- To suggest possible avenues towards adaptation and mitigation through use of livestock diversity.

Scope of the review

This review is limited to livestock diversity in relation to climate change and is based on available literature nationally and elsewhere in the world. It assesses existing information on livestock biodiversity in relation to climate change and provides recommendations on future directions and gaps to be filled. In addition to literature on local works, information from scientific studies elsewhere have been utilized to indicate potential technological options towards adaptation and mitigation.

Livestock diversity in Ethiopia

The numbers of indigenous breeds/populations/ecotypes of cattle, sheep, goat, camel, donkey, horse and chickens identified so far are 28, 9, 8, 7, 6, 8 and 7, respectively (EBI, 2014). Major exotic genotypes include 2 breeds of cattle (Holstein-Fresian and Jersey), 2 breeds of sheep (Dorper and Awassi), 3 breeds of goats (Boer goat, Anglo-Nubian and Toggenberg) and a number of chicken (White leg horn, Rhode island red, Fayoumi, Koe-Koek, etc.) genotypes (EBI, 2014; Halima Hassen, 2007; Solomon Gizaw *et al*, 2013, Solomon Abegaz *et al*, 2014). In addition to the livestock, there are about 5 honeybee races which are economically important. The diverse livestock genetic resources are adapted to various agro-ecological conditions of the country.

Indigenous cattle breeds/populations: Cattle breeds identified so far are Arsi, Begayit, Ogaden, Borena, Goffa, Arado, Nuer, Gurage, Jidu, Karayu, Afar, Harar, Horro, Simada, Fogera, Mursi, Raya-Azebo, Adwa, Jem-Jem, Sheko, Ambo, Jijiga, Bale, Hammer, Medenece, Irob and Abergelle (DAGRIS) and Begaria (EBI, Unpublished).

Indigenous sheep breeds: Major sheep breeds found in Ethiopia are Gumuz,Horro, Arsi, Short fat tailed (incudes Menz, Wollo, FartaTikur and Sekota populations), Bonga, Afar, Washera, Semien and Black Head Somali (formerly known as Black Head Ogaden) (Solomon Gizaw *et al.*, 2007).

Indigenous goat breeds:-Major goat breeds existing in the country are Abergelle, Afar, Somali,Arsi-Bale, Woyito-Guji, Keffa, Highland and Gumez goats (Tesfaye Alemu, 2004).

Equine populations: Donkey populations that exist in the country are the Abyssinian, Afar, Hararghe, Omo, Ogaden and Sinnar donkeys (Kefena Effa *et al.,* 2011). Major populations of horses that have so far been well recognized are the Abyssinian, Bale, Borana, Horro, Kafa, Kundido feral, Ogaden/Wilwal and Selale-Oromo horses (Kefena Effa *et al.*, 2012).

Camel populations: Ethiopian camel have been classified into 7 populations. These are Gelleb, Hoor, Jijiga, Amibara, Mille, Liben and Shinile (Yosef Tadesse *et al.*, 2014). The classification needs further refinement based on molecular methods.

Indigenous chicken ecotypes/populations: Indigenous chicken identified so far are Horro, Jarso, Tililli, Tepi, Cheffe (Tadelle Dessie, 2003), the naked-neck, Guangua, Melo-Hamusit, Gelila, Debre-Elias, Gasay/Farta, Mecha (Halima Hassen, 2007), Mandura and Sheka (Nigussie Dana, 2010). Additional works have also been done by large number of researchers (e.g. Reta Duguma, 2006; Addis Getu *et al.*, 2014) but their data require meta-level analysis to avoid naming the same population differently and to arrive at a clear list of the indigenous chicken genotypes in the country.

Honeybee races:-Excluding the singles bees (meliponini), so far five geographical races of honeybees (A*. m. monticola*, *A.m. jemenitica*, *A. m. bandasii,A. m. scutellata* and *A. m. woyi-gambela*) are known to exist in the country (Amssalu Bezabih *et al.,* 2004).

Major drivers of change on Livestock Animal biodiversity

Domestication of livestock started several millennia ago and humans have shaped the genetic make-up of domesticated animals to respond to human needs in different production environments. This genetic make-up of livestock that resulted from this long-term process has been put under stress by fast-paced changes over the past few decades, across the entire range of biophysical, social and economic contexts in which humans keep animals. Globally economic development and globalization; changing market demands and the "livestock revolution"; environmental impacts including climate change (Berry, 2009); and science and technology trends are important drivers of change in the livestock systems (Seré. *et al.*, 2008). Nationally economic and market drivers; human population growth; poor livestock sector policies; lack of functional institutions; disease and disease control; loss (change) of production environment; replacement of breed functions and climate change are implicated for loss of livestock diversity.

Unlike other factors which have local or national impact, climate change is a global threat to animal diversity (FAO, 2009). Global climate change is having a major impact on the viability of species and it is predicted to become a major threat to biodiversity in the 21st century (Dawson *et al*, 2011). Climate change is important driver for the emergence and spread of vector-borne parasites to new habitats (Harrus and Baneth, 2005). In the past decades climate change has resulted in frequent drought which caused significant loss of animals in pastoral areas. In addition restocking efforts after occurrence of disaster with breeds/populations other than the original, increased mobility to further areas where interbreeding with other populations can occur, change towards more adaptive species (e.g. cattle to camel, sheep to goat), increased bush encroachment (reduced range productivity and causing change from grazers to browsers) of grazing lands has significantly affected the animal genetic resources in pastoral and agro-pastoral areas. Introduction of exotic germ-plasm mainly in cattle and chicken and, to a lesser extent, in sheep and goats has been among the drivers of change in mixed crop-livestock production system. In the future, it is likely for the trend to continue but mitigation and adaptation measures are also expected to increase.

Impact, vulnerability and risks

Impact of climate change on livestock diversity

Climate change is predicted to increasingly affect the livestock sector in the coming decades, with potentially harmful consequences for production and for livestock genetic diversity. Producers will have to cope with both slow climatic changes and more frequent extreme weather events (Hoffmann, 2010). In turn, livestock contributes to climate change. Therefore the livestock sector is crucial for mitigating and adapting to climate change.

Frequencies of heat stress, drought and flooding events are likely to increase, and these will undoubtedly have adverse effects on crop and livestock productivity over and above the impacts due to changes in mean variables alone (IPCC, 2007). Despite lack of adequate research-based information within the country, major changes can thus be anticipated in livestock systems and this may include species replacement/loss and reduced within species variability.

Loss of animal genetic resources reduces opportunities to develop rural economies. It may also have negative social and cultural impacts, given the long history of domestication and the resulting incorporation of domestic animals into community cultures. Replacement of indigenous breeds could result in the loss of products and services preferred by local people, and the conservation of local breeds must, therefore, be considered within the broader context of sustaining rural communities and their existing economic foundations. The lion's share of live animal export of the country occurs from arid and semi arid areas where climate change can have significant impact on the survival of the breeds adapted to these areas. Determinations of optimal off-take along with developmental activities to increase the off-take rate and maintain export level are critical to contain such effects. In addition to impacts mentioned above, losses in livestock diversity may limit future development options based on animal products and services from specific breeds that otherwise could have added considerable micro- and macro-economic values as consumer demands become more varied. In some production environments, the loss of local breeds may have negative environmental impacts especially in dry lands and mountainous areas. Properly managed locally-adapted breeds play significant roles in landscape management, bush control and rangeland ecosystem sustainability.

In Ethiopia various droughts have occurred in the recent past. Drought affects pastoral and agro-pastoral livestock systems essentially by reducing the amount of forage available and thereby leading to the death of livestock. It may also directly kill livestock through lack of drinking water. By weakening livestock, drought may also increase their vulnerability to a range of animal diseases, both during the dry phase and also during a succeeding recovery phase when internal parasites may flourish in the ensuing rainy conditions. From an interview of pastoralists in various parts of Ethiopia Yosef Tadesse *et al.* (2013) have reported estimated loss ranging from 45 to 70% cattle in each of a series of droughts. The livestock in pastoral areas are important resources in that they are adapted to survival under marginal environmental conditions and contribute to adaptation to climate change. But recent changes are rapid and beyond the adaptive capacity of the animals and significant losses have occurred (Table 1). In addition to that, the change has caused change of species from less adapted to more adapted ones, and from grazers to browsers. In Borana area with occurrence of frequent drought, the camel population has increased while cattle population has shown reduction (Table 2 and 3).

Table 1: Quantified Impacts of Selected African Droughts on Livestock (1981-1999)

Year	Place	Impact	Source
1983-84	Ethiopia (Borana Plateau)	90% of calves, 45% cows, 22% mature males	Coppock, 1994
1983-85	Ethiopia (Borana)	37% of cattle	Solomon Desta and Coppock, 2002
1991-93	Ethiopia (Borana)	42% of cattle	Solomon Desta and Coppock, 2002
1995-97	Greater Horn of Africa (average of 9 areas)	29% of cattle, 25% of sheep and goats	Ndikumana *et al.*, 2000
1995-97	Southern Ethiopia	78% of cattle, 83% of sheep and goats	Ndikumana *et al.*,2000
1998-99	Ethiopia (Borana)	62% of cattle	Shibru 2001 cited in Solomon Desta and Coppock, 2002

Source: Alive, undated.

Table 2: Trends of camel population dynamics in the past 20 years in the Borena area of Ethiopia

Sites	Current camel number	No. of respon-dents	Percent	Camel no. before 20 years	No. of respon-dents	Percent
Borena (Yabelo)	5-10	7	26.9	5-10	4	15.4
	10-15	18	69.2	Absent	22	84.6
	>15	1	3.85			
Borena (Moyale)	<10	9	36.0	<10	6	24.0
	10-20	12	48.0	Absent	19	76.0
	>20	4	16.0			

Source: Yosef Tadesse *et al.*, 2013

Table 3. Trends of cattle population dynamics in the past 20 years and the future projection in the Borena area as reported by pastoralists

Sites	Current cattle no.	No. of respon.	Perc.	Cattle no. before 20 years	No. of respon.	Perc.	Future projection	No. of respon.	%.
Borena	<15	7	26.9	60-80	12	46.2	Decrease	26	100
(Yabelo)	15-40	18	69.2	>100	4	15.4			
	No cattle	1	3.85	40-60	6	23.1			
				20-40	4	15.4			
Borena	<15	10	40.0	40-60	11	44.0	Decrease	25	100
(Moyale)	15-40	12	48.0	>60	4	16.0			
	No cattle	3	12.0	20-40	6	24.0			
				10-20	4	16.0			

Source: Yosef Tadesse *et al.*, 2013

Drought will cause overgrazing (due to reduction in the amount of available vegetation), mass migrations and concentrations around food and water resources and as a result, there could occur increase of Foot and Mouth Disease (FMD), Peste des Petits Ruminants (PPR) and Contagious Bovine Pleuropneumonia (CBPP). Tsetse flies and ticks habitat will be modified and the repartition and spread of the disease will change. In East Africa, climate change would result in an increase in available habitat and thus a possible expansion of the overall range of tsetse, particularly into high-altitude areas that may currently exclude the species owing to low temperatures (Rogers and Randolph, 2006). By contrast, other reports have suggested a net decline in the distributional range of the tsetse species. For example, under various future climate change scenarios *Glossina morsitans* is expected to experience a reduction in suitable habitat and hence a contraction of its geographic range (Hulme, 1996 as cited in Reta Duguma, 2009). Other study (McDermott *et al.*, 2002) has also indicated that the impacts of climate change on tsetse distribution and trypanosomiasis risk in five agro-ecological environments in sub-Saharan Africa up to 2050, will tend to contract areas under trypanosomiasis risk The risk of animal trypanosomiasis will also decline in many but not all areas of Ethiopia and eastern and southern Africa. Despite the need for further studies to clarify the conflicting evidences, both the expansion and contraction can have impact (positive or negative) on the livestock diversity.

Gender aspect of impact of climate change on livestock biodiversity

The importance of livestock diversity to individuals can vary based on gender. Therefore, we need to incorporate gender dimensions into our understanding of livestock biodiversity and climate change. (CBD, 2010). Women in rural areas are important both as participants and beneficiaries of Animal Genetic Resources conservation activities (Nigatu Alemayehu *et al.*, 2004) and frequently there is a clear gender differentiation in roles and responsibilities in agriculture causing men and women to be responsible for the management of different aspects of agro-biodiversity (FAO, 2005). As a consequence, its equitable recognition and economic reward is a key issue in the sustainable management of agro-biodiversity (Padmanabhan, 2005).

Just as the impact of biodiversity loss is disproportionately felt by poorer communities, there are also disparities along gender lines. Environmental changes and conflicts impact men and women differently in the light of their gender roles and socio-cultural situation. More often than not, environmental degradation and the consequences of climate change or natural disasters reinforce existing gender discrepancies (Adelphi Research gGmbH and Germanwatch, 2007). Biodiversity loss affects access to education and gender equality by increasing the time spent by women and children in performing certain tasks, such as collecting valuable resources and services such as fuel, food and water. To conserve biodiversity, we need to understand and expose gender-differentiated biodiversity practices, gendered knowledge acquisition and usage. Both men and women benefit from the direct use-values obtained from keeping livestock. However, men often focus on income values, obtained through commercialization of livestock products or animals, whereas for women, in many cases, the non-income values are of greater importance (Anderson, 2003 as cited by FAO, 2005). The non income values mainly include food sources such as milk and egg. With loss of livestock as a result of disaster it would be relatively easier for male to get alternative income by migrating to other areas while women suffer the consequences. In pastoral areas where livestock are the major sources of livelihood, loss of livestock or reduction in productivity and can have immense impact on household food security, mainly on women.

Vulnerability of livestock biodiversity to climate change

Climate change has its major effect in marginal areas such as arid and semi-arid areas. The pastoral and agro-pastoral areas of Ethiopia are subjected to more frequent drought than the mixed crop livestock production system. These areas are known for their unique and adapted domestic animal genetic resources. As elsewhere in the world, many livestock breeds originate in drylands, providing a genetic reservoir whose importance is increasing as climate change drives the demand for new adaptations and extinctions of wild breeds (Davies *et al.*, 2012). However the extreme climatic conditions which occur in these areas create higher vulnerability as alternative livelihoods are limited. Afar, Ogaden and Boran cattle have experienced serious loss during drought (Sandford and Yohannes, 2000 as cited by Zerabruk Merha *et al.*, 2012). This is on top of other drivers which lead to loss of livestock diversity. Out of large number of breeds of cattle which are found in Africa some are being replaced by exotic breeds (Sceincedaily, 2010). These losses weaken breeding programs that could improve hardiness of livestock including adaptation to climate change impacts (FAO, 2005). For example, local chickens have more sustained egg production at times of increased environmental temperatures and better fertility of eggs compared to modern industrial breeds (Teketel Forssido, 1986) and can contribute to impart such adaptive qualities into the commercial breeds.

Adaptation, mitigation and managing risks

Past and current initiatives

The Ethiopian Institute of Biodiversity has a mandate to characterize, conserve and sustainably utilize genetic resources along with access and equitable sharing of the benefits from the resources. In the past, biochemical and morphologic traits related to adaptation have been studied on three cattle breeds and sizeable differences have been observed in the variables among the breeds adapted to different agro-ecologies (EBI, Unpublished data). Abera Melesse (2000) has identified biochemical parameters (triiodothyronine. T3; Corticosterone) which have relevance towards adaption to heat stress in Ethiopian naked neck chicken and their crosses with other exotic breeds. Verdal *et al.*, (2013) studies have indicated that genetic selection of broilers for digestive efficiency reduces poultry excretion and is a possible way to reduce the environmental impact of production over the whole rearing period without a negative impact on growth, body composition, or meat quality.

As part of Climate-Resilient Green Economy (CRGE) initiative, the Government of Ethiopia has identified an efficient livestock sector (mainly cattle value chain efficiency) among the three 'green economy' initiatives for fast-track implementation (Million Tadesse *et al.*, 2014). As GHG emission related to animal is negatively correlated with productivity and production the cattle value chain efficiency is aimed to lower the growth of cattle population by 17 million heads through increased productivity and production efficiency across the animal value chain of small holder farmers and pastoralists (Million Tadesse *et al.*, 2014). The initiative involves the use of both indigenous and exotic animals in mixed crop-livestock production system and only existing indigenous animals in pastoral areas. Additionally, promotion of low emitting animals (poultry in particular) as producer of animal protein (meat and egg) has also been identified as an important activity in the CRGE initiative.

The role of the farm animal diversity in adaptation

There is sizeable inter and intra-species variation in adaptation of livestock to change and variability in climate. The adaptations arise from variations in physiological, behavioral and morphological differences (Abera Melesse, 2000; Mengistu Urge, 2007; Zewdu Wuletaw, 2010,). Such variation can be exploited towards adaptation to climate change, particularly increased temperature and water stress. Despite within breed variation in almost all livestock breeds indigenous animal genetic resources are more suited for utilization under such conditions than many exotic high producing animals which were selected for higher production under intensive management. Utilization of classical genetics that also includes introduction of heat tolerant genes into less heat tolerant breeds is among a series of approaches to partially alleviate harsh environmental stresses on productivity and fertility of lactating dairy cows (Thatcher *et al.*, 2010). Study elsewhere has shown that heat tolerance Predicted Transmitting Ability (PTA) of sires ranged from -0.48 to 0.38 kg milk/ temperature humidity index (THI) unit above 72/d; milk yield PTAs for sires were between -8.9 and 7.9 kg/d (McGlothlen *et al.*, 1995).

Since genetic variance for heat tolerance exists in dairy cattle, there is the likelihood that specific genes controlling heat tolerance can be introduced into the gene pool of the population. One such gene is the slick hair gene (*slick hair*) originally described in Senepol cattle, subsequently identified in Carora cattle, and introduced into Holsteins by crossbreeding (Olson *et al.*, 2003). The gene has been mapped to chromosome 20 (Mariasegaram *et al.*, 2007). Animals with the dominant allele have a very short and sleek coat. Holstein (75%) x Carora (25%) crossbred dairy cows in Venezuela with slick hair coats had lower body temperatures in heat stress conditions than those with the wild-type hair coat (38.58°C < 39.09°C) and produced more milk (6 389 > 5 579 kg, 305-d milk yield; Olson *et al.*, 2003). The superior thermoregulatory ability associated with the slick phenotype is apparently the result of increased convective and conductive heat loss and decreased absorption of solar radiation. During heat stress, slick haired lactating Holstein cows had lower vaginal temperatures and respiration rates than wild-type lactating cows (Dikmen *et al.*, 2008) and greater sweating rates. Consequently, the slick hair gene is a candidate gene for incorporation into dairy cows that would improve regulation of body temperature and production potential in heat stress environments. Such genes can be looked into or introduced in the indigenous breeds of Ethiopia and made use of in conventional breeding or using molecular techniques.

Differences between thermal-adapted breeds and non-thermal adapted breeds extend to early developmental stages of the embryo (Hansen, 2007). *Bos indicus* embryos are less adversely affected by elevated temperature in culture than Holstein or Angus embryos. Furthermore, B*os taurus x Bos indicus* embryos, in response to an *in vitro* heat shock, have a higher rate of blastocyst development acquired through *Bos indicus* genes that contribute to the presence of thermotolerance factors from the oocyte or imprinting of certain embryonic paternal genes. With the known gene sequences of the bovine genome, future identification of heat tolerance genes of *Bos indicus* breeds offers the potential of introducing these genes into less heat-tolerant breeds. The *Bos indicus* breeds of Ethiopia are important assets in this regard.

With regard to water stress, Zewdu Sisay (1991) has reported that weaned male young Black Head Somali (BHS) lambs can be watered only once in three days without significant effect on production and up to once in six days without significant effect on survival. This is an important adaptation to water deprivation in BHS and can be utilized in adaptation to climate change caused water stress. Mengistu Urge (2007) has also reported that Ethiopian Somali goat rapidly adjusts to water shortage and starts to economize on water when subjected to a prolonged period of intermittent watering, and suggested that this unique adaptability need to be considered in breeding programs aimed at increasing the comparatively moderate milk production of the breed in arid and semiarid areas to which the breed is adapted to. Addis Getu *et al.* (2014) indicated the dominant existence of naked neck chicken in very hot areas of North Gondar.

The adaptive variation between and within species is not limited to heat tolerance and water stress. Breeds of livestock have been reported to have adaptation to graze on marshy areas during longer period of flooding (e.g. Fogera cattle; Zerabruk Merha *et al.*, 2007), trypanotolerance (e.g. Sheko cattle; Stein, 2011), and tolerance to drought and feed shortage (e.g. Afar cattle; Zerabruk Merha *et al.*, 2007). Such traits can be used towards adaptation to climate change. In goats significant breed differences were found for Lymphocytes, Neutrophils and Basophils which are suggestive of the existence of breed variation (Markos Tibbo *et al.*, 2004) and can have implication towards tolerance of disease epidemics related to climate change.

Mitigation and risk management options

As livestock make significant contribution to green house gases (GHG), they all play important role towards mitigation. The choice of origin and genetic set up in stockbreeding to breed livestock with higher N use efficiency or to improve individual animal performance to reduce the methane produced per unit of product can result in a significant reduction of total GHG emission in the future livestock and poultry sectors (Weiske, 2005). Sizeable reductions of CH_4 have been estimated by genetic improvement (Mosier *et al.*, 1998). There is a possibility of less N amounts in manure as result of genetic merit for higher N use efficiency.

The type of production system has also bearing on the mitigation potential. According to several studies extensive systems reduce the GHG emissions per animal or defined areas compared to intensive systems. Crutzen *et al.* (1986) suggest a lower average annual emission value of 35 kg CH_4 per animal for cattle under extensive management compared to 55 kg CH_4 under intensive management. However the most cost effective reduction are those that intensify production per animal and make more extensive use of land per animal under intensive management. This is also the case for extensive and intensive systems for sheep (5-84 kg CH_4 per animal) and swine (1-1.5 kg CH_4) per animal. This less intensive production has various positive environmental side-effects such as wildlife benefits, animal welfare benefits, improved soil structure etc. One additional way is to opt for placing the livestock sector as an integral part of any solution to climate change and this can result to contribution that can be readily reduced by up to one third(Gerber *et al.*, 2013)

Technological options for each of the five IPCC greenhouse gas emission categories/sectors namely; Energy, Agriculture, Land use change and forestry, Industrial processes and Waste are given in the Climate Change Technology Needs Assessment Report of Ethiopia (NMA, 2007). Land-use, land-use change, and forestry activities (afforestation, reforestation, avoided deforestation, and improved forest, cropland, and grazing land management practices) and implementation of renewable energy sources (hydro-, wind-, geothermal and solar power and biofuels) are important in mitigation of climate change (Gitay *et al.*, 2002). The livestock sector being a major contributor of GHG emissions is one of the targets of any mitigation action (Rivera-Ferre and Lopéz-i-Geltas, 2012).

Herbivores, especially ruminants that consume materials inedible by humans, are important for human food in the future. However, their diet should not be just ground-level plants. Silvopastoral systems, pastures with shrubs and trees as well as herbage, are normally more productive than pasture alone. When compared with widely used livestock production systems, silvopastoral systems can provide efficient feed conversion, higher biodiversity, enhanced connectivity between habitat patches and better animal welfare, so they can replace existing systems in many parts of the world and should be further developed (Broom et al., 2013). The advantages of silvopastoral systems for increasing biodiversity, improving animal welfare, providing good working conditions and allowing a profitable farming business (Table 4) are such that these systems are sustainable where many other large herbivore production systems are not (Broom *et al.*, 2013). Such systems make sizeable contribution in terms of carbon sequestration while at the same time contributing to sustainable use of diverse livestock.

Soil organic Carbon (SOC) sequestration by the world's permanent pastures could potentially offset up to 4% of the global greenhouse gas (GHG) emissions. To increase SOC sequestration on rangelands generally requires improved grazing management, introduction of legumes, and control of undesirable species. A meta-analysis of 115 studies in pastures and other grazing lands worldwide (Conant *et al.,* 2001), indicated that soil C levels increased with improved management (primarily fertilization, grazing management, and conversion from cultivation or native vegetation) in 74% of the studies considered (Soussana, 2008).

Table 4. Effect of pasture management system on emission of methane (Source: Broom et al., 2013)

Measure	Conventional Extensive pastures	'Improved pastures' without trees	Intensive silvopasto-ral system
Animal load (large animals ha^{-1})	0.5	1	3
Per animal weight gain (kg day^{-1})	0.37	0.5	0.75
Per hectare weight gain (kg ha^{-1})	0.185	0.5	2.25
Average methane emission (kg ha^{-1} $year^{-1}$)	15.5	38	105
Annual meat production- live-weight ((kg ha^{-1} $year^{-1}$)	67.5	182.5	821.3
Methane emission per tonne of meat (kg ton^{-1})	229.5	208.2	127.9
Land area required to produce a tonne of meat per year (ha)	14.8	5.5	1.2

The carbon sequestration potential by grasslands and rangelands could be used to partly mitigate the greenhouse gas emissions of the livestock sector. This will require avoiding land use changes that reduce ecosystem soil carbon stocks (e.g. deforestation, ploughing up long term grasslands) and a cautious management of pastures, aiming at preserving and restoring soils and their soil organic matter content. Combined with other mitigation measures, such as a reduction in the use of N fertilizers, of fossil-fuel energy and of N rich feedstuffs by farms this may lead to substantial reductions in greenhouse gas emissions per unit land area. Trade-offs between greenhouse gas emissions and animal production need to be better understood at the farm and regional scales through a continued development of observational, experimental and modeling approaches (Soussana. 2008).

Substantial emission reductions can be achieved across all species, systems and regions. Mitigation solutions will vary across the sector as emission sources, intensities and levels vary amongst species, production systems and regions, but the mitigation potential can be achieved within existing systems; this means that the potential can be achieved as a result of improving practices rather than changing production systems (i.e. shifting from grazing to mixed or from backyard to industrial). This has important implication for conservation of indigenous livestock.

Mitigation can also be achieved by improving animal efficiency. The diversity in the animal genetic resources contributes to variations in efficiency either between or within species. Poultry are more efficient in producing animal protein (meat and egg) as compared to small ruminants or cattle (Figure 1). There is also sizeable between or within breed variation. Exotic dairy breeds are more efficient in terms of milk production. Despite higher feed consumption per head in exotic animals, feed utilization per unit of product (e.g. per liter of milk) is lower. In addition to difference between species, Figure 1 shows that there is variation (height of the bars) in GHG emissions within the same commodity (species). This indicates that there is a big opportunity for mitigation. Measuring efficiency for comparison purpose can be done by using residual feed intake or feed conversion efficiency.

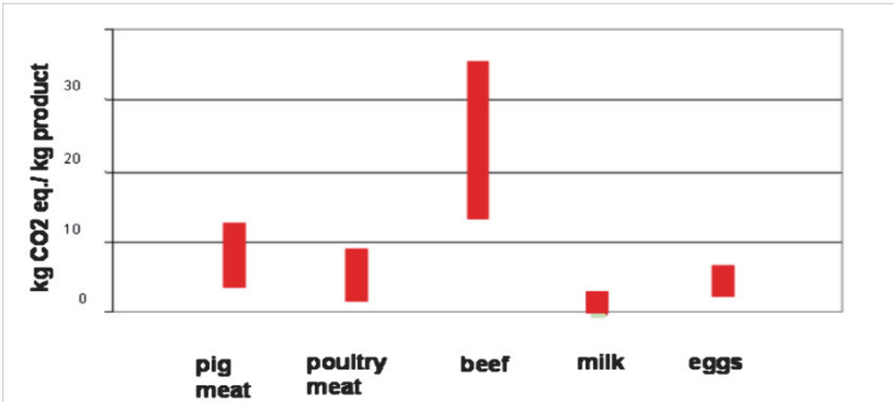

Figure 1. The GHG emissions per kg of product for meat from pigs, poultry and cattle and for milk and eggs, based on livestock production systems in OECD countries (Source: Vries and & de Boer, 2010).

Information, data gaps and research needs

Information and data requirements and gaps

Actions to deal with the harms of climate change and variability and the policy decisions that guide these actions require dependable basic data on emission rates across species and breeds of the various indigenous animals. In addition to that inter- and intra- species variations, quantified estimate of emissions under varying environmental conditions are required. These are lacking in Ethiopia. The adaptability of the diverse livestock genetic resources to the various challenges pertaining to climate change and variability needs to be known. There is also need to quantify the 'cost' to the animal of such adaptation. Possible avenues of adaptation and mitigation relevant to livestock diversity need to be tested for their efficacy and efficiency. Available indigenous coping mechanisms need to be identified and the relationship of these mechanisms with the level of emission and the way these can be integrated with other actions needs to be determined. In a survey of climate related research in the country (Brook Lemma, 2014), it was shown that very few have addressed biodiversity and none has addressed livestock diversity directly. Coping mechanisms developed over generations can be important to have effective adaptation and understanding of available indigenous knowledge is important. Out of 191 research activities, only one focused on indigenous knowledge (Brook Lemma, 2014) showing the need to strengthen research in this area with focus on livestock diversity. Gender relations and their linkages with agro-biodiversity is far more complex and ways must be found to tap women's knowledge, needs and requirements, and to determine their commitment and contributions to agro-biodiversity management (FAO, 2005).

Research needs

Research should focus to fill the information and data gaps identified above. Adaptive research towards making use of technologies developed elsewhere and which have relevance to climate change adaption and mitigation as related to agro-biodiversity in general and livestock diversity in particular need to be areas of focus for research. The following aspects are important research areas:

- Quantifying production efficiency of the various species and breeds of livestock
- Quantifying emission rates of the various livestock species and breeds under varying environments
- Characterizing the various species and breeds of livestock for adaptive traits
- Testing efficacy of various technologies which have relevance towards reducing the impact of climate change on livestock biodiversity. This include determination of emission reduction potential, environmental side-effects, technical feasibility and the specific costs
- Finding ways of building complementarities between agriculture and biodiversity.

Policy implications and recommendations

Relevant policies on climate change in relation to livestock diversity

Including the constitution of the Federal Democratic Republic of Ethiopia (No.1/1995) there are various legislations and policies which have direct or indirect relevance to climate change and livestock biodiversity. Articles 43, 44 and 55 of the constitution have provisions for sustainable development and environment and these give the legal ground for public institutions dealing with the environment and biodiversity. The Environmental Policy of the country legislates the conservation and sustainable utilization of the country's environmental resources. Biodiversity is among the resources covered by the policy. The Growth and Transformation Plan (GTP) also addresses both appropriate climate change adaptation and mitigation measures. The National Adaptation Plan of Action (NAPA) and the Nationally Appropriate Mitigation Action (NAMA) have also components of biodiversity. In Ethiopia's Program of Adaptation to Climate Change (EPACC) by the former Environmental Protection Agency, biodiversity has been identified as one of climate change risks. In addition to that the climate resilient Green economy (CRGE) initiative of Ethiopia has important fast track activities which would pertain to livestock biodiversity.

Policy requirements and recommendations

Policies which have relevance towards climate change as pertains to livestock biodiversity need to focus on adaptation and mitigation strategies that serve both development and environmental objectives. Policies guiding judicious use of genotypes in relation to the environment they are to be maintained, which address long term consequences of such use need to be put in place. Identification of areas and genotypes for implementation of either intensive or extensive system should be guided by clear policies, and the legislation of a livestock breeding policy in this regard cannot be overemphasized.

Much of the mitigation potential in the livestock sector is achievable by using available practices that improve production efficiency, which can reduce emissions while supporting social and economic goals such as improving food security and income generation. In turn, mitigation policies that focuses on strategies that are able to deliver private benefits, are likely to enjoy greater success and uptake (Gerber *et al.*, 2013). Additionally making use of the possible variation between and within species for the purpose of adaptation and mitigation of climate change is worthy of policy focus. In general, policies relevant to climate change in relation to livestock diversity need to be integrated in sectorial policies (e.g. agricultural, livestock development), making these sectors responsible for carrying out the adaptation and mitigation strategy. The gender aspect of livestock biodiversity in relation to climate change is important for effective adaption and mitigation and addressing the issue also need policy support. The following points are also important aspects which need policy focus.

- Ensuring public participation in the conservation of livestock diversity and use for mitigation and adaptation to climate change
- Incentives for effective use of indigenous genetic resources in marginal areas
- Development of markets through enhanced consumer demand for the diverse indigenous animal resources
- Eliminating subsidies for exotic animals for distribution in marginal and extensive production areas

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