Journal of Sustainable Development in Africa (Volume 13, No.7, 2011)
ISSN: 1520-5509
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DRY, HOT, AND BRUTAL: CLIMATE CHANGE AND DESERTIFICATION IN THE SAHEL OF MALI

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ABSTRACT

This paper describes the connections and effects between climate change and desertification in the Sahel region of Mali as well as proposing mitigation strategies for sustainable development. Desertification is quickly becoming an environmental issue of increasing concern because of its complex relationship with and the implications of climate change. The Sahel, which runs through Mali, is especially prone to desertification as it is a fragile ecosystem easily affected by climatic changes and human activities. Mali is experiencing major problems, particularly because of a high population growth rate, intensive cultivation (agriculture and farming) methods and an increasing demand for resources, such as firewood, land and water. Mitigation to address these issues will have to be implemented both at the national level and enforced at the local level, forming and utilizing relationships between government departments, non-governmental organizations and other groups such as local community organizations. Current mitigation efforts include agroforestry, *Jatropha* cultivation and many other activities. Whatever action is taken, it must take cultural traditions as well as modern practices into consideration to ensure environmental stability and sustainable development.

Keywords: Desertification; Mali; Climate change; Sahel region; Agriculture; Sustainable development

NTRODUCTION

Mali is a dry, landlocked country in Northwestern Africa roughly twice the size of the state of Texas (1,240,000 square kilometers or 478,767 square miles) (U.S. Department of, 2010). Much of it lies in the Sahel region on the southern fringe of the Sahara Desert. The climate is arid in the north and subtropical in the southern part of the country with annual rainfall varying from around 1,400 millimeters in the south to 127 millimeters or less in the north (Library of Congress, 2005). The entire country is situated on a plateau. In the north, Mali's geography consists of mostly flat to rolling landscapes covered by sand and drought-resistant steppe vegetation slowly transitioning to savannas along with more varied topography to the south. Most of Mali's soil has a high clay content (especially prevalent in the ultisols and alfisols that are found in the southern half of the country and aridisols in the north) which holds moisture well but forms characteristic cracks and crevices during dry seasons. In addition, because of the high clay content, these soils can be prone to erosion, both through wind and water, often exacerbated through Mali's climate and anthropogenic activities (Library of Congress, 2005). In Mali's past, Timbuktu and Gao were once fabled trading centers for Trans-Saharan caravans. The capital Bamako is located in southeast Mali along the Niger River, which is used as a source of food, drinking water, irrigation, and transportation (Library of Congress, 2005).

Most of Mali's people live along the Niger River, which (due to a growing population and intensive cultivation methods) has caused a strain upon available water and arable land. In recent times, Mali has suffered from recurrent droughts killing tens of thousands of Malians and millions of cattle; such devastating events have been increasing in frequency and severity over the last century (Shoumatoff, 2006). Climate change may increase the risk of drought conditions and lead to accelerated desertification, a problem Mali shares with many other countries of the Sahel region.

Figure 1. Map of Mali
Note: Retrieved February 27, 2011, from https://www.cia.gov/library/ publications/the-world-factbook/geos/ml.html.

HISTORY AND BACKGROUND

Desertification is a word commonly seen especially in conjunction with climate change. However, the entire process that desertification tries to describe is quite complicated. Desertification encompasses various physical process such as declines in soil structure to losses of biodiversity and biomass to increased soil erosion by wind and water (Munn, 2002). In fact, the very definition of desertification has been debated for over thirty years by the United Nations Environment Programme (UNEP) (Munn, 2002). Definitions have ranged from the "spread of desert-like conditions in arid or semi-arid areas due to human influence or climatic change" to later versions which placed desertification as a product mainly caused by human activities in terms of destructive land use. The current definition (accepted by the United Nations Conference on Environment and Development) states that desertification is "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (Munn, 2002). In whatever way desertification has been defined, it remains a problem. From a global viewpoint, about half (approximately 28 million square acres) of the world's land surface is defined as "dryland," which includes plains, grasslands, savannas, steppes and pampas

(Shoumatoff, 2006). Of those 28 million square acres, 19 million square acres (67.8%) are quickly becoming desert or are currently threatened with desertification. These affected "drylands" are home to over 1.5 billion people in 100 countries, many of whom live in Africa. One of the areas that is experiencing the fastest rates of desertification is the Sahel (Shoumatoff, 2006) . This narrow, semi-arid band, which separates the Sahara Desert to the North and humid savannas to the South, stretches nearly 5,000 miles across the African continent from Mauritania to Sudan (Goudie & Cuff, 2002). The Sahel is a very fragile ecosystem as it is a transition zone in terms of climate and vegetation. In its most natural state, the Sahel is an acacia forest mixed with other small, thorny trees, shrubs and grassland. However, the vegetation cover can change dramatically from year to year as it is dependent upon the amount of rain, which in turn is highly variable because the Sahel possesses a monsoonal climate (Hulme & Kelly, 1993). Simply explained, the region's climate displays dramatic differences between seasons, with a "near 180˚ reversal of the prevailing wind direction," resulting in a few months of rainfall followed by dryness for the remainder of the year (Hulme & Kelly, 1993; Goudie & Cuff, 2002). In fact, Mali copes with some of the highest variations in rainfall sometimes changing between 200-300 millimeters (Economics, 2009). This can cause major problems, such as drought, considering that the Sahel region typically receives between 200 and 600 millimeters of precipitation per year (Leisinger et al., 1995; Library of Congress, 2005).

Despite the fluctuations in weather and drought-like conditions, Africans have survived in the Sahel for over 7,000 years through pastoralism (Brooks, 2006). Pastoralism, especially cattle domestication (which was estimated to have entered the Sahara around 6,000 years ago), was attractive as a lifestyle because it could more easily secure food resources in a climate that was often (and remains) harsh and unpredictable. The Sahara, which has direct influences upon the Sahel, has experienced long-term climate variability and was beginning to undergo another shift towards increasing aridity due to a collapse of the monsoon (which controls rainfall) around 7,000-6,000 years ago (Brooks, 2006). Cattle, as mentioned, became a favored commodity as they provided flexibility and communities could respond quickly in their search for water and pasture if the environment suddenly changed. Once the monsoon finally collapsed 5,000 years ago, cattle became confined to smaller areas and sedentary lifestyles and their associated economies became increasingly common. In fact, this led to the emergence of agriculture, approximately another 2,000 years later (Brooks, 2006). These sedentary lifestyles, which ranged from a combination of animal husbandry and agriculture to purely subsistence farming, greatly changed the state of the Sahel as they placed a greater demand upon resources which will be discussed later in this paper.

However, even with the appearance of agriculture, pastoralism remained strong throughout the Sahel region. Cattle, as mentioned earlier, were extremely important to pastoralists. In fact, the seeming obsession with these creatures was first coined "cattle complex" by anthropologists in East Africa; cattle were treated as nearly sacred and played a vital role in social activities and interactions. Livestock and cattle were foremost a commodity, but moreover a flexible, mobile commodity that functioned as "major wealth store" (Turner, 2009). As described by Mortimore and Adams, cattle and livestock were "a depository for savings, a reserve for contingencies, a self-reproducing asset, a source of current income, and a source of energy" (Mortimore & Adams, 2001). In addition, livestock and cattle provided a variety of useful products, such as milk, butter, fiber, traction, and manure throughout their lives and meat upon their demise (Turner, 2009). To support their livestock, pastoralists shifted their herds between northern and southern pastures in the Sahel (during the rainy season) and

then further south to cultivated areas for the remainder of the dry season. This in turn formed a strong, symbiotic relationship between nomadic-like pastoralists and more sedentary-like farmers. During the dry season, pastoralists needed pastures in the South to support their herd and farmers in return depended upon milk, butter, meat and other cattle products (Turner, 2009).

The Sahel (in addition to climate and vegetation) has also served as a cultural transition between pastoral livestock economies of Saharan people and the agricultural economies found south in the savannas. A broad range of cultures and languages mixed in the Sahel including Berber and Arabic speaking people from North Africa and various groups from further south (Leisinger et al., 1995). Different lifestyles, such as pastoralists and nomads, all came into contact with one another through trade despite the dry and arid climatic conditions. In fact, Mali itself is "the cultural heir" to the succession of several ancient African empires that dominated the trading scene, including the Ghana, Malinké, and Songhai (Leisinger et al., 1995). The Sahel's trade relied on a variety of goods such as salt, various millets and cereals, cotton, indigo, rice and even slaves. Slaves were quite a lucrative trade and raids were performed at specific times, usually during the dry season, so newly captured slaves could work to plant millet and other valuable crops at the beginning of the following rainy season (Leisinger et al., 1995; Library of Congress, 2005). However, during the colonial era the Sahel's trade, culture and environment changed drastically.

Towards the end of the 1800s, France began to penetrate the area of Mali by military force. In 1893, France went on to appoint a civilian governor for the conquered territory (then known as French Soudan) despite resistance from the Malians. The French pressed on and by 1905, most of Mali was under their control (Library of Congress, 2005). Naturally, the French were interested in using Mali for economic growth. However, many of the agricultural routines practiced by Malian farmers were seen as ineffective, especially brush firing (which in fact is very important since it spurs the growth of pasture and field vegetation) (Munn, 2002). As a result, the French implemented several policies (*colonization indigène*- native colonization) and practices (*mise en valeur*- development) to encourage correct, "rational" agricultural development (van Beusekom, 1999). The growth of crops such as cotton and rice were highly emphasized by the French. Plows- "the catalyst that would transform African agriculture"- as well as intensive plow agriculture and chemical fertilizers were introduced, all in hopes of increasing yield and efficiency. Other programs by the French included installations of major dams and flood plain agriculture, the most popular and lasting example being the Office du Niger, "a large-scale cotton and rice irrigation scheme in the Niger River valley" (van Beusekom, 1999). However, instead of combating soil degradation and desertification as observed by the French during the beginning 1900s, these issues only worsened. As Monica van Beusekom described, the plows that the French had introduced with great fervor ended up "[exacerbating] the very practice that the French sought to change, the regular clearing of new land for cultivation" (van Beusekom, 1999). The French greatly lacked knowledge about tropical agriculture, mixing both irrigated and dryland conditions for intensive agriculture. Under the French programs that sought to properly "develop" agriculture, yields began to decrease and many traditional, sustainable practices from Malian farmers such as crop rotation and green manuring were discouraged. Malian farmers went bankrupt trying to provide nutrients for their crops with expensive chemical fertilizers that only further degraded the soil (van Beusekom, 1999). Even

the plows, which quickly became very popular and widespread during the 1940s, were leading to erosion and the loss of soil fertility.

Not only were these French practices damaging to the environment, they were also destructive to the cultures and livelihoods of several local agropastoralist groups in Mali, such as the Marka and Fulani (Crane, 2010). The Marka were originally farmers, but through the introduction of the plow and the emphasis on increased food production, the Marka were forced to adopt animal husbandry. Plows need traction and livestock quickly became part of the Marka livelihood (Crane, 2010). Cattle also provided a form of mobile investment and more importantly manure, an increasingly valuable resource especially in light of soil-fertility maintenance. Over the last century, livestock as well as smaller ruminants such as goats have become an important part of Mali's agricultural system as a source of traction for field work, a gateway to the market and a natural resource to sustain soil fertility. However, the adoption of animal husbandry by the Marka has also affected another local group: the Fulani (Crane, 2010). For at least the last 600 years, the Fulani survived as nomadic cattle herders moving their cattle herds between Mali's northern Sahel region and the southern farming and savannah areas by the Niger River. They developed a symbiotic relationship with the Marka; the Fulani would trade milk, butter and sometimes their prized cattle in exchange for cloth, produce, grain and other needed goods (Crane, 2010). However, the Fulani nomadic livelihoods and cultural identity became threatened during the French occupation, as the French made efforts to "sedentarize" the Fulani in order to make them "more governable and taxable" (Crane, 2010). Moreover, the devastating droughts during the 1970s and 1980s destroyed the Fulani herds. With few cattle left and a growing dependency upon food aid, the Fulani were forced to adopt an agricultural-based livelihood. Unlike the Marka, the Fulani have become mainly subsistence farmers and remaining herders have becoming increasingly marginalized (Crane, 2010). Increases in sedentary lifestyles and animal husbandry have additionally placed greater stress on various resources (such as water and arable land) and led to problems such as food scarcity as well as and cultural and political conflicts. Even though Mali gained independence in 1960, most of the agricultural systems and practices originally introduced by the French have remained in place. In fact, many of these practices have led to the numerous environmental, political and poverty-related issues that currently plague Mali.

CURRENT SITUATION

Introduction and Basic Demography

Simply stated, Mali's condition is in many respects - political, economic, environmental- quite dire. Since its independence in 1960, it is struggling to support itself. Like many other African countries, Mali is experiencing major problems in terms of resources and food security. In addition, Mali has a high population growth rate between 2.4% to 2.8% with an equally high fertility rate at 6.6 children born per woman (UNdata, 2010; Library of Congress, 2005). In other words, within thirty years Mali can expect its population to double from the current 12,706,00 to 25,412,000 inhabitants (UNdata, 2010). Moreover, 44.2% (5,616,052) of Mali's population is below the age of fourteen (median age is 16.3 years), clearly signifying a "youth bulge" (*Mali*, n.d.) This naturally can lead to larger human security issues, such as mass unemployment, social unrest as well as political instability. In fact, according to the United Nations Human Development Report (UNHDR) released in 2005, Mali ranks as the 174th worst country in the world (out of 177) based on data concerning distribution of well-being for inequality, gender equity and poverty (Shoumatoff, 2006).

Health and Welfare

A negative trend pervades Mali's health and welfare sectors as well. Out of the 175 countries ranked in the 2003 UNHDR, Mali ranked as 172nd in terms of quality of life along with one of the world's highest rates of infant mortality (Library of Congress, 2005). Poverty, malnutrition, as well as inadequate hygiene and sanitation are all major problems. Access to safe drinking water and sanitation services ranges between 62-69% and is even lower for rural villages (Library of Congress, 2005). Appropriate health care is severely limited, with only 5 physicians per 100,000 inhabitants. In fact, only roughly a third of Malians have any access to health services within a five-kilometer radius (Library of Congress, 2005). Education faces similar issues in terms of funding and access. Although public education is provided for through the government and is required until age sixteen, attendance is low (approximately 64.3%) because most families are unable to cover even the basic costs of uniforms, books, supplies, and various other fees for public school (U.S. Department of, 2010). Out of those who do have to ability and resources to attend school, most leave at age twelve. Along with massive shortages of teachers, supplies, and schools (especially in rural areas), Mali also has one of the lowest literacy rates in Africa (31%) with an even lower rate (12%) for women (U.S. Department of, 2010; Library of Congress, 2005).

Economy

From an economic standpoint, Mali's situation remains bleak. In terms of GDP (PPP) per capita (with estimates ranging from $470 to $676.80), Mali ranks as one of the ten poorest countries in the world with approximately one third of the population living below the poverty line (defined as $1 per day or less) (U.S. Department of, 2010; UNdata,2010). However, Mali's worsening economic situation is more of a recent development. Like many other countries located in the Sahel region, Mali was once self-sufficient in food production of grains such as millet, sorghum, rice and corn (U.S. Department of, 2010). Beginning in the 1960's, "food production in the Sahel rose by only 1.8% per year," whereas the rate of increase in population was much higher (Leisinger et al., 1995). In addition, several other factors such as reduced harvests due to weather, changing dietary habits and policy restrictions concerning agricultural production led to considerable grain deficits from 1965 to 1986 (U.S. Department of, 2010). This in turn has made Mali dependent on food aid and has created a substantial trade deficit due to massive amounts of imports.

As a least developed nation (a term used by the UN for countries that exhibit the lowest indicators of socioeconomic development and Human Development Index ratings out of all countries in the world) with limited financial resources, Mali's economy remains heavily agrarian. Nearly 80% of the labor force is engaged in agriculture or fishing making up on average 33% to 46% of Mali's GDP (U.S. Department of, 2010; Library of Congress, 2005). Small-scale traditional and subsistence farming makes up the majority of the agricultural sector. Subsistence farming (which is 90% of all land under cultivation in Mali) produces mostly cereals such as sorghum, millet, and maize. Cash crops and agricultural export products include corn, cotton (Mali's second largest export product), peanuts, rice, sugarcane, and various vegetables (Library of Congress, 2005; UN UNdata, 2010). Cotton is highly vulnerable to price fluctuations because it is risky to cultivate as bad weather and insects (such as Mali's locust plague of 2004) can easily destroy it (Library of Congress, 2005). In addition, cotton uses more pesticides than any other agricultural product; in turn, this cash crop can cause freshwater pollution due to high inputs of

fertilizers and pesticides, wasteful water use, salinization, and other water quality problems, many of which are current environmental issues along the Niger River in Mali (Library of Congress, 2005). Outside of agricultural products, livestock also makes up another sizeable part of Mali's GDP (roughly 20%), mainly exporting cattle, goats, sheep, and associated livestock products (Library of Congress, 2005).

Mining is a growing industry in Mali, which currently contributes 16.9% to Mali's GDP (Library of Congress, 2005). It could become quite lucrative as Mali has an array of resources such as phosphates, kaolin, salt (which has long been mined and traded for hundreds of years), limestone, uranium, gypsum and granite (*Mali*, n.d.). In addition, Mali has known reserves of other valuable natural resources, such as bauxite, iron ore, manganese, tin and copper, that have not yet been developed or exploited as the infrastructure and funding currently does not exist to support these industries (*Mali*, n.d.). Gold is one of the few natural resources to have been mined extensively (through investment from two private, multinational South African companies) and it accounts for 80% of all mining in Mali (Library of Congress, 2005; U.S. Department of, 2010). In fact, Mali is Africa's third largest gold producer and gold is also Mali's largest export product (Library of Congress, 2005).

In 2008, Mali's exports amounted to $1.9 billion (UNdata, 2010). Since Mali mainly exports commodities and has a largely undeveloped industrial sector, numerous goods need to be imported to support the needs and demands of its growing population. In 2008, Mali imported $3.3 billion in capital goods, motor cars and vehicles, petroleum products, cement, rice and sugar (UNdata, 2010). Although the amount of exports from Mali have increased by 18.1% from 2004 to 2008, the amount of products Mali imports has risen by 25.1% over the same time period (UNdata, 2010). Thus, Mali faces a continuing and increasing trade imbalance as well as an external debt of $2.8 billion (Library of Congress, 2005). Together all of these issues- an agriculture based economy, a lack of diversity in terms of exports, and commodities that are vulnerable to price fluctuations- make Mali's economy very weak and highly dependent on foreign aid as well as trade partners in neighboring countries.

Environment

Along with a fragile economy, Mali also deals with an equally (if not more) fragile environment. Although the Sahel is known for its unpredictable climate and variable precipitation, Mali has experienced an overall decrease in rainfall of 30% over the years since 1968 (Shoumatoff, 2006). Drought has always been a part of life in Mali and other countries located in the Sahel, several at regular intervals within the last 400 years (Leisinger et al, 1995). However, within the last century droughts have been increasing both in frequency and duration. Long droughts of twelve to fifteen years were events that only happened once or possibly twice in a century. Mali has already experienced five since 1900 and is currently recovering from a drought during which 350,000 people faced starvation and 1,200,000 were at risk of famine across the Sahel (Leisinger et al., 1995; U.S. Department of, 2010). The worst of these droughts occurred from 1968 to 1973. During this period, precipitation dropped by 15-40% from the long term mean and over 250,000 people and 3.5 million head of cattle died of starvation (Leisinger et al., 1995; Shoumatoff, 2006). Millions more throughout Mali and other countries of the Sahel were affected by loss of water resources and crop failures. Fish production dropped by 20%, rice cultivation along the Niger River was severely reduced and harvests of staple grains such as sorghum and millet decreased between 40% to 50% (Goudie & Cuff, 2002). Pastoralists in the north of Mali suffered the most; entire herds were wiped out and they were forced to move

southwards, adopt agricultural lifestyles or sell off any remaining cattle to obtain foodstuffs. This created a much greater strain on resources, water, and land and has fueled many of the conflicts between different farmer and herder groups throughout Mali (Crane, 2010; Turner, 2009). Not long after the drought of 1968-1973, another devastating drought ensued from 1980-1984. For example, during this particular drought the city of Gao (situated in eastern Mali) received only 60 millimeters of precipitation while the average for this region is about 250-300 millimeters (Economics, 2009; Leisinger et al., 1995). Over one third of Mali's population continued to suffer from this drought late into the 1980s (Leisinger et al., 1995). In addition to recurrent droughts, Mali's rainy season (crucial to the success and survival of farmers and herders alike) has been reduced to only two months: July and August. Since 65% of Mali is desert or semi-desert, most economic and agricultural activity is concentrated along the Niger River, where the Office du Niger supplies water for such water intensive crops as cotton through an irrigation system developed by the French in 1932 (van Beusekom, 1999). Only 3.8% of the area of Mali is classified as arable land and less than 0.1% is planted with permanent crops (Library of Congress, 2005). Moreover, cotton and other cash crops have displaced subsistence farming, pushing local people into increasingly marginal areas in order to survive. Because of limited availability of arable land, high demand for farmland as well as over-exploitative farming methods, over-cultivation and soil degradation are now major problems (Munn, 2002). In spite of decreased cattle herds since the droughts in the last half of the century, over-grazing has also become a major problem as many farmers have adopted some form of animal husbandry usually involving cattle, sheep or goats as an investment against small calamities. In addition, manure from livestock is highly valued as it is cheaper than fertilizers and sustainable farming methods, such as fallowing, that are no longer practiced (Crane, 2010). However, livestock "wreck environmental damage" (Turner, 2009). As Alex Shoumatoff described in his article, "goats have penetrated every corner of the landscape. Every reachable plant not protected by thorns or toxic alkaloids has been clipped by their teeth… The Sahel is hardly a 'natural' landscape anymore. It belongs to the goats" (Shoumatoff, 2006).

During the French Colonization, traditional Malian farming methods, especially pastoralism and fallowing methods, were discouraged while sedentary, intensive farming lifestyles were promoted (van Beusekom, 1999). Even after Mali's independence in the 1960s, the farming methods advocated by the French continued and policies were adopted to spur industrialization and agricultural modernization (Benjaminsen, 2008). Nomadism and pastoralism were considered obstacles in becoming a strong, developed nation; consequently the Malian government made efforts to "sedentarize" these ways of life. Incidentally, these have led to the marginalization of many nomadic and pastoralist groups, which will be discussed later (Benjaminsen, 2008). Along with the loss of nomadic lifestyles, fallowing methods were additionally discouraged leading to declines in soil structure and permeability, depletion of soil nutrients and organic matter as well as increased susceptibility to erosion (Munn, 2002). The natural vegetation which protects the soil against erosion is also being decimated. The issue now is a growing population of which many are dependent upon agriculture as a livelihood as well as survival. Similarly, this growing population has led to a growing demand for firewood which is the main source of cooking fuel for Malians (Shoumatoff, 2006). Firewood is also an additional source of income for many people as well as a source of traditional plant medicines. Approximately one million acres of trees and forests are cleared in Mali each year (Shoumatoff, 2006). This deforestation in turn leads to the artificial establishment of savanna vegetation, loss of soil-stabilizing vegetation, exposed and eroded soil, soil desiccation, increased frequency of dust storms, and dune mobilization (Munn, 2002). In fact, dust

storms pick up between two to three billion tons of Sahara dust per year (Shoumatoff, 2006). These fine dust particles can be found up to 12,000 feet in the atmosphere where they can be transported globally by winds. Dust from the Sahara has been found in Austria, England and Greenland and even as far away as Florida and Texas in the United States (Shoumatoff, 2006). In short, the environmental issues that Mali faces are extensive and diverse. Few other regions and countries have experienced such dramatic shifts in climate zones and extreme changes in precipitation as Mali. Moreover, many of Mali's current environmental problems (such as over-cultivation, overgrazing, and deforestation) function as trigger factors in perhaps the greatest environmental threat today, desertification, which is proceeding at "a faster rate than perhaps any other time in recorded history" (Shoumatoff, 2006; Desertification, 2002). Although it is difficult to accurately measure the desertification of the Sahel because vegetation growth varies highly from year to year due to rainfall, it has been measured in general that the Sahara is advancing south into the Sahel at a rate of about 48 kilometers (30 miles) per year (Munn, 2002). However, to solely blame anthropogenic activities such as over-cultivation or deforestation as the main causes for desertification in Mali would be to ignore half of the problem. Desertification is incredibly complex and the web of its associated trigger factors, whether they are caused by land use or fluctuations of climate, only multiplies its intricacy. Currently, there are several schools of thought regarding the causes of desertification. One of the first responses to the droughts of the 1970s in the Sahel, was the "desertification paradigm," or Charney's hypothesis (Giannini et al., 2008). Basically, Charney proposed that desertification was a product of anthropogenic origin (Goudie & Cuff, 2002). Increasing population and grazing pressures upon the land, he argued, led to a reduction of surface plant cover, which in turn increased the albedo, the proportion of incoming solar radiation reflected from the earth's surface (Munn, 2002). An increase in albedo would result in a decrease of land surface temperatures during the daytime, and thus a reduction in local convection leading to less rainfall. This begins to form a vicious cycle through land-surface interaction that continues to suppress rainfall and increase moisture stress on vegetation (Hulme & Kelly, 1993).

Beyond anthropogenic activities such as intensive agriculture that lead to land degradation, several other anthropogenic activities may possibly play a role in Mali's desertification issues (Taylor, 2001). Activities such as burning of fuel wood and clearing of woodlands for fields may greatly affect precipitation through common "by-products" of these activities including dust and smoke. According to Daniel Rosenfeld,

"Activities such as grazing and agricultural cultivation that expose and disrupt topsoil can increase the amount of dust blown into the air. More dust reaching rain clouds reduces their rainfall, which exacerbates drought conditions and contributes to the spread of desertification of the landscape" (Rosenfeld, 2001).

The Sahel in Mali, an already fragile ecosystem with easily erodible soil, is especially susceptible to dust production. Moreover, the Sahara to the North with its massive dust storms only multiplies the effect. Smoke (produced from burning of fuel wood, fields, and other biomass) has also been shown to suppress and reduce the efficiency of precipitation (Rosenfeld, 2001; Giannini et al., 2008). Since Africa is the largest source of biomass burning, the argument can be made that through these various anthropogenic activities that are further exacerbated by smoke and dust, "mankind may already have had a significant impact" upon rainfall, "affecting water resources, global atmospheric circulation and weather patterns" (Rosenfeld,

2001). The only optimistic part of this theory is that because desertification and decreased precipitation are hypothesized to be caused by anthropogenic activities, mitigation can be implemented to "halt such emissions" and "have positive local and regional effects almost immediately" (Rosenfeld, 2001).

Unfortunately, the web of trigger factors of desertification extends far beyond relations between land surface and atmospheric feedback. Although Charney argues that desertification is driven purely by anthropogenic activities further examination of his hypothesis has shown that the link between land surface and atmosphere is quite weak. Recent research and models have suggested that desertification of the Sahel in Mali is instead linked with observed sea surface temperature (SST) patterns in the tropical Atlantic and Pacific Oceans and the El Nino/Southern Oscillation (ENSO) events (Taylor et al., 2002).

It is well known that global climate change has resulted in warming of oceans worldwide; oceans naturally play an important part in establishing weather patterns, such as the El Nino/La Nina events. El Nino (or warm ENSO) events are usually associated with droughts whereas La Nina (or cold ENSO) events correspond to abundant rainfall (Giannini et al., 2008). Studies have consistently shown that "both a warming of the equatorial Indian Ocean, and a warmer South Atlantic compared to the North Atlantic are dynamically consistent with a drier Sahel" (Giannnini et al, 2008). Rainfall in the Sahel is highly dependent upon the monsoonal climate, which results in two to three months of rain followed by a dry period for the remainder of the year. The rainfall is specifically influenced by the "intertropical convergence zone" (ITCZ), which forms when the Harmattan (a dusty wind from the Sahara that blows toward the western coast of Africa during the winter) and the Southwest Monsoon air streams join together (Goudie & Cuff, 2002). This convergence leads to cloud formation and convection currents, which eventually causes rainfall. Typically, the ITCZ moves upward during the summer bringing rain with it up into the Sahel (Goudie & Cuff, 2002). However, warmer oceans (specifically during El Nino events) trigger drought-like conditions and affect the path of the ITCZ. Studies are showing that higher global temperatures due to climate change may be increasing evaporation from land as well as the rate of moisture transfer to the air, thereby intensifying storms, floods, droughts and other weather associated with El Nino. Over the last few decades these ENSO events have been occurring with higher frequency and intensity, with the El Nino (drought) events occurring at a 3:1 ratio in comparison to La Nina (abundant rainfall) events (Giannini et al., 2008). During El Nino events, the ITCZ follows the warmest waters and may not necessarily stray northwards into the Sahel. In addition, the atmosphere in the Sahel may not be able to maintain convection currents that lead to precipitation (Giannini et al., 2008). Climate change thus plays a direct role in the desertification of the Sahel in Mali. In this hypothesis, the future seems bleak; desertification is then fueled by the carbon emissions of the world as a whole and anthropogenic activities at the local level would have little effect either way.

However, it is more likely that there is some validity to both theories. Hulme notes that "the desiccation recently observed in the Sahel (a 20% to 30% decline in rainfall) is greater than nearly all the predictions of global warming-induced rainfall change for this region made by global climate models" (Hulme, 2001). Thus, it is probable that other factors contribute to desertification, most likely environmentally-destructive anthropogenic activities. Desertification and climate change are undeniably linked; although one may not directly cause the other, they both have the ability to affect one another. As Williams describes, "both climate and desertification interact at a variety of scales through a complex and still only partially

understood series of feedback loops" (Williams, 2001). This in turn makes it difficult to accurately forecast the environmental future of Mali. Some models show prolonged humid periods and shorter dry episodes in the Sahel, as well as an increase in vegetation cover due to an enhanced CO_2 fertilization effect (Brooks, 2006). However, in general, the consensus is bleak; Mali's forecast is dry and hot (Shoumatoff, 2006). Based on twenty-two global climate models, Mali can expect an increase in temperature of 1.2 °C and a decrease in precipitation of -2.2% (Economics, 2009). Mali has already experienced a drop in rainfall by 200 millimeters and a rise of average temperature by 0.5 °C within the last fifty years and it is expected that droughts will increase in frequency and severity (Economics, 2009). In addition, Mali is experiencing a climate zone shift of agro-ecological regions southward which will only be hastened with a decrease in rainfall as predicted (Economics, 2009). Both of these will have devastating effects, resulting in lower yields of agriculture and biomass production. More specifically, Mali could potentially lose up to $300 million in its agriculture and livestock industry, which would negatively affect Mali's economic prospects (Economics, 2009).

Besides environmental and economic stress, tensions between different ethnic groups within Mali are expected to increase. Conflicts over resources will most likely worsen and become more violent. For example, during an early 1990s rebellion led by the Tuareg in Northern Mali, nearly 1,000 people were killed and more than 250,000 were displaced in a dispute about access to resources along the Niger River (Benjaminsen, 2008). As many pastoralist groups in Mali, the Tuareg divide their time up in the north of the Sahel during the rainy season and return to the south for the remainder of the year. The Tuareg depended on food reserves by the river during the dry season which caused conflict with sedentary groups like the Songhay who farmed rice (Benjaminsen, 2008). These conflicts of land and resources sometimes turned violent, as with the case of the Tuareg rebellion. These sort of conflicts can be expected to increase as Mali faces a more unstable environmental situation along with a higher population requiring greater access to and quantity of various resources.

STAKEHOLDERS AND CURRENT MITIGATION EFFORTS

Despite the state of Mali's economy, innumerable organizations and NGOs are investing in and executing environmental programs in the country. Because Mali is considered a "least-developed country" (LDC), the United Nations has been actively involved in the country's affairs, specifically those pertaining to Mali's degrading environment as well as economic and agricultural issues. Moreover, the environmental challenges facing Mali are of global importance; desertification is a major worldwide problem, threatening 19 million square miles of the earth's land surface spread out over 100 countries (Shoumatoff, 2006). In 1992, Mali signed the UN Framework Convention on Climate Change (UNFCCC) (ratifying it in 1994) and the Kyoto Protocol shortly thereafter under which the Malian government is responsible for "gathering and sharing information on greenhouse gas emissions, national policies and best practices" as well as "launching nation strategies (clean development mechanisms- CDM) for adaptation to the impacts of climate change" (UNFCCC, 2011). Under the Kyoto Protocol, Mali is responsible to complete tasks under the Clean Development Mechanism, seven groups of goals including energy, agriculture and natural resources, all geared towards sustainable development (UNIDO, 2005). Specifically, the Permanent Technical Secretariat of the Institutional Group on Environmental Questions Boubacar Sidiki Dembélé (designated as Mali's National CDM Authority), Board Member of National Meteorology (of Mali) Mama Konaté and their

associated committees in Mali's government are responsible for implementing and enforcing criteria for sustainable development as defined under the UNFCCC (United Nations, 2005).

In 1997, Mali also ratified the United Nations Convention to Combat Desertification (UNCCD) under UNEP which formed to begin "action involving international cooperation and a partnership approach" (UNCCD, 1997). The convention focused specifically on "improving land productivity, rehabilitation of land, conservation and sustainable management of land and water resources" in order to "prevent the long-term consequences of desertification, including mass migration, species loss, climate change and the need for emergency assistance to populations in crisis" (UNCCD, 1997). Developed countries, such as the United States, Germany, and France, are responsible to provide "substantial financial resources" and promote environmental programs as well as access to appropriate knowledge. In return, Mali is obliged to "give priority to combating desertification" and to create and enforce "appropriate laws, policies and action programmes" (UNCCD, 1997). This program is executed and implemented by the Government of Mali through national partner institutions, led by the Department of Environment and Sanitation through its National Directorate for Conservation of Nature, National Project Management Unit and the PRSP Unit of Ministry of Economy and Finance. In particular, Mali's government (through the Ministry of Environment and Sanitation) is encouraged to establish a National Action Plan (NAP) to address desertification through grass-roots participation, particularly with the input of those who live off the land (UNCCD, 1997). In this sense, the pastoralists and subsistence farmers of Mali are perhaps the greatest stakeholders as they comprise nearly 70% of Mali's total population and rely exclusively upon the land for their resources and livelihoods. According to the UNCCD, "local people, who are often poor, know more than anyone else about the fragile ecosystems in which they live and work and are thus in the best position to contribute to the fight against desertification" (UNCCD, 1997).

Along with various other conventions, Mali also signed on to the Convention of Biological Diversity (CBD). Under the 2010 target, Mali (through supervision and direction under the National Directorate of Nature Conservation, the Centre for Institutional Management of Environmental Issues [STP / CIGQE], and the Department of Environment and Sanitation of Mali) is expected to have developed programs to "protect local plant varieties and some animal species… through creation of research and implementation of biodiversity projects" (Country profile- Mali, n.d.). In addition, promotion of "sustainable agriculture, forestry, fisheries and mining" as well as "traditional knowledge and practices" is heavily emphasized by the CBD to address climate change, desertification and pollution in Mali. To protect biodiversity Mali, the Department of Environment and Sanitation is expected to increase protection of "large natural areas, highly threatened areas, and areas that are home to highly threatened species" from 4% to 15% (Country profile- Mali, n.d.).

Beyond programs through the United Nations, Mali's government has taken action to address climate change and desertification on its own. Although it is extremely underfunded, the government plays a key role as a stakeholder in policy making (legislative branch) and executing programs (executive branch). Recently, Mali's government has taken steps through several different departments and ministries to raise awareness about desertification. In response to the droughts that had devastated agriculture, fisheries and livestock near Lake Faguibine (often described as "the heart of economic development for Mali"), Mali's government set up l'Office pour la Mise en Valeur du Faguibine (OMVF- Office for the

Development of the Faguibine) to help support local response in addressing desertification in the region and reduce conflict potential in the future (*Primature*, 2011). In the beginning of 2011, Salikou Sanogo (the Minister of Education, Literacy and National Languages) and the Syndicat National de l'Education et de la Culture (SNEC- National Union of Education and Culture) opened a short training workshop on environmental education for sustainable development as well as integrative methods to deal with pollution and desertification for teachers and professors from schools and universities in and around Mali's capital Bamako (*Primature*, 2011). In addition, Sanogo has been the force behind organizing "Arbor Day" as well as "Operation Green School," which aims to insert concepts regarding protection and promotion of the environment in all education at all levels. In 2009, Mali's government ratified a convention with member countries of the Communauté des Etats sahélo-sahariens (CEN-SAD- Countries of the Community of Sahel-Saharan States) to create a belt of vegetation (green belt) fifteen kilometers wide and over 7,000 kilometers long, running from Senegal to Djibouti (*Primature*, 2011). The goal is to slow desert encroachment by planting trees which will in turn lead to water retention. It is the hope that this green belt will cover demands for fuel wood, restore biodiversity, improve soil stability, and help secure livelihoods of those living in marginalized land. In addition, this initiative will support national priorities in the fight against desertification and promote sustainable management of natural resources as directed under the environmental action plan of the New Partnership for Africa's Development (NEPAD), an African Union strategic framework for pan-African socio-economic development (*Primature*, 2011). The Department of Environment and Sanitation is responsible for implementing and directing the construction of the green belt in Mali, with technical partners and administrative supervisors of the United Nations Fund for Food and Agriculture Organization (FAO) and the World Food Programme (WFP) executing the greater green belt project through the Sahel (*Primature*, 2011).

In addition the government has formed alliances with individual or groups of African countries, many of which are located in the Sahel. One such example is SOS Sahel UK which operates through several independent offices throughout the Sahel region, such as Sahel ECO in Mali, which aims to promote the participation of pastoralists in decentralized government through methods of civic education, literacy and awareness of environmental issues (*SOS Sahel*, 2010). Although these organizations often lack in internal funding and rely upon various outside sources for resources and investment (including various UN agencies, World Bank, International Fund for Agricultural Development, Bill & Melinda Gates Foundation, among many others), they are still important as they create a united front to combat climate change, desertification and related environmental issues (UNDP, 2010). Many of the countries in the Sahel rely upon one another economically, thus it is useful to create intergovernmental negotiating committees and alliances. Some of these organizations include the Sahel and West Africa Club (SWAC), the Permanent Interstate Committee for the Fight against Drought in the Sahel (CILSS), and the Economic Community of West African States (ECOWAS). The main goal of many of these organization is to raise international support for and awareness of the drought crises in the Sahel. Other collective goals include food security, domestic energy, and sustainable agriculture education.

Along with international and national stakeholders, many foreign governments and private sectors (specifically agriculture and cash crops) are beginning to wield a large amount of influence over Mali's land. Some of these foreign investors include China and South Africa which have devoted capital towards considerable tracts of land along the Niger River to grow sugar

cane. Other countries include Libya and Saudi Arabia (interested in rice cultivation and exportation), as well as Canada, Belgium, France, South Korea, India, the Netherlands, and multinational organizations like the West African Development Bank (MacFarquhar, 2010). According to an article by Neil MacFarquhar, foreign aid for agriculture has dwindled from about 20 percent of all aid in 1980 to about 5 percent now, creating "a need for other investment to bolster production" (MacFarquhar, 2010). Throughout Africa (particularly in Mali and other least-developed countries), private investors and foreign governments are buying up huge areas of arable land, often thousands of acres or more (MacFarquhar, 2010). In Mali, land is typically handed down from generation to generation according to tradition. However, the Malian government technically owns the land and has begun leasing it to various foreign investors. The reason for this, as Abou Sow explains is, "even if you gave the population their the land, they do not have the means to develop it, nor does the state" (MacFarquhar, 2010). Currently, foreign investors (mostly China, Libya and South Africa) control between 600,000 to 1,500,000 acres of arable land in Mali mostly located near the fertile Niger River. Although the World Bank and the UN argue that these investments "could help feed the growing global population by introducing large-scale commercial farming," they have instead resulted in the displacement of thousands of farmers and villagers now facing shelter and food security problems (MacFarquhar, 2010). These displaced Malians are forced to move to increasingly-marginalized land where their farming practices and livelihoods serve as catalysts for desertification. Moreover, much of the food cultivated on land owned by investors is exported to wealthier, developed nations. "Land-grabbing" by foreign investors is expected to increase, giving them more power and influence over Mali's land than the millions of Malians who depend on it for their food, shelter, livelihoods and more (MacFarquhar, 2010). These foreign investors will serve as strong stakeholders in Mali's environmental situation. The Malian government (specifically the Department of Agriculture and Bakary Kante, technical and agricultural advisor to the prime minister) supports private investment because multinationals have the capital to finance needed infrastructure for the country's agricultural sector. Thus foreign investors have free rein over land, developing and exploiting it through various highly-intensive agriculture and cultivation practices which can lead to further soil degradation and desertification (MacFarquhar, 2010).

Apart from the United Nations, most financial and practical assistance to combat the effects of climate change comes from NGOs. Currently, there are over fifty-nine organizations present in Mali managing anti-desertification programs alone (Shoumatoff, 2006). These organizations include Sahel ECO, Tree Aid, the Joliba Trust and the Mali-Folkecenter among others. The Mali-Folkecenter (one of Mali's most prominent NGOs) works to " promote the sustainable management of natural resources and the use of these resources to catalyze local economic growth & sustainable development by working in partnership with rural populations and local entrepreneurs" (*MFC Nyetaa*, n.d.). Their projects have included implementing clean, renewable energy sources in rural areas, developing greater access to water supplies, educating women about sustainable agriculture, the importance of trees in reference to fuel wood consumption as well as *Jatropha* cultivation. Trees are imperative to battling desertification because they provide soil stability and water retention. In fact, most NGOs emphasize the use of agroforestry techniques in their projects even though this practice is one of the most difficult to implement. Given that 70% of Malians (of whom the median age is 16.3 years) are farmers and a third of Mali's population lives below the poverty line, it is challenging to illustrate the long-term importance of trees in terms of farming and cultivation. Malians are dependent upon land for food, shelter and income; these three factors alone take up all the time,

energy and expenditure from most Malians. Simply stated, "[Most] see so little money and they're so focused on where the next meal is coming from, they don't have the luxury of long-term thinking" (Shoumatoff, 2006). As one Malian farmer stated, "When the rains come, we have to plant millet and other crops every day, from sunup to sunset, for four months. We don't have time to plant trees" (Shoumatoff, 2006). Although trees are extremely important for successful crop yields and soil stability, most Malians cannot "wait 10 years [for the trees to mature] to be rewarded with the fruit of their labor, of investing time and energy in something that they may get a return on in the distant future but that every year they have a chance of losing" (Shoumatoff, 2006). In addition, intensified through Mali's youth bulge and a low literacy rate, there is a growing knowledge gap between generations. Once the forest disappears, the land turns into desert, or a plant becomes extinct, "the knowledge goes… the old people die, [and] the young don't get it" (Shoumatoff, 2006). Thus the young generation continues to destroy forests and practice unsustainable farming methods without comprehension or concern for consequences, leading to further desertification and ecosystem instability.

Other creative ways to address desertification by NGOs have included efforts to stop the loss of heirloom varieties of millet and other food plants which are often better adopted to dry conditions than common, advertised GMO varieties, and the "medicinal-plant initiative." Many native plants in Mali are highly prized for their medicinal purposes; however, between twenty to twenty five of these species have become extinct due to deforestation, lack of precipitation and "heedless harvesting" (Shoumatoff, 2006). The "medicinal-plant initiative" aims at educating farmers, especially women, on correct techniques to grow and make cuttings of these important medicinal plants without killing them or harming surrounding plants. This provides women with an alternative, more sustainable livelihood, and it also helps protect the forests and ecosystems in which these medicinal plants are found.

One of the most interesting current mitigation strategies, which is gaining much popularity and interest, is the cultivation of *Jatropha carcus*. Several NGOs (specifically the Mali-Folkecenter) now incorporate Jatropha cultivation in their activities which are funded and supported mainly through foreign investors from developed European countries; one example is that of Mali Biocarburant SA, a Dutch-backed biodiesel program in Mali. Although *Jatropha* originates from Latin America, it is a drought-resistant perennial that can grow well on marginal and even sandy soils (Henning, 1996). It also grows very quickly, producing seeds in less than two years (*MFC Nyetaa,* n.d.). The plant has become very attractive to Malians for several reasons. From an environmental standpoint, *Jatropha* seems like the perfect solution to desertification. Planted in hedges, *Jatropha* reduces erosion and damage from wind and water (which cause 30% of soil degradation) and protects gardens and farmland from animals, who often destroy anywhere between 5%-10% of crop yield (*MFC Nyetaa,* n.d.). Moreover, soil collects at the base of the hedges due to wind, which leads to higher absorption and retention of water. The roots of the *Jatropha* plant can help loosen the soil, which is especially important during the dry season as the soil can become compacted and in turn easily erode during the rainy season (*MFC Nyetaa*, n.d.). Along with all of the other properties of *Jatropha*, the press cake, a byproduct formed after the extraction of oil from the *Jatropha* seeds, functions as a high-grade organic fertilizer. This is highly prized by farmers as soils are usually low in humus and chemical fertilizers are very expensive (Henning, 1996). In addition, *Jatropha* works well in inter-cropping systems; because it grows well in dry, arid areas, it tends to complement rather than compete with other crops (Worldchanging Team, 2007).

Along with environmental benefits, *Jatropha* also provides economic potential. 35% of *Jatropha* seeds consist of a non-edible oil, which can be pressed and used as biofuel (Henning, 2006). Traditionally, this oil has been used for various purposes such as soap and medicine (*MFC Nyetaa*, n.d.). Increasingly, *Jatropha* has become an appealing, low-cost and locally produced biofuel because many rural areas in Mali use pre-combustion chamber diesel engines to provide electricity for lighting homes, running water pumps and grain mills (Worldchanging Team, 2007; Henning, 1996). With the addition of a fuel filter, these engines can easily run off *Jatropha* oil. Moreover, *Jatropha* oil burns much cleaner since it produces less carbon than fossil fuel by roughly 73% and creates a closed CO_2 cycle; carbon emissions that are produced as the *Jatropha* oil is burned are re-absorbed by the next *Jatropha* crop (*MFC Nyetaa*, n.d.). Currently 700 communities throughout Mali have biodiesel generators powered by *Jatropha* oil. This provides economic security for the villages because the money paid for the fuel goes straight back to farmers who produced the seeds. Thus the villages become self-sufficient in terms of energy production, reducing the need to import increasingly expensive fossil fuels (Henning, 1996). From an environmental and economic point of view, *Jatropha* seems attractive as a mitigation strategy since it addresses desertification and provides a local, inexpensive source of fuel (Worldchanging Team, 2007).

However, *Jatropha* cultivation has several drawbacks. First of all, *Jatropha* is a non-food crop. It may be useful as an alternative crop to generate additional income in areas that have basic necessities met, but for countries such as Mali where food security remains a major problem, *Jatropha* is more of burden to Malians than a benefit. Although the crop is documented to grow in marginal, arid areas (such as the Sahel) and can survive with rainfall anywhere between 300 millimeters to 1,000 millimeters, Jatropha needs at least 600 millimeters per year to thrive and produce nuts (Benge, 2006). *Jatropha* can survive droughts and dry conditions by dropping its leaves; however, overall productivity and yield are drastically reduced as well. In fact, *Jatropha* needs at least five years before it beings to produce optimal supplies of oil (Benge, 2006). Moreover, further refinement through hybridization and selection of the best *Jatropha* plants can take seven cycles, meaning it could potentially take over 35 years to reach the highest function and efficiency of *Jatropha* oil production (Benge, 2006). For dry, arid regions like the Sahel in Mali, the *Jatropha* plant may be able to endure prolonged drought-like conditions. Even if nuts were to be produced, the oil extraction process is highly time and energy consuming since it requires specialized equipment, expensive chemicals (specifically methanol and caustic soda which are highly flammable, toxic and not readily available to those in rural areas), as well as infrastructure and trained personnel (Benge, 2006). There must be considerable investment in all of these before *Jatropha* cultivation can even begin and this is simply unfeasible for typical Malian subsistence farmers. In addition, unrefined *Jatropha* oil is restricted to only certain types of diesel engines, specifically Lister-type engines. Even though these small, biodiesel engines are used in a few small farming villages in Mali, they require modifications to use *Jatropha* oil and are high-maintenance.

Outside of the economic expenditures for *Jatropha*, this plant also poses significant environmental issues. Although there are arguments supporting *Jatropha* when used in inter-cropping systems, some studies have shown that *Jatropha* could have a negative impact on surrounding crops due to its lateral root development which would cause competition for moisture and nutrients (Benge, 2006). It has also been shown to eliminate grasses and shrubs, plants that are necessary for livestock feed.

Little study has been done into whether *Jatropha* poses a threat as an invasive species, but it has already been listed as a weed in several countries worldwide, including Australia, India (which is one of the biggest producers of *Jatropha* oil), Brazil, Fiji, Honduras, Panama, El Salvador, Jamaica, Puerto Rico, and other parts of the Caribbean (Benge, 2006). In addition, *Jatropha* does not address the problem and need for firewood and charcoal production as the crop is too light of a wood and burns too quickly to be of any use. Although *Jatropha* cultivation and oil production could be beneficial for subsistence farmers as an additional source of income, this crop needs more time, energy and investment than most Malian farmers could provide. Ultimately, Mali does not have the specific conditions to support *Jatropha* oil production and its numerous drawbacks outweigh its possible benefits.

Preferred Mitigation Strategy for Sustainable Development: Solar Energy and Applied Uses

In the grand scheme, Mali's situation seems quite bleak. The Sahel is threatened by desertification and the frequency as well as severity of droughts are on the rise. Moreover, forests are disappearing at alarming rates due to increased demand for fuel wood. In Mali, nearly 90% of the population uses firewood and charcoal each day as their main fuel source; approximately one million acres of trees are cleared each year in Mali (Diarra & Akuffo, 2002; Shoumatoff, 2006). With only 14% of the population having access to electricity, traditional biomass continues to meet 80% of gross energy demand (Nygaard et al., 2010). Together these resource management and consumption issues have led to several environmental problems and strains upon remaining forests. A huge environmental consequence is deforestation which has led to increasing soil erosion, a key trigger factor for desertification (Munn, 2002). Fewer trees mean that women must walk further to find fuel wood or use dried animal dung, which is highly prized as a fertilizer. Less dung for farming results in a loss of soil fertility and a decrease in crop yield (Martinez-Alier, 1995).

Despite its dire condition, Mali has one resource in abundance that possesses incredible potential: solar radiation. Mali lies between 10˚ and 25˚ north of the equator, situating the country in a prime "sun location;" in fact, Mali receives twelve full hours of sunlight on most days (Diarra & Akuffo, 2002). A high exposure to sunlight year-round creates an opportunity for effective mitigation against the anthropogenic causes of desertification in the form of solar cookers.

Solar cookers come in various shapes and sizes. A solar cooker is basically a simplified oven consisting of a sturdy frame lined with reflective materials to concentrate the sun's rays upon a pot centered in the middle, heating food without the use of any fuels or production of carbon dioxide emissions. In addition, most solar cookers are very simple to assemble and are low tech in terms of needed materials; in fact, most can be produced locally or constructed of recycled materials (*KoZon*, 2010). For example, an NGO from the Netherlands named KoZon has been working with several countries throughout the Sahel region for many years to provide inexpensive and effective solar cookers. Their solar cookers (named Cookits) consist of a "foldable cardboard box covered on the inner side with reflecting aluminum foil and a heat-resistant plastic bag in which a black metal pot can be placed" (Bontkes & Jongbloed, 2005). Within a few hours of sunshine the Cookit can attain a temperature of 135˚C and upwards, easily cooking food and boiling water (*KoZon*, 2010). In addition, as mentioned, solar cookers are completely self-sufficient, do not need any supplementary fuel sources and do not produce any carbon dioxide emissions. Soot and fine particulate emissions now rank as the second largest source of overall carbon dioxide emissions,

with Africa contributing the most due to biomass burning (Goudie & Cuff, 2002). Therefore, along with their low-tech composition, solar cookers provide an environmentally friendly and scientifically sound approach to mitigation.

In terms of economic feasibility, solar cookers are quite an investment, especially considering Mali's overall economic situation. With a GDP (Purchase Power Parity per capita) ranging from $470.00 to $676.80 and a third of the population living on less than a dollar a day, a Cookit solar cooker costing between 5,000-7,500 CFA Francs ($10.65-$15.97) is usually too expensive to pay all at once (Bontkes & Jongbloed, 2005). However, with an average savings of 50-180 CFA Francs ($0.11-$0.38) per use, the solar cooker pays for itself in as little as thirty uses and saves time and energy otherwise spent on collecting firewood. In comparison to cooking over a traditional three-stone fire, there is no longer a need to survey the process since there is virtually no risk of burning (*KoZon*, 2010). Thus, solar cookers allow women (who usually carry out the cooking process) more freedom and time to complete other productive tasks. Without having to collect firewood or supervise cooking, women can spend more time participating in various cottage industries, such as producing shea butter, soap and incense to sell at the market. Women can use their time efficiently and effectively by focusing on cultivating plants and crops beyond the subsistence level to sell in order to earn money (as well as socioeconomic independence and empowerment) to provide for their children and extended family (*KoZon*, 2010). Although the start-up price may seem high, solar cookers are repaid quickly in terms of resources, trees, time, and energy saved.

In general, according to studies and evaluations from KoZon, their Cookit solar cookers have been received quite well in small, rural villages especially by smaller families and bachelors (Bontkes & Jongbloed, 2005). In addition, the Cookit solar cookers have been culturally accepted quite well especially in light of Mali's dominant religion: Islam. Nearly 90% of Malians are Muslims and solar cookers have been very handy for certain Islamic rituals and festivities (U.S. Department of, 2010). For example, during the Islamic fasting month of Ramadan, Muslims may only eat after sunset since the focus during the day is upon praying. Because traditional cooking methods consume the majority of women's time during the day and require her constant attention, women must begin cooking at 3:00am or 4:00am in the morning to guarantee dinner later (Bontkes & Jongbloed, 2005). However, with the Cookit solar cookers, woman can let the sun cook the food during the day and once night arrives, the food is ready and there is no conflict with their religious rituals or any extra cooking burdens for women. In fact, women have become enthusiastic proponents of solar cookers since they are usually responsible for collecting firewood, a task that is becoming increasingly time-consuming as women have to walk further and further to find wooded areas (*KoZon*, 2010). There has been especially strong support by the Association of Handicapped Women of Mali (Association Malienne des Femmes Handicapées) as well as the Association of Women Engineers of Mali (Association des Femmes Ingénieurs du Mali). Both of these organizations receive funding through KoZon, UN, and World Bank and regularly lead training sessions as well as conduct follow-ups months later to ensure proper use and understanding of the Cookit solar cookers (*KoZon*, 2010). Women with any sort of handicap (mental or physical) or any disease are often the women who carry the heaviest social and economic burdens; they are, as the president of the Association of Handicapped Women of Mali wrote, "the poorest among the poor" (*KoZon*, 2010). Because of their condition, whether it be blindness, deafness, leprosy or physical disfigurements, these women and girls are forced to stay at home. They have few to no opportunities at all to attend school or become employed; their future, out of all Malians, is especially dire (*Courants de*

Femmes, 2010). Moreover, it is often difficult to find a husband for handicapped women thus they often place a heavy burden upon their parents and relatives. For example, leprosy can cause the loss of nerve sensation thus making traditional open fire cooking dangerous for women suffering from the disease as they can unknowingly burn themselves (*Courants de Femmes*, 2010). Solar cookers, although seemingly simple, can greatly influence and improve the lives of handicapped women. It gives them the opportunity to be productive and appreciated. In addition, understanding and use of the solar cookers gives these women increased status in their communities since they can utilize resources that others do not have the knowledge or comprehension of (*Courants de Femmes*, 2010). In this sense, women have the most to gain as well as the most to give and share with their fellow community members.

However, there are some disadvantages. Most families are quite large in rural villages, upwards of ten family members. In this case, two solar cookers may be needed which may be seen as too large of an investment. In addition, cooking times may be affected if there are dust storms or the weather becomes unfavorable. Despite the easy assembly and simple technology of the Cookit solar cookers, rural villages may not have access to needed materials such as aluminum foil and thermo-resistant plastic bags (Bontkes & Jongbloed, 2005). However, the Cookit solar cookers are quite accommodating; they can use a variety of different materials without losing their effectiveness or efficiency. For instance, in the situation that aluminum foil cannot be obtained, old chewing gum wrappers can be used to line the solar cooker and will provide the same amount of reflectivity (Bontkes & Jongbloed, 2005). Some of these issues can easily be overcome if the solar cooker is used in combination with a heat retention bag or hay box in which the food can be further cooked to completion, as advocated through KoZon's "Integrated Solar Cooking" approach (*KoZon*, 2010). All in all, solar cookers have been received well in past efforts and seem to be socially as well as culturally accepted. Other than KoZon, various NGOs have implemented successful solar cooker programs and training sessions further supported by the Mali-Folkecenter and (as mentioned) several women's groups such as the Association of Handicapped Women of Mali and the Association of Women Engineers (*KoZon*, 2010).

Although implementation of this mitigation strategy would most likely be funded and executed through an NGO like KoZon, Mali's government should take proactive measures in terms of policy. To encourage use of solar cookers, the government should offer subsidies or set up incentive programs (probably funded by UN conventions and environmental organizations) for the country's rural population. In addition, Mali's government should encourage use of solar cookers by offering loans or helping those in rural farming communities solicit microloans from international organizations. After all, the small price of one solar cooker is a valuable asset in Mali's long-term environmental stability and sustainable development. In addition, to further promote use of solar cookers, Mali's government could increase enforcement of threatened forests or wooded areas, thereby fulfilling its obligations and target goals under the Convention on Biological Diversity. By 2010, Mali was expected to increase protection of "large natural areas, highly threatened areas, and areas that are home to highly threatened species" from 4% to 15% (Country Profile-Mali, n.d.). Increased protection of natural and threatened wooded areas would compel those situated in rural villages to consider investing in solar cookers as access to fuel wood would be restricted.

Beyond solar cookers, solar resources have been and continue to be widely exploited throughout Mali. This is mostly done so through solar photovoltaic (PV) installations as well as thermal applications, such as water heating, drying and cooking

(Nygaard et al., 2010). The current exploitation is mainly through the support and efforts of various donors, including numerous NGOs, UN programs and the World Bank. Although solar energy is by no means a common sight in Mali, villagers are becoming more familiar and aware about its potential use; in fact, according to Ivan Nygaard, "more than 95% of people in both rural and urban centers [in Mali] have already heard of or seen PV systems" (Nygaard et al., 2010). In 2007, more than 800 solar pumps providing drinking water and over 70,000 Solar Home Systems (SHS) were installed throughout Mali (Nygaard et al., 2010). Other solar energy applications include lighting in schools and public squares as well as lighting and refrigeration of medicines and vaccines in the clinics (*MFC Nyetaa*, n.d). These solar PV system have also been used for electrification of the schools for evening adult literacy classes as well as children's classes during the day and of the clinics for improved healthcare provision. The Mali-Folkecenter has been responsible for most of these installations and works very closely with local villages, educating and training them to maintain their solar PV systems and ensure the highest efficiency; through these programs, villagers gain the essential skills for management and repairs of solar PV systems without having to leave their homes and risk socioeconomic instability in the cities (i.e. slums) (*MFC Nyetaa*, n.d.). Not only does solar PV technology provide a sustainable and renewable source of energy, it (through all of its applications) also improves health conditions and the quality of life for local villagers (electrification of schools and clinics) and encourages a greater diversity of economic activities. This in turn ensures greater economic stability for the villages and reduces the chances of urbanization (MFC Nyetaa, n.d.). Through electrification, community centers and schools can bring *in* opportunities to villages, such as literacy classes, cultural classes, lectures on health, HIV/AIDS, environmental issues, democracy and innumerable other important topics (Nygaard et al., 2010). And all of this can be done without dependence upon traditional biomass for energy or mass deforestation to obtain needed resources.

However, solar PV energy has quite a costly price tag. Despite aid and investment from numerous organizations (NGOs, Mali-Folkecenter, UN, etc.), solar energy remains very expensive and inaccessible to the majority of Malians. Simply explained, if Malians are already struggling to justify the investment in one or two Cookit solar cookers, then a solar PV system (despite generous donations) is entirely out of the picture. In addition, as explained by Diarra and Akuffo, the following issues are problematic constraints to the widespread utilization of solar PV technologies: decreased efficiency of solar PV cells due to dust and high temperatures, high initial cost (exacerbated by lowered efficiency and power output of solar PV cells), underdeveloped solar energy sector policy, and low participation of local communities in terms solar PV technology programs, training, implementation, and maintenance (Diarra & Akuffo, 2002; Nygaard et al., 2010). Moreover, Nygaard has shown that NGOs often do not socialize well or effectively with the local population, resulting in the feeling among villagers that the solar PV system does not actually belong to them or that they have any control or influence over it; thus, the local population may not have much interest in maintaining the system or learning about its various applications (Nygaard et al., 2010). Yet another issue is that of a lack of qualified commercial solar PV system dealers and trained personnel for installation and maintenance (specifically at the local level). Additionally, proper education to consumers on the limits and uses of technology continues to be a problem. Finally, as mentioned, there is a major lack of credit facilities for rural communities (Nygaard et al., 2010).

Although solar energy has great potential to push Mali towards a sustainable future (both in terms of the environment and development), there are so many financial constraints that the widespread use and implementation of solar PV systems is not possible at this time. Solar cookers may seem to provide a rather small solution to an enormous environmental problem, but they can actually become quite effective if used extensively throughout Mali. With nearly 90% of Malians depending upon firewood for fuel each day, solar cookers could make a considerable impact, moving away from environmentally destructive routines to ecologically sound practices (Bontkes & Jongbloed, 2005).

CONCLUSION

Half of the world's land surface is defined as "dryland" (a total of 28 million square miles) of which 19 million square miles are becoming desert or are currently threatened with desertification; this means that over 1.5 billion people in more than 100 countries are being affected by desertification (Shoumatoff, 2006). The Sahel, a narrow, semi-arid area that runs from Mauritania to Chad between the Sahara to the North and savannas to the South, is especially prone to desertification as it is a very fragile ecosystem, easily altered by climate changes as well as human activities (Goudie & Cuff, 2002; Krech et al., 2004). In Mali alone, over a million acres of trees a year are cleared (Shoumatoff, 2006). Dust storms from the Sahara pick up between 2 to 3 billion tons of sand a year, spreading it around the world, from the Sahel region to Florida and Texas. In addition, between the 1970s to mid-1980's, numerous droughts plagued Mali and other Sahelian countries, killing over 250,000 people and 3.5 million heads of cattle (Shoumatoff, 2006). Along with a booming population rate of 2.6% and 47% of the total population below 14 years of age, Mali is facing major problems (U.S. Department of, 2010). Forests and Sahel land are being cleared for agriculture, already fragile areas are becoming overgrazed and overstrained and droughts are ever increasing in frequency. Resources, such as firewood, are in high demand but in decreasing availability and food security is an issue for millions of Malians (Shoumatoff, 2006; Goudie & Cuff, 2002). These problems are expected to worsen in the coming century as the forecast is dry, hot and brutal.

However, Mali's government (with support from the United Nations and many NGOs) is taking progressive steps to reduce the impact of climate change and desertification while supporting sustainable development. Several mitigation efforts are currently in place, ranging from agroforestry to *Jatropha* cultivation. Solar cookers offer an inexpensive yet effective mitigation strategy to combating deforestation and consequent environmental problems by reducing the need for firewood. This particular strategy will help meet and ensure the growing needs for resources of current and future generations while preserving Mali's fragile environment. Sustainable development is based on the comprehension and recognition of the relationship shared by the environment and natural resources that provide the material and environmental base, ecosystems, and energy upon which economic and social stability ultimately depend. In other words, sustainable development cannot occur without taking the long-term stability and health of the environment into account. Low-tech and self-sufficient in terms of energy, solar cookers offer a bright and green alternative to address Mali's desertification and climate change related issues.

ACKNOWLEDGEMENTS

No research article or scientific inquiry is ever the product of one person's efforts, and certainly this one was no different. This paper would never have become reality without the help and suggestions of Jacqueline Maximillian, PhD, at the

University of Idaho. In addition, my supportive friends and colleagues from the University of Idaho Environmental Science 225 class, International Environmental Issues Seminar, were incredibly helpful. Thank you for your inspiration and guidance throughout the process of writing this article; I would not have been able to do it without all of you.

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