Civil and Environmental Research www.iiste.org
ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online)
Vol.8, No.6, 2016

# Effects of Global Climate Change on Wildlife: A Review

Wondimagegnehu Tekalign[1] M. Balakrishinan[2]
1.Department of Biology, College of Natural and Computational Sciences, Wolaita Sodo University, PO Box 138, Wolaita Sodo, Ethiopia
2.Department of Zoological Sciences, Addis Ababa University, Addis Ababa, Ethiopia
Department of Biology, Wolaita Sodo University, P. O. Box 138, Wolaita Sodo, Ethiopia

**Abstract**
Global warming, which is also referred to as climate change, is an increase in the world's temperature, believed to be caused in part by the greenhouse effect. Climate change can have serious consequences on a variety of species and their habitats. Accumulation of carbon dioxide, methane and other greenhouse gases in the atmosphere is the root cause of global warming. Anthropogenic activities such as deforestation, extensive burning of fossil fuel, commercial agriculture, chemical industries and automobiles contribute highly for greenhouse gas emission. Every year, human activities release 28 billion tones of $CO_2$ and half of which remains in the atmosphere. About 80% of $CO_2$ emission is from industries and the rest is affected by land-use changes including deforestation. With continued and more severe changes in the climate, the ability of wildlife to adapt through physiological and behavioural changes will be increasingly limited. It is clear that global warming has started negatively affecting a wide variety of wildlife worldwide. Extinctions have started, and much wildlife is being pushed closer to extinction or local extermination as a direct or indirect result of climate change. For the continued existence of wildlife, it is essential to limit greenhouse gas emissions and mitigate the threat of global warming.
**Key words**: Adaptation, Climate change, Global warming, Green house effect, Mitigation, Wildlife

## INTRODUCTION

Global climate change is an increase in the world's temperature, regarded as a potential consequence of the greenhouse effect (Price and Glick, 2002). The link between global warming and increased greenhouse gas emissions is well established (King, 2005). When climate changes, there can be serious consequences for species and their habitats (Hannah *et al.*, 2005). The planet as a whole is warming up (Lavendel, 2003; Tarbuck and Lutgens, 2006). Over a very long period of time, there has been a natural variation in the average temperature of the planet earth, and considerable variations have appeared in the sea level (Rahmsorf *et al*., 2007; Tisdell, 2007). In response to such variations, there are also changes visible on many physical and biological characteristics over the planet earth (Canadell *et al*., 2007). However, only few researchers have assessed the magnitude of such threat at the global scale (Kappelle *et al.,* 1999; Noss, 2001; Malcolm *et al.,* 2006; McKellar and Abbott, 2007). Earth's warming climate is responsible for the shrinking glaciers, rising sea levels, thawing permafrost and changing phenology (Bolen and Robinson, 2003).

The process of global warming is expected to significantly disrupt the climatic patterns of the earth by altering the exchange of water among the oceans, atmosphere and land. As a result, regional temperatures and precipitation patterns are expected to shift, affecting nearly every aspect of the earth's ecological systems and the organisms depend on them (Parmesan and Yohe, 2003; Root *et al*., 2003). The earth's atmosphere and oceans are warming, hurricanes are becoming more intense, and heat waves and droughts are increasing in severity, causing greater harm to agriculture and human health (Martens, 1999; Khasnis and Nettleman, 2005). The impacts of climate change affect plants, animals, human beings and their habitats altogether (Root *et al*., 2003). Plant and animal species across the globe are changing their ranges, migration patterns and the timing of their life-cycles (Taylor, 2007). Plants respond to climate change in different ways such as, flowers blooming earlier even at their upper limits, due to different preferences to topographically determined habitats. Plants attempt to shift their ranges, seeking new areas as old habitats grow to warm (Pauli *et al*., 2003).

There are two broad causes of long term climate changes. Variations in the amount of solar radiation and energy, resulting from minor alterations in the earth's orbit around the sun, the tilt of the earth's axis and a wobble in the earth's axis which could combine to alter the amount of solar energy received on the earth's surface. Such long-term influences on the earth's climate, now termed 'Milankovitch Cycles', have influenced the development of glaciations and warmer periods for millions of years (Raymo, 1997; Karl and Trenberth, 2005). The second cause is resulting from human activities commonly termed as the green house effect due to increase of population and the technological revolution (McKellar and Abbott, 2007). Anthropogenic activities such as deforestation, burning of fossil fuel, extension of agriculture, industries and automobiles contribute for high greenhouse gas emission, which is a major cause of global warming (Moore, 2003; Meinshausen *et al*., 2009). Increasing accumulations of carbon dioxide, methane and other greenhouse gases in the atmosphere is the root cause of global warming (Hayhoe *et al*., 2002; Bolen and Robinson, 2003; Lovejoy and Hannah, 2005). Greenhouse gases absorb heat radiating upward from the surface of the earth. As more of these gases accumulate in the atmosphere, more heat is trapped on the earth's atmosphere and as a result, temperature steadily rises (Levitus *et al*., 2000; Barnett *et al*., 2001).

As the human population has grown and technologies advanced, the scope and nature of modification of the environment has changed drastically (Vitousek *et al*., 1997). With such drastic environmental changes, the average global surface temperature has increased in large parts of the world (IPCC, 2001; Keeley, 2002; Tisdell, 2007). Since the Industrial Revolution, there has been increased use of fossil fuel including natural gases, timber and other biomass. This process has accelerated substantially to the levels of greenhouse gases in the atmosphere, particularly $CO_2$ (Peters and Darling, 1985; Tisdell, 2007). Human population growth and related industrial expansion have led to greater air pollution and a change in the composition of the earth's atmosphere. Some pollutants enhance the natural greenhouse effect, resulting in increased global atmospheric temperatures (Pickering *et al*., 2004).

The earth's surface temperature was warmed more during the last century than during the past thousands of years. Moreover, 1998 was the warmest year on record (Price and Glick, 2002). During the 20$^{th}$ century, the average global temperature increased by about 0.6 $^{o}$C annually (Wallington *et al*., 2004). Climate modeling projections summarized in the latest report of the Intergovernmental Panel for Climate Change (IPCC) indicate that the global surface temperature will probably rise a further 1.1 to 6.4$^{o}$C during the present century (IPCC, 2007; Solomon *et al*., 2009). The planet earth is currently experiencing rapid warming, mainly due to the pumping of huge amounts of greenhouse gases by humans into the atmosphere (Lovejoy and Hannah, 2005).

The immediate consequences of global warming would be melting of the ice caps; submergence of coastlines; devastating weather threatening life, property and crops, and health issues (Martens, 1999; Hinzman *et al*., 2005). Wildlife would also share many of these fates (Bolen and Robinson, 2003). Global warming may also bring famine and drought, leaving populations more susceptible to diseases (Khasnis and Nettleman, 2005). Ecological systems have evolved over geological time scales to suit the prevailing climate (Wallington *et al*., 2004). The earth's climate system has demonstrably changed in both global and regional scales since the pre-industrial era. The atmospheric concentrations of key greenhouse gases reached their highest levels in the 1990s, primarily due to the combustion of fossil fuels, agriculture and land-use changes (IPCC, 2001; Lovejoy and Hannah, 2005).

Climate change has the potential to adversely affect species. Some contend that effects from recently projected climate change will promise mitigation of effects to wildlife and that planning for mitigation is prudent now. Others assert that the effects of climate change on species may not require intervention and that many species may be able to adapt successfully (Halpin, 1997). Species and populations have demonstrated that they can adapt in a variety of ways to some degree of climate change. For example, they can shift their ranges, change their phenologies, and with sufficient time, may adapt to climate change through evolutionary processes (Goklany, 2005). However, as the rate of climate change reported in the past is uncharacteristically rapid, it is doubtful that the species would be able to adapt to such fast changes around their surroundings (Case, 2006). To be able to better conserve biodiversity, it is imperative to understand how species and ecosystems are likely to change under varying climate change scenarios (Erasmus *et al*., 2002).

## SIGNS OF GLOBAL WARMING

The levels of emissions and atmospheric concentrations of greenhouse gases are rising. There are signs of rapidly increasing average surface temperatures. Scientists have detected diagnostic signals such as greater high-latitude warming, which is related to the increasing concentrations of greenhouse gases (Nordhaus, 2007; Meinshausen *et al*., 2009). Snow and ice-cover have decreased over vast areas during the last few decades and deep ocean temperatures have increased over the same period. The latter indicates increased atmospheric water vapour (Hinzman *et al*., 2005). The heat is not only melting glaciers and sea ice; it is also shifting precipitation patterns and setting animals on the move (IPCC, 2001). Ecosystems are changing, and some species are moving where they become more successful. On the other hand, several others (for example, Polar bears) are going to be affected, and are at the risk of extinction (Malcolm *et al*., 2002). Climate models suggest that the frequency and intensity of extreme weather events, including floods, droughts, storms and temperatures are on the increase (Fahrig, 2003). As a result, biodiversity all over the planet earth is expected to be under increasing stress (Solomon *et al*., 2009). Climate change has adverse consequences on wildlife. Further north or south, seasonal changes become much more pronounced, shaping the type of animals that live in different habitats and their strategies for survival (Danavaro *et al*., 2004). Recent warming has already affected the geographical and altitudinal ranges of a number of species (Walther, 2002; Parmesan and Yohe, 2003).

## GREENHOUSE EFFECTS

The term greenhouse effect is used to describe the warming effect that certain gases have on the temperature of the earth's atmosphere under normal conditions (Peters and Darling, 1985). It is a natural process that occurs when such gases trap heat from the sun falling on earth, preventing it reflecting back. This process acts like a greenhouse, keeping the planet warm and enabling it to sustain life (Burns *et al*., 2003; Wallington *et al*., 2004). This is essential to maintain a constant global climate. In the absence of this property, the earth would have been just like an ice ball (Campbell-Lendrum *et al*., 2007). Much of the solar energy radiates back out into space, but some of it is stored in the atmosphere (Khasnis and Nettleman, 2005). Global warming has impacts on the natural ecosystems (Martens, 1999). Greenhouse gas pollution has already doubled the risk of extreme heat waves (Moore, 2003). Most scientists are convinced that the greenhouse gases generated by human activities will trap more heat and rise the earth's surface temperature (Gucinski *et al*., 1990; Price and Glick, 2002). As a result of related changes, Polar Regions warm faster than tropical areas, and land areas warm faster than oceans (Aalst, 2006).

**GREENHOUSE GASES (GHGs)**

The major gases in the atmosphere, nitrogen, oxygen and argon make up to 98 % of the earth's atmosphere (Khasnis and Nettleman, 2005). They are transparent to both the radiation incoming from the sun and outgoing from the earth, so they have little or no effect on greenhouse warming (Princiotta, 1996). It is the more exotic components like water vapour, carbon dioxide ($CO_2$), ozone ($O_3$), methane ($CH_4$), nitrous oxide ($N_2O$) and carbon fluorocarbons (CFCs) that absorb heat, not transparent and thus responsible for the increase of atmospheric temperature. These are the greenhouse gases (Mintzer, 1992; Wallington *et al*., 2004; Meinshausen *et al*., 2009). The three most powerful long-lived greenhouse gases in the atmosphere are $CO_2$, $CH_4$ and $N_2O$ (Peters and Darling, 1985; UNEP, 1999). Burning of fossil fuel and land clearing are generating and accumulating more greenhouse gases on the surface of the earth (Gucinski *et al*., 1990). The most important of all GHG is $CO_2$, whose emissions have risen rapidly in recent decades (Nordhaus, 2007). Since the Industrial Revolution, it has increased from 230 ppm in the Earth's atmosphere to 380 ppm, and is now at levels that are much higher than recorded in the last 650,000 years (Nordhaus, 2007). Every year, human activities release 28 billion tones of $CO_2$ into the atmosphere and half of which remains in the atmosphere (Pollock, 2002). The source of almost 80% of $CO_2$ is industries and the rest by deforestation (Costello *et al*., 2009).

**EFFECTS OF GLOBAL WARMING ON WILDLIFE**

Relationships between global warming and its effects on wildlife may be quite complex and involve a chain of several links (Goklany, 2005). Since the Industrial Revolution in the 1800s, global temperatures have warmed faster than at any other time in the previous tens of centuries. The problem is not just that our climate is changing, but also the fastest rate at which such changes are takes place in different parts of the globe. As a result, the places that wildlife relies on for survival are also changing (Pollock, 2002). Changing patterns in global climate will continue to affect the behaviour, distribution, populations and welfare of wildlife of all kinds (Wuethrich, 2000). Changes in food availability, species-specific differences in thermal tolerance and disease susceptibility, and shifts in the competitive advantage of species will alter species assemblages (Gucinski *et al*., 1990).

The 21$^{st}$ century has thus come up with new challenges for wildlife managers and those concerned with the conservation of natural resources (Bolen and Robinson, 2003). Sedentary species seem particularly vulnerable to global warming, because, unlike mobile species, they cannot quickly escape from environments altered by rising temperatures (Pearson and Dawson, 2003). Species may shift their distribution poleward and higher altitudes when faced with a warmer climate to which they cannot readily adapt (Hoegh-Guldberg, 2005). Parmesan *et al*. (1999) have already reported a northward shift in the distribution of non-migratory butterflies in Europe. Barry *et al*. (1995) recorded distributional changes in the fauna of a rocky intertidal community in California. Cameron and Scheel (2001) predicted the effects of global warming on the distribution of rodents in Texas, including the extirpation of two species. Unfortunately, many species of vertebrates or invertebrates may not find suitable habitats to colonize if they attempt to escape to higher latitudes or higher elevations. In this context, the polar and alpine organisms will have negative impacts as they cannot move farther to avoid a warming environment (Hannah and Salm, 2005).

Penguins and other seabirds in Antarctica have shown dramatic responses to changes in sea-ice extent over the past century (Croxall *et al*., 2002). The sea-ice dependent Ad´elie and emperor penguins (*Pygoscelis adeliae* and *Aptenodytes forsteri*, respectively) have nearly disappeared from their northernmost sites around Antarctica. Emperors have declined from 300 breeding pairs down to just 9 in the western Antarctic Peninsula. As ice shelves contract effectively shifting this species pole ward. In the long-term, sea-ice-dependent birds will suffer a general reduction of habitat. Nearly every Arctic ecosystem shows marked shifts. Diatom and invertebrate assemblages in Arctic lakes have shown huge species' turnover, shifting away from benthic species toward more planktonic and warm-water-associated communities (Parmesan, 2006). Study across 26 mountains in Switzerland documented that alpine flora have expanded toward the summits (Grabherr *et al.*, 1994). Upward movement of tree-lines has been observed in Siberia. Records show strong shifts of phytoplankton and zooplankton communities in concert. Shifts in marine fish and invertebrate communities have been particularly well documented off the coasts of western North America and the United Kingdom (Parmesan, 2006).

Endangered species are also highly vulnerable to climate change, as most of such species are geographically restricted (Glick *et al*., 2001). Their small gene pools may limit opportunities for adapting to warmer environments, and some endangered species require habitats where global warming poses greater risks than others (Bolen and Robinson, 2003). Approximately, 20-30% of the species assessed so far are likely to be at increased risk of extinction if increase in average global warming exceeds 1.5-2.5°C. Climate change over the past several years has produced numerous shifts in the distribution and abundances of species and has been implicated in species extinction (Noss, 2001; Camille and Gary, 2003). With continued and more severe changes in the climate, the ability of wildlife to adapt through migration and physiological changes will be increasingly limited (Budyko, 1980).

Wildlife can be affected by several climatic variables such as increasing temperatures, changes in precipitation, and extremes of weather events. Some scientists predict that climate change can cause extinctions, which would lower biodiversity. Others contend that many species could benefit from climate change, such as some migratory bird species, which may have shorter distances to migrate for breeding and over wintering (Camille and Gary, 2003; Root *et al*., 2003; Pickering *et al*., 2004). Climate change is projected to be the dominant driver of wildlife loss by the middle of the 21st century (Scholes *et al*., 2007).

**EFFECTS OF SEA LEVEL RISE**

Recent estimate by the IPCC (2007) predicts an increase of sea level between 9-88cm by 2100 (Khasnis and Nettleman, 2005; Tisdell, 2007). Global sea level rise is caused by the delivery of water to the ocean as ice melts, such as mountain glaciers and polar icecaps (Taylor, 2007). As the temperature of the waters in the oceans rises, they will spread, occupying more surface area on the planet (Price and Glick, 2002; Glick and Clough, 2006). Water from melting ice in the Greenland, the Arctic, and Antarctica are contributing to rising ocean levels. The impacts of sea level rise would be widely felt, as half of the world's population live in coastal areas (UNEP, 1999; Price and Glick, 2002). Sea level rise also poses threats to wildlife that need these areas for survival, such as shorebirds that use sand dunes, tidal marshes, and coastal wetlands for breeding (Princiotta, 1996; Croxall *et al*., 2002; Pickering *et al*., 2004; Environment Canada, 2002). Global warming would act as a major factor in the decline of populations of polar bear in the Arctic region. Researchers predict a 30% loss of Arctic sea ice by 2040 (Hinzman *et al*., 2005), possibly resulting in the disappearance of all polar bears from Alaska due to drowning, starvation, reproductive declines, dispersal and related effects (Croxall *et al*., 2002). If sea ice disappears over the next century as climate models predict, polar bear populations would be decimated or possibly even wiped out (Stirling and Parkinson, 2006).

**CHANGES IN AQUATIC HABITATS**

Climate change has already altered patterns of rain and snowfall from which the characteristics of many aquatic habitats are derived. In the Pacific Northwest, for example, warming temperatures have shifted the timing of peak snow accumulation and snow melt-derived runoff, decreased the total snow pack, and melted glaciers (Hinzman *et al*., 2005). This means significant changes in the timing and level of stream flows, water temperatures and water quality. As different species and stocks have developed over time, the migratory and spawning behaviour that correspond with variations in stream flows may not be able to adapt to such rapid changes for survival (Donner, 2005).

**CHANGES IN PRIMARY PRODUCTIVITY**

Current climate change is complex because it includes simultaneous increase in atmospheric $CO_2$ and temperature (IPCC, 2001; Beier, 2004). These two factors are directly involved in regulating biological and chemical processes at scales ranging from individuals to the ecosystem. Atmospheric $CO_2$ enrichment tends to have a fertilizing effect on agricultural plants by enhancing photosynthesis and water use efficiency (Acock *et al*., 1985; Nijs *et al*., 1988). Growth in woody species is also stimulated by increases in $CO_2$, but there is a wide range of response among deciduous and coniferous species (Eamus and Jarvis, 1989). Virtually all plants have a threshold at which further $CO_2$ enrichment will not continue to increase photosynthetic processes due to other limiting factors. Despite the potential benefits of $CO_2$ enrichment, limited soil nutrients and water may offset potential gains in productivity (Lockwood, 1999). Differences in carbon-fixation pathways may explain some differences in species response to $CO_2$ enrichment. In general, plants that use the $C_3$ photosynthetic pathway (for example, most trees and shrubs and some grasses and sedges) may be enhanced by atmospheric $CO_2$ enrichment more than those with $C_4$ systems (for example, many tall grass prairie species) (Drake,1992; Marsh, 1999).

**EFFECTS ON PHYSIOLOGY**

Changes in atmospheric $CO_2$ concentration, temperature or precipitation will directly affect rates of metabolism and development in many animals, and processes such as photosynthesis, respiration, growth and tissue composition in plants (Howden *et al*., 2003). Organisms have evolved powerful mechanisms to regulate their physiology. Therefore, they will primarily experience climate change effects through pathways involving their food source, habitat, and predators, rather than through direct effects of climate change on body temperature (Gray *et al*., 2008). Many physiological processes in plants and animals are sensitive to changes in greenhouse gas concentration (notably $CO_2$) and climate. Other physiological characteristics that may respond to climate change include dormancy in insects and the breaking of dormancy in plants (Howden *et al*., 2003).

**PATHOGENS**

Some pathogens could increase their ranges due to climate change, whereas others may diminish their ranges (Pounds, 2006; Blaustein and Dobson, 2006). Global warming will certainly affect the abundance and distribution of disease causing pathogens and has the potential to alter patterns of disease. Altitudes that are currently too cool to sustain vectors will become more conducive to them. Some vector populations may expand into new geographic ranges, whereas others may disappear (Khasnis and Nettleman, 2005). Diseases carried by arthropod vectors seem particularly able to expand as more of earth's environments warm in the years to come. For example, a milder climate will improve the winter survival of adult mosquitoes, lengthen their breeding season, and speed up the development of their larvae. Invasive species, which often harm native wildlife, also may benefit from global warming (Bolen and Robinson, 2003).

Warmer temperatures in general would lead to an expansion in the potential habitat of mosquitoes, which carry malaria causing parasites (Van Lieshout *et al*., 2003). Other vector-borne diseases potentially susceptible to climate change include leishmaniasis and tick-borne diseases. Accelerated climate change would increase further potential for transmission of such vector-borne diseases (Arnell *et al*., 2005). Due to the spread of such infectious diseases, higher rates of mortality could result (Princiotta, 1996). Insect development is generally temperature-dependent, with at least some non-indigenous insect forest pests likely to have greatly increased populations due to faster development with rising temperatures (TWRA, 2009). The spread of animal infections, such as blue-tongue virus and orbiviruses, provides further evidence of the consequence of climate change on vector-borne diseases (Purse *et al*., 2008). Ecosystem modifications through climate change could lead to catastrophic disease outbreaks (Aguirre and Tabor, 2008). According to many researchers, increasing temperatures will result in more winter survival and greater numbers of insect generations per year, therefore greatly increasing pest pressures on forest vegetation (TWRA, 2009).

**SEASONAL ACTIVITIES AND BEHAVIOURS**

Global warming is impacting seasonal activities and behaviours of a variety of species. Spring events in temperate zones take place; such as earlier arrival and breeding of birds, earlier appearance of butterflies, earlier breeding behaviour in amphibians, and earlier sprouting and flowering of plants. Global warming is attributed to be the cause of such shifts, which poses significant impacts on wildlife (Gucinski *et al*., 1990, Lovejoy and Hannah, 2005).

**PHENOLOGICAL CHANGES**

Many of the seasonal biological phenomena such as plant growth, flowering, reproduction, and migration are more prominent in the temperature regions. Organisms require the appropriate amount of heat at the required time to transfer from one stage to the other in their life cycles. Such phenomena are therefore expected to respond to climate change (Penuelas and Filella, 2001). The scientific community has begun to quantify ecological responses to recent climate changes and has realized that some communities experience marked changes with slight shifts in temperature or length of growing season (Chapman *et al.*, 2005).

Phenological changes may be the primary short-term response to climate change. The most important environmental cues affecting plant life cycles are photoperiod and temperature, and less commonly, moisture availability. In temperate zones, the time of spring-growth phases, such as, budding, leafing and flowering are mainly a response to accumulated temperature, or total heat, above a threshold level (Penuelas and Filella, 2001; Root and Hughes, 2005). Plant phenology is expected to be most sensitive to warming at higher latitudes because temperature increase will be most pronounced in these regions and because phenological responses are most closely tied to temperature in more seasonal environments. Direct effects of warming are likely to be particularly obvious at high elevations where primary productivity is strongly limited by the snow-free growing season, and where spring snowmelt serves as an environmental cue initiating growth and flowering (Price and Waser, 1998). Phenological observations are recorded for flowering of cherry trees *Prunus jamasakura* as timing of blossom in Japan was highly variable among years (Parmesan, 2006). In the tropics, phenology is most related to rainfall. Substantial increase in the length of the dry season adverse affects the phenology of plants in the tropics (Root and Hughes, 2005).

Life cycles of animals also depend on climate. Warming is expected to allow insects and other ectothermic animals to pass through their juvenile stages faster, thus becoming adults more quickly, which could result in smaller body size and possibly allow some species to undergo more generations per year (Penuelas and

Filella, 2001). Higher ambient body temperatures will likely to reduce the time for winged insects, such as butterflies, to reach flight threshold, allowing an increase in flight-dependent activities, such as mate location, dispersal, predator evasion and egg laying (Root and Hughes, 2005).

## SHIFTS IN RANGE

Climate is crucial in determining where plant and animals live. Different regions have different climates and in turn, communities of plants and animals are well adapted to particular conditions (Goklany, 2005). As climate conditions change, some regions become more difficult for species to live in the absence of species-specific eco-requirements (Hinzman *et al*., 2005). Changes in the distributions of plants and animals during and after the last glaciations provide unambiguous examples for climate driven range shifts. As the temperature warmed and glaciers retreated, species shifted their ranges to follow their major habitat types where is essential ecological requirements are met with (Parmesan, 2006). For endothermic animals (i.e. birds and mammals), ambient temperatures influence the energy expended to maintain homeostasis. As the globe warms, animals will probably shift both their ranges and densities. Species will be able to move in to regions that are moderately warmed, and retreat from areas that are too warm (Graham and Grimm, 1990). Species can shift their ranges, change their phenologies, and with sufficient time, may adapt to climate change through evolution (Lovejoy and Hannah, 2005); but not all.

Climate change may also affect species range, which would have profound impacts on population size (Case, 2006). Wetlands that were once prime habitat for migratory birds, turtles and amphibians, could dry up and be replaced by woodlands, threatening rare plants and animals (Hoegh-Guldberg, 2005). The geographic ranges of numerous wildlife species around the world are shifting (Hannah *et al*., 2005). However, because most habitats are so heavily fragmented, species are losing habitat without gaining access to new alternative habitats nearer the poles or at higher elevations. Habitat loss increases the likelihood of extinction, and for species already at risk, it makes the future events more uncertain (Lovejoy, 2005). As areas become warmer, species currently found there would migrate to new locations with their preferred environmental conditions. The new location would most likely be in an inherently cooler place, such as further from the equator, closer to a moderating influence such as an ocean or higher in the landscape, such as further up on a mountainside (McKellar and Abbott, 2007).

Climate change will be beneficial for some species, but it is likely to be detrimental for others. In response to climate change, plants and animals can adapt, migrate (i.e., shift their range), or become extirpated or extinct (Noss, 2001). Some species will lose habitat altogether as their ranges shift or disappear due to climate change. Global warming is already resulting in significant range shifts among a wide variety of species (Schlyer and Nelson, 2008). Range shifts of wildlife are likely depending upon factors such as the availability of migration corridors, suitable habitats, and the concurrent movement of forage and prey (IPCC, 2001).

One of the serious challenges for many of the species in the future will be moving across the landscape to find suitable habitat. Although few habitats are relatively well connected, most are highly fragmented and isolated. The inability to move through relatively inhospitable environments such as agricultural fields or urban and suburban areas is likely to prevent many species from successfully expanding their ranges. Studies that have investigated the potential impact of habitat fragmentation and landscape patterns on species movements in a changing climate have concluded that fragmentation will act as a barrier against movement for several species (Opdam and Wascher, 2004; Lawler and Mathias, 2007). If habitats are altered due to the changing climate, instinct may guide migrating wildlife to places where they used to find food, to find that those places are no longer able to provide the essentials for survival (Pollock, 2002). Populations of many highland taxa will likely decrease as global warming forces them to move to higher elevations, resulting in reductions in range size and leading to greater extinction risk (Thomas *et al*., 2006; Sekercioglu *et al*., 2008), particularly where there is no land or habitat available at higher elevations (Sekercioglu *et al*., 2008).

## THREATS TO GENETIC DIVERSITY

Changes to variation within populations and the extinction of geographic races and subspecies represent potential evolutionary responses to climate change (Thomas, 2005). Threats to genetic variations have concentrated on the effects of habitat destruction and hybridization (Rhymer and Simberloff, 1996). Climate warming is probably a much greater threat than either of these, with climate change disproportionately causing extinction of the parts of species' ranges that contain the greatest genetic diversity (Thomas, 2005). In the last glacial period, many temperate-zone animals and plants occurred at lower latitudes, shifted their ranges to higher latitudes after the retreat of the ice sheets (Huntley, 1991). Most of such species have reduced genetic variation within populations and divide into fewer subspecies and races at higher latitudes (Stone and Sunnucks, 1993). Over the past several glacial cycles, there is little evidence to suggest that dramatic climatic changes caused major evolution at the species level. That is, most species appeared to shift their distributions as though tracking the changing climate, rather than staying stationary and evolving new forms. Within a species, there may be significant variation among individuals in their climate tolerances, which could result in the evolution of new phenotypes with observable characteristics, within a particular population. Species' ranges shifted with past major global climate changes indicate that all species have climatic limitations beyond which they cannot survive (Parmesan, 2006).

## FIRE AND CLIMATE CHANGE

There exists a strong link between climate and the extent, severity, and frequency of wildfires (McKenzie *et al*., 2004; Lawler and Mathias, 2007). Climate change may result in the increase of intensity, extent and frequency of forest fire (Dale *et al.*, 2001). Fire can affect forests by killing trees, altering nutrient cycling and volatilizing soil nutrients, changing direction of succession, destroying soil seed banks, changing surface-soil organic layers and underground plant roots and reproductive tissues (Dale *et al*., 2001). Under the warmer and drier climate scenarios, catastrophic fire could be the major agent for decline of southeastern forests (TWRA, 2009).

## GLOBAL WARMING AND EXTINCTION OF WILDLIFE

Global warming threatens wildlife. Ecosystems are already being degraded by habitat loss, fragmentation and pollution. The millennium ecosystem assessment suggested that three known species are becoming extinct every hour, whereas the 2008 living planet report suggested that biodiversity of vertebrates had fallen by over a third in just 35 years, an extinction rate 10,000 times faster than any observed in the fossil record (Hails, 2008). Global warming is likely to exacerbate such degradation (Costello *et al*., 2009). There is growing evidence that climate change will become one of the major drivers of wildlife extinction in the 21st century (Meehl *et al*., 2004). Many wildlife species are at far greater risk of extinction than in the recent geological past (Stefanski and Nyenzi, 2008).

A number of studies have documented a variety of changes attributable to climate change (IPCC, 2007). It is suggested that 15-37 % of wildlife might extinct by 2050 due to climate change (Hannah *et al*., 2005; Botkin *et al*., 2007; Foden *et al.,* 2008). Very high extinction risks caused by global warming are predicted globally by Thomas *et al*. (2004) and Vescovi *et al*. (2009). Among the factors driving the current wave of anthropogenic extinctions, the impact of climate change is increasingly being recognized as comparable to that of habitat loss, overexploitation and invasive species (Carroll, 2007). Current empirical and theoretical ecological forecasts suggest that much wildlife could be at risk from global warming (Botkin *et al*., 2007). Species those are unable to tolerate changed conditions within their current ranges, or that cannot migrate fast enough to keep up with moving climate zones, face eventual extinction. The most vulnerable species will be those with long generation times, low mobility, highly specific host and habitat association, small or isolated ranges, and low genetic variations (Howden *et al*., 2003).

## WILDLIFE MANAGEMENT UNDER A CHANGING CLIMATE

Globally, two broad policy responses to address climate change have been identified. The first is mitigation, which refers to actions aimed at slowing down climate change by reducing net GHGs emission. The second is adaptation, which refers to actions taken in response to, or in anticipation of, projected or actual changes in climate (CRM, 2007).

## MITIGATIVE MEASURES

Global reductions in GHG concentrations are expected to slow down the rate and magnitude of climate change over the long term. To do this, both the sources and sinks of greenhouse gases must be managed. Examples are using fossil fuels more efficiently and expanding forests to sequester greater amounts of carbon dioxide from the atmosphere (CRM, 2007). Many nations are reluctant to commit themselves to the costly changes necessary to reduce greenhouse gas emissions in view of the uncertainties surrounding the precise effects of global warming (Lavendel, 2003; Goklany, 2005). Mitigation efforts had begun in the context of Kyoto protocol, which called for a cut of 5.2% in green house gas emissions from 1990 levels by developed countries (UNEP, 1999; Goklany, 2005; Watson, 2005). All key industrialized countries except the United States and Australia have ratified the protocol, which contains a number of core elements including the flexibility mechanisms (i.e. carbon trading), land-use change, forestry activities and funding for developing countries (Watson, 2005). The United States has stated that the Protocol is a flawed policy because: i) there are still significant scientific uncertainties; earth's climate system has been overestimated and the impact of human activities on the earth's climate system has been underestimated; ii) high compliance costs would hurt the United States economy; iii) it is not fair because large developing countries such as India and China are not obligated to reduce their emissions and iv) it is not effective because developing countries are not obligated to reduce their emissions. Developing countries did not want to do that because they already produced relatively small amounts of greenhouse gases and feared that to agree to reduction targets would prevent their struggling economies (UNEP, 1999; Watson, 2005), even though India and China are positive in their response.

To mitigate the effects of global warming on wildlife or biodiversity in general, two distinct kinds of actions are proposed. These are reducing emissions of greenhouse gases, and the other is developing nature reserves (Botkin *et al*., 2007). By taking responsible actions to cut emission of $CO_2$ and other greenhouse gases, we can slow down global warming and help reduce the threat it poses on wildlife (Price and Glick, 2002; Green *et al*., 2003). Greenhouse gas concentrations need to be limited to levels that would not be dangerous. This will require reductions in global net emissions of such gases by 50% or more by the middle of the current century (Topfer, 2003; McKellar and Abbott, 2007). Halting climate change can only be accomplished through concerted global actions to increase energy efficiency. The only way to effectively mitigate is through the intensive development of renewable energy options, such as solar and wind power. Technological innovations and minimizing land clearing are also essential mitigation measures (UNEP, 1999; Nordhaus, 2007). Industrialists and governments have key roles to play in this input (Princiotta, 1996). Mitigation and adaptation options in the forest sector need to be fully understood and used in the context of promoting suitable development (Gupta *et al*., 2009).

**CARBON SINKS**

Maintaining the stores and sink of carbon in natural ecosystems can play key role to reduce future emission of greenhouses gases (Gupta *et al*., 2009). With climate change riding high on the political and economic agenda, more and more attention is being paid to different mechanisms for offsetting, reducing and preventing carbon releases into the atmosphere. It is estimated that land-use change and deforestation in particular is responsible for 18 % of global green house gas emission (Roe *et al*., 2007). Habitat destruction and degradation are implicated in the decline of over 85 % of the world’s threatened mammals, birds and amphibians (Boakes *et al*., 2009). A wide range of forest-based projects can help to reduce, prevent or offset carbon emissions. These include: afforestation, reforestation and slowing or preventing deforestation (Roe *et al*., 2007). Afforestation activities can play an important role in reducing net greenhouse gas emissions to the atmosphere. Reforestation of degraded ecosystems and plantations is a proven technology that can absorb significant amounts of carbon (Lovejoy and Hannah, 2005). Afforestation and reforestation can have positive, neutral or negative impacts on biodiversity depending on the ecosystem being replaced and management options applied. Plantations of native tree species will usually support more wildlife and plantation of mixed tree species will usually support more wildlife than monocultures (IPCC, 2001; Hoffert *et al*., 2002; Pollock, 2002; Watson, 2005). Slowing deforestation and forest degradation can provide substantial biodiversity benefits in addition to mitigating greenhouse gas emissions and conserving ecological services (Watson, 2005). Forests are important as a major carbon pool as trees have more storage of carbon per unit area as compared to other types of vegetation (Gupta *et al*., 2009). They play an important role in regional and global carbon cycles because they store massive quantities of carbon in vegetation and soil, exchange carbon with the atmosphere through photosynthesis and respiration, become atmospheric sinks during re-growth, and can be managed to conserve significant quantities of carbon on the land (Singh *et al*., 2009).

In terms of adaptation to the adverse effects of climate change the Copenhagen conference agreement provides that developed countries shall provide adequate, predictable and sustainable financial resources, technology and capacity building to support the implementation of adaptation action in developing countries; especially in those that are particularly vulnerable, least developed countries, small island developing States and Africa (Costello *et al*., 2009; Dringer *et al*., 2009).

**CONCLUSION**

Climate has been varying ever since the earth was formed. However, the unprecedented recent and rapid climate warming, which is enhanced by anthropogenic activities has significant consequences for wildlife and their habitats. Anthropogenic warming could lead to some impacts that are irreversible, depending upon the rate and magnitude of the climate change. Its effects depend upon the adaptability of wildlife and their habitats. Species with small and/or isolated populations and low genetic variability will be least likely to withstand impacts of climate change. On the other hand, species with broader habitat ranges, wider niches, and greater genetic diversity should fare better. Wildlife managers have to take effective steps to enhance the ability of a species to withstand global climate change by ensuring widespread habitat availability and managing for self-sustaining populations. Given enough time, many wild species would likely be able to adapt to shifts in the climate, as they have done in the past. It is time for in depth understanding of the link between global warming and extinction, an understanding that leads to solutions to safeguard the diversity of life on the planet Earth. It is time to work together at the national, regional and global levels on this global issue to reduce the effects of global warming and sustain life. Our success at slowing global warming will depend on meaningful actions by individuals and governments and all over the world. This is not just about the quality of life for wildlife; it is about the future of mankind itself. Climate change is a global issue affecting the planet’s ecosystems and biodiversity including the future of *Homo sapiens* as a whole.

**REFERENCES**

Aalst, M. K. (2006). The impacts of climate change on the risk of natural disasters. *Disasters* 30: 5−18.

Acock, B., Reddy, V. R., Hodges, H. F., Baker, D. N. and Mckinion, J. M. (1985). Photosynthetic response of soybean canopies to full season carbon enrichment. *Agrono. J.* 77: 942–947.

Aguirre, A. A. and Tabor, G. M. (2008). Global factors driving emerging infectious diseases. *Ann. N. Y. Acad. Sci.* 1149: 1–3.

Arnell, N., Tompkins, E., Adger, N. and Delaney, K. (2005). *Vulnerability to Abrupt Climate Change in Europe.* Tyndall Centre Technical Report 34. University of Southampton, East Anglia. 70pp.

Barnett, T. P., Pierce, D. W. and Schnur, R. (2001). Detection of anthropogenic climate change in the world's oceans. *Science* 292: 270-274.

Barry, J. P., Baxter, C. H., Sagarin, R. D. and Gilman, S. E. (1995). Climate-related, long-term faunal changes in a California rocky intertidal community. *Science* 267: 672-675.

Beier, C. (2004). Climate change and ecosystem function, full-scale manipulations of $CO_2$ and temperature. *New Phytol.* 162: 243–245.

Blaustein, A. and Dobson, A. (2006). A message from the frogs. *Nature* 439: 143-144.

Boakes, E. H., Mace, G. M., McGowan, P. J. K. and Fuller, R. A. (2009). Extreme contagion in global habitat clearance. *Proc. R. Soc. B*. http://rspb.Royalsocietypub-lishing.org/content/early/2009/11/25/rspb.2009.1771.full.ht Accessed on 23/2010.

Bolen, E. G. and Robinson, W. L. (2003). *Wildlife Ecology and Management*. Pearson Education, Inc., New Jersey. 494pp.

Botkin, D. B., Saxe, H., Araujo, M. B., Betts, R., Bradshaw, R. H. W., Cedhagen, T., Chesson, P., Dawson, T. P., Etterson, J. R., Faith, D. P., Ferrier, S., Guisan, A., Hansen, A. S., Hilbert, D. W., Loehle, C., Margules, C., New, M., Sobel, M. J. and Stockwell, D. R. B. (2007). Forecasting the effects of global warming on biodiversity. *Bioscience* 57: 227-236.

Budyko, M. I. (1980). *Global Ecology*. Progress Publishers, Moscow. 322pp.

Burns, C. E., Johnston, K. M. and Schmitz, O. J. (2003). Global climate change and mammalian species diversity in U.S. National Parks. *Ecology* 100: 11474–11477.

Cameron, G. N. and Scheel, D. (2001). Getting warmer: effect of global climate change on distribution of rodents in Texas. *J. Mamm*. 82: 625-680.

Camille, P. and Gary, Y. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421: 37-42.

Campbell-Lendrum, D., Corvalan, C. and Neira, M. (2007). Global climate change: implications for international public health policy. *Bull. WHO*. 85: 235-237.

Canadell, J. G., LeQuere, C. and Raupach, M. R. (2007). Contributions to accelerating atmospheric $CO_2$ growth from economic activity, carbon intensity and efficiency of natural sinks. *Proc. Natl. Acad. Sci*. 104: 1866-1870.

Carroll, C. (2007). Interacting effects of climate change, landscape conversion and harvest on carnivore populations at the range margin: Marten and Lynx in the northern Appalachians. *Conserv. Biol*. 21: 1092–1104.

Case, M. (2006). *Climate Change Impacts on East Africa. A Review of the Scientific Literature.* WWF-World Wide Fund for Nature, Gland. 12pp.

Chapman, C. A., Chapman, L. J., Struhsaker, T. T., Zanne, A. E., Clark, C. J. and Poulsen, J. R. (2005). A long-term evaluation of fruiting phenology: importance of climate change. *J. Trop. Ecol.* 21:31–45.

CRM (Compass Resource Management) (2007). Major Impacts: Climate Change. The biodiversity British Columbia technical subcommittee for the report on the status of biodiversity. British, Columbia. 41pp. www.compassrm.com. Accessed on 21 January 2010.

Costello, A., Abbas, M., Allen, A., Ball, S., Bell, S., Bellamy, R., Friel, S., Groce, N., Johnson, A., Kett, M., Lee, M., Levy, C., Maslin, M., McCoy, D., McGuire, B., Montgomery, H., Napier, D., Pagel, C., Patel, J., Oliveira, J. A. P., Redclift, N., Rees, H., Rogger, D., Scott, J., Stephenson, J., Twigg, J., Wolff, J. and Patterson, C. (2009). Managing the health effects of climate change. *Lancet* 373: 1693–733.

Croxall, J. P., Trathan, P. N. and Murphy, E. J. (2002). Environmental change and Antarctic seabird populations. *Science* 297: 1510 – 1514.

Dale, V. H., Joyce, L. A., McNulty, S., Neilson, R. P., Ayres, M. P., Flannigan, M. D., Hanson, P. J., Irland, L. C., Lugo, A. E., Peterson, C. J., Simberloff, D., Swanson, F. J., Stocks, B. J. and Wotton, B. M. (2001). Forest disturbances and climate change. *BioScience* 51: 723-734.

Danavaro, R., Dell'Anno, A. and Puceddu, A. (2004). Biodiversity response to climate change in a warm deep sea. *Ecol. Lett.* 7: 821-828.

Donner, S. (2005). Global assessment of coral bleaching and required rates of adaptation under ulimate change. *Glob. Clim. Chan. Biol.* 251: 245-561.

Drake, B. G. (1992). A field study of the effects of elevated $CO_2$ on ecosystem processes in a Chesapeake Bay wetland. *Austr. J. Bot*. 40: 579–595.

Dringer, E., Cecys, K., Patodia, N. and Bodansky, D. (2009). Fifteenth Session of the Conference of the Parties to the United Nations Framework Convention on a Climate Change and Fifth Session of the Meeting of the Parties to the Kyoto Protocol. Summary of COP 15 and CMP 5 prepared by the Pew Center on Global Climate Change Copenhagen, Denmark. http://unfccc.int/2860.php. Accessed on 04 February 2010.

Eamus, D. and Jarvis, P. G. (1989). The direct effects of increases in the global atmospheric $CO_2$ concentration on natural and commercial temperate trees and forests. *Adv. Ecol. Res.* 19: 1–55.

Environment Canada (2002). Climate change and wildlife. *Sci. Environ.* 30: 1-8.

Erasmus, B. F. N., Van Jaarsveld, A. S., Chown, S. L., Kshatriya, M. and Wessels, K. J. (2002). Vulnerability of South African animal taxa to climate change. *Glob. Clim. Chan. Biol*. 8: 679-693.

Fahrig, I. (2003). Effects of habitat fragmentation on biodiversity. *Ann. Rev. Ecol. Evol. Syst.* 34: 487-515.

Foden, W., Mace, G., Vie, J. C., Angulo, A., Butchart, S., DeVantier, L., Dublin, H., Gutsche, A., Stuart, S. and Turak, E. (2008). Species susceptibility to climate change impacts. In: *The 2008 Review of the IUCN Red List of Threatened Species*, pp 46-57, (Vie, J. C., Hilton-Taylor, C. and Stuart, S. N., eds). International Union for Conservation of Nature and Natural Resources, Gland.

Glick, P. and Clough, J. (2006). *An Unfavorable Tide-Global Warming, Coastal Habitats and Sport fishing in Florida*. National Wildlife Federation and Warren Pinnacle Consulting, Inc., Florida. 56pp.

Glick, P., Inkley, D. and Tufts, C. (2001). Climate change and wildlife: integrated global climate policy implementation with local conservation action. *Trans. N. Am. Wildl. Nat. Resour. Conf.* 66: 380-391.

Goklany, I. M. (2005). *Living with Global Warming*. National Center for Policy Analysis, Dallas. 23pp.

Grabherr, G., Gottfried, M., and Pauli, H. (1994). Climate effects on mountain plants. *Nature* 369: 448.

Graham, R. W. and Grimm, E. C. (1990). Effects of global climate change on the patterns of terrestrial biological communities. *Trends Ecol. Evol*. 5: 289-292.

Green, R. E., Harley, M., Miles, L., Scharlemann, J., Watkinson, A. and Watts, O. (2003). *Global Climate Change and Biodiversity*. Summary of papers and discussion. University of East Anglia, Norwich. 36pp.

Gray, G., Lautenbacher, C., Hays, S., Freilich, M. H., Connaughton, J., Foster, R. E., Myers, M., Hirsch, L. P., Ellis, B. K., Buchanan, G., Lawson, L., Olsen, K. L., Wilson, S. H., Bates, J., Davis, B., McMurray, C., Williamson, S. P., Orbach, R. L. and Kupersmith, J. (2008). *Scientific Assessment of the Effects of Global Change on the United States*. A Report of the Committee on Environment and Natural Resources National Science and Technology Council, Washington, D.C. 261pp.

Gucinski, H., Lackey, R. T. and Spence, B. C. (1990). Global climate change: policy implications for fisheries. *Fisheries* 15: 33-38.

Gupta, S. R., Neelam and Kumar, R. (2009). Soil ecology, biodiversity and carbon management. *Int. J. Ecol. Environ. Sci.* 35: 129-161.

Hails, C. (2008). *Living Planet Report 2008*. http://assets.wwf.org.uk/down loads/lpr2008. pdf. Accessed on October 2, 2009.

Halpin, P. N. (1997). Global climate change and natural-area protection: management responses and research directions. *Ecol. Applicat.* 7: 828–843.

Hannah, L.; Lovejoy, T. E. and Schneider, S. H. (2005). Biodiversity and climate change in context. In: *Climate Change and Biodiversity*, pp 3-14, (Lovejoy, T. E. and Hannah, L., eds). Yale University Press, New Haven.

Hannah, L. and Salm, R. (2005). Protected areas management in a changing climate. In: *Climate Change and Biodiversity*, pp 363-371, (Lovejoy, T. E. and Hannah, L., eds). Yale University Press, New Haven.

Hayhoe, K., Kheshgi, H. S., Jain, A. and Wuebbles, D. J. (2002). Substitution of natural gas for coal: climatic effects of utility sector emissions. *Clim. Chan.* 54: 107–139.

Hoegh-Guldberg, O. (2005). Climate change and marine ecosystems. In: *Climate Change and Biodiversity*, pp 256-273, (Lovejoy, T. E. and Hannah, L., eds). Yale University Press, New Haven.

Hoffert, M. I., Caldeira, K., Benford, G., Criswell, D. R., Green, C., Herzog, H., Jain, H., Kheshgi, H. S., Lackener, K. S., Lewis, J. S., Lightfoot, H. D., Manheimer, W., Mankins, J. C., Mauel, M. E., Perkins, L. J., Schlesinger, M. E., Volk, T. and Wigley, T. M. L. (2002). Advanced technology paths to global climate stability: energy for a greenhouse planet. *Science* 298: 981-987.

Hinzman, L. D., Bettez, N. D., Robert Bolton, W. R., Chapin, F. S., Dyurgerov, M. B., Fastie, C. L., Griffith, B., Hollister, R. D., Hope, A., Huntington, H. P., Jensen, A. M., Jia, G. J., Jorgenson, T., Kane, D. L., Klein, D. R., Kofinas, G., Lynch, A. H., Lloyd, A. H., Mcguire, A. D., Nelson, F. E., Oeche, W. C., Osterkamp, T. E., Racine, C. H., Romanovsky, V. E., Stone, R. S., Stow, D. A., Sturm, M., Tweedie, C. E., Vourlitis, G. L., Walker, M. D., Walker, D. A., Webber, P. J., Welker, J. M., Winker, K. S. and Yoshikawa, K. (2005). Evidence and implications of recent climate change in northern Alaska and other

arctic regions. *Clim. Chan.* 72: 251–298.
Howden, M., Hughes, L., Dunlop, M., Zethoven, I., Hilbert, D. and Chilcott, C. (2003). *Climate Change Impacts on Biodiversity in Australia*. Biological Diversity Advisory Committee (BDAC), Australia, Canberra. http://www.ea.gov.au /biodiversity/science/bdac/index.html. Accessed on 25 March 2010.
Huntley, B. (1991). How plants respond to climate change: migration rates, individualism and the consequences for plant communities. *Annals Bota.* 67: 15-22.
IPCC (Intergovernmental Panel on Climate Change) (2001). Climate change 2001: the scientific basis. In: *Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, pp 264-266, (Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K. and Johnson, C. A., eds). Cambridge University Press, Cambridge.
IPCC (Intergovernmental Panel on Climate Change) (2007). *Climate Change 2007. Synthesis Report*. Cambridge University Press, Cambridge. 69pp.
Kappelle, M. M., Van Vuuren, M. I. and Baas, P. (1999). Effects of climate change on biodiversity: a review and identification of key research issues. *Biodiv. Conserv*. 8: 1383–1397.
Karl, T. R. and Trenberth, K. E. (2005). What is climate change? In: *Climate Change and Biodiversity*, pp 15-28, (Lovejoy, T. E. and Hannah, L., eds). Yale University Press, New Haven.
Keeley, J. E. (2002). Native American impacts on fire regimes of the California coastal ranges. *J. Biogeogr*. 29: 303–320.
Khasnis, A. A. and Nettleman, M. D. (2005). Global warming and infectious disease. *Arch. Med. Res.* 36: 689–696.
King, D. (2005). Climate change: the science and the policy. *J. Appl. Ecol.* 42: 779–783.
Lavendel, B. (2003). Ecological restoration in the face of global climate change: obstacles and initiatives. *Ecol. Restor.* 21: 199-203.
Lawler J. J. and Mathias, M. (2007). *Climate Change and the Future of Biodiversity in Washington.* Report prepared for the Washington Biodiversity Council, Washington. 42pp.
Levitus, S., Antonov, J. I., Boyer, T. P. and Stephens, C. (2000). Warming of the world ocean. *Science* 287: 2225-2229.
Lockwood, J. G. (1999). Is potential evapotranspiration and its relationship with actual evapotranspiration sensitive to elevated $CO_2$ levels? *Clim. Chan.* 41: 193–212.
Lovejoy, T. E. (2005). Conservation with a changing climate. In: *Climate Change and Biodiversity*, pp 325-328, (Lovejoy, T. E. and Hannah, L., eds). Yale University Press, New Haven.
Lovejoy, T. E. and Hannah, L. (2005). Global greenhouse gas levels and the future of biodiversity. In: *Climate Change and Biodiversity*, pp 387-396, (Lovejoy, T. E. and Hannah, L., eds). Yale University Press, New Haven.
Malcolm, J. R., Liu, C., Neilson, R. P., Hansen, L. and Hannah, L. (2006). Global warming and extinctions of endemic species from biodiversity hotspots. *Conserv. Biol*. 20: 538-548.
Malcolm, J. R., Markham, A., Neilson, R. P. and Garaci, M. (2002). Estimated migration rates under scenarios of global climate change. *J. Biogeogr.* 29: 835-849.
Marsh, A. S. (1999). How wetland plants respond to elevated carbon dioxide. *Nat. Wetl. Newslet.* 21: 11–13.
Martens, P. (1999). How will climate change affect human health? *Am. Sci.* 87: 534-541.
McKellar, R. and Abbott, I. (2007). Climate change and biodiversity. *Landscape* 22: 54-61.
McKenzie, D., Gedalof, Z. E., Peterson, D. L. and Mote, P. (2004). Climatic change, wildfire and conservation. *Conserv. Biol.* 18: 890-902.
Meehl, G. A., Washington, W. M., Ammann, C., Arblaster, J. M., Wigley. T. M. and Tebaldi, C. (2004). Combinations of natural and anthropogenic forcings and 20th century climate. *J. Climate* 17: 3721-3727.
Meinshausen, M., Meinshausen, N., Hare, W., Raper, S. C., Frieler, K., Knutti, R., Frame, D. J. and Allen, M. R. (2009). Greenhouse gas emission targets for limiting global warming to two degree centigrade. *Nature* 458: 1158-1196.
Mintzer, I. M. (1992). Living in a warming world. In: *Confronting Climate Change: Risks, Implications and Responses*, pp 382-383, (Mintzer, I. M., ed). Great Britain University Press, Cambridge.
Moore, P. D. (2003). Back to the future: biogeographical responses to climate change. *Progr. Phys. Geogr.* 27: 122–129.
Nijs, I., Impens, I. and Behacghe, T. (1988). Leaf and canopy responses of *Lolium perenne* to long-term elevated atmospheric carbon-dioxide concentration. *Planta* 177: 312–320.
Nordhaus, W. (2007). *The Challenge of Global Warming: Economic Models and Environmental Policy*. Yale University, New Haven. 253pp.
Noss, R. F. (2001). Beyond Kyoto: forest management in a time of rapid climate change. *Conserv. Biol*. 15: 578–590.
Opdam, P. and Wascher, D. (2004). Climate change meets habitat fragmentation: linking landscape and

biogeographical scale levels in research and conservation. *Biol. Conserv.* 117: 285-286.

Parmesan, C. (2006). Ecological and evolutionary responses to recent climate change. *Annu. Rev. Ecol. Evol. Syst.* 37: 637-669.

Parmesan, C. and Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421: 37–42.

Parmesan, C., Ryrholm, N., Stefanescus, C. and Hill, J. K. (1999). Poleward shifts in the geographical ranges of butterfly species associated with regional warming. *Nature* 399: 579-583.

Pauli, H., Gottfried, M. and Grabherr, G. J. (2003). Effects of climate change on the alpine and nival vegetation of the Alps. *J. Mt. Ecol*. 7: 9–12.

Pearson, R. G. and Dawson, T. P. (2003). Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? *Glob. Ecol. Biogeogr.* 12: 361–371.

Penuelas, J. and Filella, I. (2001). Responses to a warming world. *Science* 294: 793–795.

Peters, R. L. and Darling, J. D. (1985). The greenhouse effect and nature reserves. *BioScience* 35: 707–717.

Pickering, C., Good, R. and Green, K. (2004). *Potential Effects of Global Warming on the Biota of the Australian Alps*. Australian Greenhouse Office, Canberra. 51pp.

Pollock, J. S. (2002). *Climate Change and Wildlife*. Catalogue No. En CW66. www.wild lifeweek.org and www.on.ec.gc.ca/wildlife. Accessed on 19 January 2010.

Pounds, J. A. (2006). Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature* 439: 161-167.

Price, J. and Glick, P. (2002). *The Birdwatcher's Guide to Global Warming*. National Wildlife Federation and American Bird Conservancy, Virginia. 62pp.

Price, M. V. and Waser, N. M. (1998). Effects of experimental warming on plant reproductive phenology in a subalpine meadow. *Ecology* 79: 1261-1271.

Princiotta, F. T. (1996). Greenhouse warming: the uncertificaties and the mitigation challenge. *Clean Technol.* 2: 150-164.

Purse, B. V., Brown, H. E., Harrup, L., Mertens, P. P. and Rogers, D. J. (2008). Invasion of bluetongue and other orbivirus infections into Europe: the role of biological and climatic processes. *Rev. Sci. Tech.* 27: 427–442.

Rahmstorf, S., Cazenave, A., Church, J. A., Hansen. J. E., Keeling, R. F., Parker, D. E. and Somerville, R. C. (2007). Recent climate observations compared to projections. *Science* 316: 709-716.

Raymo, M. E. (1997). The timing of major climate terminations. *Paleoceanography* 12: 577–585.

Rhymer, J. M. and Simberloff, D. (1996). Extinction by hybridization and introgressions. *Annu. Rev. Ecol. Evol. Syst*. 27: 83-109.

Roe, D., Reid, H., Vaughan, K., Brickell, E. and Elliott, J. (2007). *Climate, Carbon, Conservation and Communities*. International Institute for Environment and Development (IIED) and WWF UK. www.wwf.org.uk and www.iied.org. Accessed on 22 January 2010.

Root, T. L. and Hughes, L. (2005). Present and future phonological changes in wild plants and animals. In: *Climate Change and Biodiversity*, pp 61-69, (Lovejoy, T. E. and Hannah, L., eds). Yale University Press, New Haven.

Root, T. L., Price, J. T., Hall, K. R., Schneider, S. H., Rosenzweig, C. and Pounds, J. A. (2003). Fingerprints of global warming on wild animals and plants. *Nature* 421: 57–60.

Schlyer, K. and Nelson, P. (2008). *Your Lands, Your Wildlife*. Defenders of Wildlife. Washington, D.C. 36pp.

Scholes, B., Ajavon, A.,Tony Nyong, T., Tabo, R., Vogel, C. and Ansorge, I. (2007). *Global Environmental Change (including Climate Change and Adaptation) in sub-Saharan Africa.* ICSU Regional Office for Africa, Seychelles. 27pp.

Sekercioglu, C. H., Schneider, S. H., Fay, J. P. and Loarie, S. R. (2008). Climate Change, Elevational Range Shifts and Bird Extinctions. *Conserv. Biol.* 22: 140–150.

Singh, L., Yadav, D. K., Pagare, P., Ghosh, L. and Thakur, B. S. (2009). Impact of land-use changes on species structure, biomass and carbon storage in tropical deciduous forest and converted forest. *Int. J. Ecol. Environ. Sci.* 35: 113-119.

Solomon, S., Plattner, G. K., Knutti, R. and Friedlingstein, P. (2009). Irreversible climate change due to carbon dioxide emissions. *Proc. Nat. Acad. Sci*. 106: 1704-1709.

Stefanski, R. and Nyenzi, B. (2008). *Climate Change Impacts on Forest Biodiversity*. World Meteorological Organization, Panama. 42pp.

Stirling, I. and Parkinson, C. L. (2006). Possible effects of climate warming on selected populations of polar bears (*Ursus maritimus*) in the Canadian Arctic. *Arctic* 59: 261-275.

Stone, G. N. and Sunnucks, P. J. (1993). The population genetics of an invasion through a patchy environment. *Molec. Ecol*. 2: 251-268.

Tarbuck, E. J. and Lutgens, F. K. (2006). *Earth Science*. Pearson Education Inc., New Jersey. 726pp.

Taylor, J. M. (2007). *Global Warming and its Real-world Effects: Supplemental Facts*. Montana Environmental Quality Council, Montana. 42pp.
Thomas, C. D. (2005). Recent evolutionary effects of climate change. In: *Climate Change and Biodiversity*, pp 75-88, (Lovejoy, T. E. and Hannah, L., eds). Yale University Press, New Haven.
Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C. and Williams, S. E. (2004). Extinction risk from climate change. *Nature* 427: 145-148.
Thomas, C. D., Franco, A. M. A. and Hill, J. K. (2006). Range retractions and extinction in the face of climate warming. *Trends Ecol. Evol.* 21:415–416.
Tisdell, C. (2007). *Global Warming and the Future of Pacific Island Countries*. Working Paper No. 147. University of Queensland, Brisbane. 24pp.
Topfer, K. (2003). *How Will Global Warming Affect My World? A Simplified Guide to the IPCC's Climate Change 2001: Impacts, Adaptation and Vulnerability*. UNEP, Geneva. 24pp.
TWRA (Tennessee Wildlife Resources Agency) (2009). *Climate Change and Potential Impacts to Wildlife in Tennessee.* Tennessee Wildlife Resources Agency, Nashville. 106pp.
UNEP (United Nations Environment Programme) (1999). *Forth Global Training Programme in Environmental Law.* UNON print shop, Nairobi. 206pp.
Van Lieshout, M., Kovats, S., Livermore, M. T. J. and Martens, S. (2003). Climate change and malaria: who is vulnerable? *Glob. Environ. Change* 14: 87-99.
Vescovi, L., Berteaux, D., Bird, D. and de Blois, S. (2009). *Freshwater Biodiversity Versus Anthropogenic Climate Change.* UNESCO, Paris. 14pp.
Vitousek, P. M., Mooney, H. A., Lubchenco, J. and Melillo, J. M. (1997). Human domination of earth's ecosystems. *Science* 277: 494-499.
Wallington, T. J., Srinivasan, J., Nielsen, O. J. and Highwood, E. J. (2004). Greenhouse gases and global warming. In: *Encyclopedia of Life Support Systems (EOLSS)*, pp 1-27, (Aleksandar, S., ed). Eolss Publishers, London.
Walther, G. R. (2002). Ecological responses to recent climate change. *Nature* 416: 389-395.
Watson, R. T. (2005). Emissions reductions and alternative futures. In: *Climate Change and Biodiversity*, pp 375-386 (Lovejoy, T. E. and Hannah, L., eds). Yale University Press, New Haven.
Wuethrich, B. (2000). How climate change alters rhythms of the wild. *Science* 287: 793-795.