Global Change and Wild Species : Observations and Predictions^{*}

NI JIAN^{1,2}

1 *Laboratory of Quantitative Vegetation Ecology, Institute of Botany, Chinese Academy of Sciences 100093 Beijing, China*

2 *Climate Impacts Group, Department of Ecology, Lund University, S-223 62 Lund, Sweden*

Abstract The world is warming up because of human activities. The rapid global changes are likely to have a large impact on wild species as they combine with loss and damage of natural habitats caused by urbanization, agricultural and silvicultural practices. The observed and predicted effects of climate change on wild species were looked at in four ways: timing of life cycles, distributions of species and population patterns, migration strategies, and important sites. Some species may become extinct because of climate change. Changes in the distribution of wild species because of climate change are likely to have far reaching effects on humans.

Key words Climate change, extinction, global warming, migration, range shift, wild species

1 INTRODUCTION

The world is warming up(IPCC WGI,1996). There is increasing evidence that the current warming is a result of human activities, primarily emissions from energy generation and transport(IPCC WGI, 1996). A human-driven warming trend differs from a natural warming cycle in two important ways (it occurs faster and, unlike a natural cycle of warm and cold periods, will continue to warm unless greenhouse gases (GHGs) are controlled.

Global warming means not only that the Earth is, overall, getting warmer, but also that local temperatures and rainfall will change to a completely new pattern(IPCC WGI,1996). This will affect the complex interactions between the atmosphere and the biosphere, especially wild species in oceans and terrestrial ecosystems. How will the interactions affect wild species in a warmer world? What are the responses of wild species to and the consequences of global warming? These are what will be present in this paper.

2 GREENHOUSE GASES, GLOBAL CHANGE AND WILDSPECIES

The greenhouse effect is a natural phenomenon. Naturally occurring water vapour and carbon dioxide act as an atmospheric blanket. This reduces the amount of heat energy that the earth radiates into space, so that average surface temperatures are 15℃, not -6℃ as they would be otherwise. However, emissions of greenhouse gas pollutants (CO₂, CH₄ and N₂O) from human activities cause more heat to be retained. As a result, the temperature of the atmosphere is increasing at a rate greater than that at any other time since the end of the last ice age 10 000 years ago, and the delicate balance of the planet is changing-with serious consequences.

Carbon dioxide(CO₂) is the most significant greenhouse effect gas currently being released into

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the atmosphere by humankind. Historically, the global CO_2 concentration at the end of the Pleistocene is not well defined. Atmospheric CO_2 concentration climbed from 200 to 280 ppmv from 18 000 to 10 000 year before present (aBP). During the past 1000 years the atmospheric CO_2 concentration was relatively stable, ranging from 270 to 290 ppmv (Smith et al., 1993).

Human activities began to significantly influence atmospheric CO_2 in the late 1700s. The most complete historic record derived from ice-core samples collected at Siple Station in Antarctica (Sundquist, 1993) has been used to estimate the variation in atmospheric CO_2 concentration over the two hundred years from 1750 to 1950. Between 1750 and 1850 only a small increase in atmospheric CO_2 was estimated to occur from 280 ppmv to 285 (290 ppmv), an average rate of increase of $0.05 \sim 0.1 \text{ ppmv yr}^{-1}$. However, between 1850 and 1950 both the pace of the Industrial Revolution and population growth increased dramatically. During this period CO_2 concentrations increased from 290 ppmv to 315 ppmv, that is, an average rate of $0.35 \text{ ppmv yr}^{-1}$. By comparison, CO_2 concentrations have risen from 315 ppmv to $> 350 \text{ ppmv}$ in the last 45 years, an average rate of ca. $0.83 \text{ ppmv yr}^{-1}$ (Taylor and Lloyd, 1992).

CO_2 concentrations are currently increasing by $1.5 \sim 1.8 \text{ ppmv yr}^{-1}$. If CO_2 emissions were maintained at near current (1994) levels, they would lead to a nearly constant rate of increase in atmospheric concentrations for at least two centuries, reaching about $500 \sim 700 \text{ ppmv}$ (approaching twice to pre-industrial concentration of 280 ppmv) by the end of the 21st century (IPCC WGI, 1996).

Global mean surface air temperature has increased by between about 0.3 and 0.6°C since the late 19th century. Climate is expected to continue to change in the future. For the midrange Intergovernmental Panel on Climate Change (IPCC) emission scenario, assuming the "best estimate" value of climate sensitivity and including the effects of future increases in aerosol, models project an increase in global mean surface air temperature relative to 1990 of about 2°C by 2100. A "low" and "high" values of climate sensitivity and including the effects of future changes in aerosol concentrations give warming of about 1 and 3.5°C , respectively by 2100. Temperature would continue to increase beyond 2100, even if concentrations of greenhouse gases were stabilised by that time (IPCC WGI, 1996). Important uncertainties remain, but these have been taken into account in global precipitation pattern and sea level change (IPCC WGI, 1996).

Wild species already face all kinds of threats, and many species and habitats are vulnerable to human activities. Although we do not fully understand the details of how climate change will affect wild species, it is clear that its impact will make things even worse, especially wildlife. The climate has always been in a state of fluctuations, but the change caused by human is at a rate faster than wild species has ever had to deal with in the earth's history. The rapid changes are likely to have an especially large impact on wild species as they combine with loss and damage of natural habitats caused by urbanisation, agricultural and silvicultural practices. Currently, habitat loss through direct destruction, changes in land-use and various forms of exploitation are more important than the effects of climate change, but in the long run, the combination of the two could be devastating.

Some species may become extinct because of climate change. This may seem to be a minor loss when compared with the predicted impact on human welfare of sea level rise, flooding and drought. However, the world's ecosystems provide services of huge and basically untold value to humans. Loss of species may disrupt the functioning of ecosystems in the long term and will forfeit the aesthetic and potential economic value of individual species forever. Added to the effects of loss of biodiversity, changes in the distribution of wild species because of climate change are likely to have far reaching effects on humans. Wild species important as food, agricultural pests and diseases are all likely to be affected by climate change, with potentially dire consequences for humans—especially in societies which rely on access to natural, and semi-natural ecosystems.

3 THE IMPACT ON WILD SPECIES

Many papers were presented on the observed and predicted changes to wild species now as a result of a warming world. A BirdLife International and WWF summary(BirdLife International and WWF , 1997) showed that the observed and predicted effects of climate change on wild species were looked at in four ways ; changes to : timing of life cycles ; distributions of species and population patterns ; migration strategies ; and important sites.

3.1 Timing of life cycles

Many types of wild species depend on natural signals , such as temperature or day length , to time their life cycles. This is clear in the wet season in the tropics and every spring in the northern hemisphere when , in a burst of activity , many different species breed and migrate in synchrony with the changing temperature and length of day. If some of these signals change as a result of climate change , it will lead to changes in the timing of life cycles. Those species which depend on temperature may migrate or breed earlier than those species which depend on day length. In a warmer world , birds and amphibians might migrate and breed earlier than expected.

Long-term studies in the UK and US have shown that this is already happening. The leafing dates of more than a dozen species of trees in the UK are known to be strongly correlated with temperature , such that a 1 °C increase in temperature would result in earlier leafing by 5 ~ 7 days (Sparks and Carey 1995). Similarly , many insects are very sensitive to climate fluctuations. Butterflies in the UK , for example , may appear 4 ~ 10 days earlier for each 1 °C increase in temperature (Spark and Yates , 1997). Twenty species of UK breeding birds , including the redstart , are laying their first egg an average of nine days earlier(Crick , 1997). Amphibian reproductive cycles can respond sensitively to climate change. In a study of UK frogs , toads and newts , observed data of 17 years showed that the species arrived at ponds and spawned 9 ~ 10 days earlier for each 1 °C increase in temperature(Beebee , 1995).

3.2 Distributions of species and population patterns

Most scientists accept that global warming will cause the normal range of a species to shift both northward and to higher elevations. Such range shifts are well-documented for past climate changes that occurred during the many glacial(cold) and interglacial(warm) periods of the Pleistocene period , and observed thousands of years ago.

A study of the earth's checkerspot butterfly (Parmesan , 1996) showed that populations at the far southern end of its range(in Mexico) have four times the extinction rate of populations in the far northern end of its range(in Canada). Extinctions are also about two-and-a-half times higher at low elevations compared with populations above 2400 m. An analysis of land use change showed that human degradation of habitat could not have caused this pattern. The pattern of extinctions means that , over this century , the average distribution has shifted northward by 92 km and upward by 124 m.

Changes to alpine flora over 70 to 90 years showed that even moderate warming causes plant communities to migrate(Grabherr et al. , 1994). As the temperature has increased , alpine flora has migrated to higher elevation where it is relatively cool. However , migration is occurring at a much slower rate than changes in temperature. New areas are being colonised more slowly than the rate at which the original areas are becoming unsuitable , because they are too warm. The area of suitable habitat is therefore diminishing in size.

Species can survive by shifting their geographic range northwards or to higher elevations. However , they may not be able to do so if climate change is so rapid that they , or the other species on which they depend for food and shelter , cannot disperse to colonise new areas where the climate has become suitable for them. Estimates of the dispersal abilities of some plants indicate that they will be unable to shift their distribution by dispersal rapidly enough to keep pace with the shift in the location of their optimal climate conditions.

Dispersal will be even more problematic in landscapes where farmland or buildings have ren-

dered scarce and isolated the places where the plants or animals can live and reproduce. For example , if the climate changes as forecast for the next century , the climatic conditions associated with most grassland breeding bird species in the US will shift northward into a region presently occupied by forests. It is unlikely that the grassland plant and insect communities , on which the birds depended , will shift northward at the same rate. There is a risk that grassland birds will be unable to maintain their range and numbers in the face of this mismatch(BirdLife International WWF , 1997).

3.3 Migration strategies

Many animal species migrate. Bird migration has been studied in particular detail and it has become clear that the success of migration depends on the right places being available at the right times of year with the right food needed to complete the migration. Damaging the links in the chain of areas vital to migration threatens the survival of migrants. The quality of departure sites , staging posts and final destinations , is extremely important. If the habitat conditions and availability of food change , the suitability of the site may be drastically reduced. For example , in the US , Delaware Bay is a vital feeding ground for red knots , which feed on the eggs of the horseshoe crab. Eggs are a vital fuel source of food to sustain the red knots in the arctic. Any changes in the timing and availability of eggs or the arrival of the knots will have an adverse impact on the success of the birds in reaching their destination(BirdLife International WWF , 1997). Food supplies at staging areas during the spring migration may affect not only a bird's ability to reach its destination but also its breeding success.

Changes to important sites , as a result of climate change leading to drought or sea level rise , could have serious impacts on the populations that rely on these habitats for wintering and refuelling. Permanent removal of these sites through drought could require changes in migration routes , which is only possible if the species can make the necessary changes to its navigational programme. The effect of change on long-distance migrants will depend on how quickly it occurs because this will determine whether they can adapt. For example , knots spend many months of the year on the move , covering great distances , to breed in the arctic. If they continue with their old migration strategy after climate changes have affected their feeding grounds and staging posts , their populations will decline(Ens , 1996). At present , some species of songbirds and shorebirds rely on wind assistance to cross areas in which they cannot feed , such as the Sahara Desert. If wind circulation patterns change then migrants may not be able to cross these ecological barriers , especially if they are carrying maximum fuel loads on departure.

Plant species migrate too. Forecasts of global warming are often illustrated with maps showing the poleward movement of plant species , as though the biosphere were made up of puzzle pieces that could be rearranged at will. In reality , it may take plant populations years or decades to move substantial distances. Moreover , today must move through a landscape that human activity has rendered increasingly impossible. Under the circumstances , it is possible that many species might perish , caught in the double bind of climate change and habitat degradation(Pitelka et al. , 1997).

Some scientists have examined the fossil record of plant migration following ancient climate upheavals. Others have studied contemporary invasions of exotic species. Still others have analysed the mathematics of dispersal mechanisms and the interaction of those mechanisms with contemporary landscape patterning(Pitelka et al. , 1997). These three lines of research provide disparate – even contradictory – insights. Past migrations have been much faster than simple calculations based on seed dispersal by wind or by vertebrate animals would predict. Plants appears to be capable of long-distance jumps and of rapidly spreading from pre-established outliner positions. But it is also evident that human activity has greatly altered patterns of plant migration. People disperse seeds farther and faster than the seeds' own dispersal mechanisms can take them. But people also fragment the land space , creating habitat patchworks that are usually less able to support either plant species or their animal conveyances than are undisturbed landscapes. Some of these factors would seem to retard plant migration and others to accelerate it.

The paleorecord provides compelling evidence that plant migration can be rapid enough to track climate change and that migrations can take place by means of sporadic long-distance leaps. For example, by mapping the accumulation of pollen in lake sediments at sites widely dispersal in time and space, paleoecologists have produced maps that indicate some tree species advanced rapidly during the early Holocene epoch, following the retreat of the North American glaciers(Webb et al., 1987). The high migration rates and the ability of species to jump large bodies of water reveal an underlying potential for relatively rapid response to climate change.

How many kilometers can a tree species traverse in a year? A plausible set of velocities can be calculated from analyses of past migrations. In eastern North America, the migration velocities were as high as 1 kilometer a year. Moreover, these velocities seem to have been unaffected by dispersal barriers, even ones the size of the Great Lakes and the North and Baltic seas(Woods and Davis, 1989 ; Kullman, 1996). How could trees move so fast and leap obstacles so broad? This outcome had led modellers to suspect that migration is accomplished mainly by rare long jumps that escape our observation.

On the whole, plants have moved fast enough to track climate change, and may be capable of faster migration than is seen in the paleorecord. These migrations have come in response to change that in some cases has been as fast as the rapid warming predicted for the next few decades. During the last glacial period, there were repeated episodes of warming in which the mean annual global temperature rose by 5 °C or more within a few decades(Nicholls et al., 1996).

Studies of contemporary plant invasions also provide evidence for the long-jump-and-outlier mechanism of spread. A particularly dramatic example is the recent expansion of cheatgrass, the Eurasian grass *Bromus tectorum*, in western North America(Mark, 1986). This aggressive alien grass occupied most of its current range of about 2×10^5 km² within the last decade of a 40 year invasion process. The evidence suggests that the grass arrived in the region in the 1880, as a contaminant in agricultural seed. Before 1990, the species had established itself in at least five locations in the region. Over the next 20 years at least 50 additional foci appeared, but the total area occupied by the grass was still small. Then, within only about 10 years(1920 ~ 1930), the grass filled in between these foci, becoming a dominant species throughout the region.

Evidence of plant migration are not only from observations but also from predictions. In the past species have responded individually(Huntley, 1991) to climate change. Different species together in present-day plant assemblages could respond in very different ways to rapidly changing climate. Predicting how a species range may change under a future climate is therefore important in trying to understand how a landscape as a whole may respond(Sykes, 1997). To be able to do this in any sensible way it is first important to have tools that accurately describe present-day species distributions. STASH is a simple equilibrium model(Sykes, 1997 ; Sykes et al., 1996) which is used as a tool to simulate such distributions. It describes plant species' ranges in terms of a number of bioclimatic variables which represent distinct physiological limiting mechanisms rather than using simple correlation with some climate variables. The model and some bioclimate variables were used to model individual species' potential range changes in the global environment(Sykes, 1997) and to simulate potential distributions of European trees and transient forest dynamics(Sykes and Prentice, 1996). For example, *Picea abies*, *Fagus sylvatica*, and *Quercus robur*, simulations of two Atmospheric General Circulation Models (GFDL and OSU scenarios) induced dramatic changes in the equilibrium distribution to northward and to high elevation(Sykes et al., 1996).

3.4 Important sites

Some places are vital for the maintenance of biodiversity. Many special wild species sites are fragments of natural areas that were once more extensive, but are now isolated remnants within large tracts developed for human use. Other sites hold unique combinations of plant and animal species because of their unusual topography or hydrology, such as an isolated mountain top. Past changes in climate would have altered the flora and fauna of these sites, but, with more extensive natural areas,

they would probably have caused shifts in the distribution of species and communities , rather than their disappearance.

Many wild species sites are nature reserves and already have recognition under one of several international conventions , but preventing loss of biodiversity in the world's protected areas will require careful planning and management. We must forecast the way in which climate change will affect the world's most precious wild species areas and develop conservation strategies which recognise that the natural ranges of species will not be static in the face of global climate change. The geographic ranges of many species will need to shift if they are to survive. Improving the connections which allow dispersal between remnants of natural habitats may be necessary to accommodate such shifts.

A 1°C increase in temperature may significantly alter the species composition in some statutory protected areas. For example , montane habitats supporting ptarmigans , snow buntings and dotterels have a very specific - and very cold - climate(BirdLife International WWF , 1997). Such a cold winter climate will not be found by the end of next century.

The distribution of most plant species in Europe shows a close match to particular combinations of summer warmth , winter cold and drought. The climate changes forecast for the next century will result in large shifts in the location of climate regimes suitable for many species. Estimates of the ability of each species to colonise new areas and to spread across barriers of unsuitable habitat indicate that plants may not be able to occupy much of their potential range. This will be because of a combination of restricted seed dispersal and the presence of barriers caused by fragmentation of suitable habitat by human land-use. Shifts in geographic range in response to climate change may not be possible for species with low dispersal rates confined to isolated areas by past habitat fragmentation (Huntley et al. , 1995).

4 SUMMARY

Climate change is expected to affect wild species because environmental factors determined by climate affect the physiology , survival and performance of every species studied in detail. These environmental factors include air , water and soil temperatures , humidity , soil moisture and wind speed.

Wild species will be influenced not only by the direct effects of temperature and humidity , but also by the indirect effect of changes in their competitors , predators , parasites and diseases. The effect of climate change on individual species will be complex , and therefore even subtle changes may cause large changes in plant and animal communities.

Macro-fossils and pollen show that , in the past , species shifted the geographic range as the climate changed. However , current estimates suggest that some species will not be able to move quickly enough to respond to the predicted climate change. This is especially true of areas where human land-use has made suitable conditions scarce and fragmented.

Climate change , particularly it is rapid , could considerably disrupt long established relationships between species. The timing of important events in the life cycle of plants and animals , such as leafing , flowering , migration , emergence from pupae and egg-laying , is sensitive to annual fluctuations and long-term trends in climate. The timing of events is often finely adapted to coincide with life cycle events of other species that provide food or shelter.

Climate change is already cited as the most likely case of changes in the abundance and distribution of a number of plants and animals. In some cases more investigation is needed to exclude possible alternative explanations. Research into many other species is also required. However , the impact of small recent changes in climate on wild species is already sufficient to trigger concern about the effects of the larger climate changes forecast for the next century.

The world's ecosystems are of immense value to humans. Given the lack of our knowledge about biodiversity and the complexity of ecological relationships , it seems probable that their importance is even greater than we suppose. Therefore , the disruptive effects of climate change on ecosystems may

be a serious threat to human welfare.

The challenge of climate change demands that we adopt new approaches to studying its impact on flora and fauna (BirdLife International and WWF , 1997). We need : (1) increased co-ordination between scientific disciplines , for example between climatologists and ecologists ; (2) to understand the mechanisms by which climate change affects flora and fauna ; (3) to search for , and analyse , long-term data sets , many of which will have been collected in unconventional ways ; (4) to ensure that long-term monitoring of flora and fauna continues into the future ; (5) to focus on changes in timing of the life cycles of interacting species , for example predators and their prey ; (6) to understand the impacts on endangered species , those of economic importance (e. g. pests and game species) and those responsible for infectious diseases ; (7) to build the evidence of the impact of climate change by studying more species from more geographical areas , especially the tropics ; (8) to fully consider competing hypotheses that many explain and observed changes ; (9) rapid dissemination of findings to political as well as scientific audiences , but using the pre-reviewed scientific literature

We must act now on the warning wild species is giving and reduce emissions of GHGs pollutants to secure a future for global wild species. Governments and everyone worldwide should support and work together to meet that aim. However , even if emissions are drastically reduced tomorrow , the climate will still change because some GHGs stay in the atmosphere for a very long time. Therefore , as well as the serious impacts we are already witnessing , we also face the prospect of inevitable impacts of future climate change.

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全球变化与野生物种 :观测和预测

倪健^{1, 2}

1 中国科学院植物研究所植被数量生态学开放研究实验室 , 北京 100093
2 瑞典隆德大学生态学系气候影响室 , 隆德 22362

摘 要 由于人类活动的影响 ,世界正在变暖。迅速的全球变化很可能对野生物种产生巨大影响 ,同时伴随着城市化、农垦和造林实践所引起的自然生境的丧失和破坏。观测和预测的气候变化对野生物种的影响着眼于 4 个方面 :生活史的时间、物种分布与种群格局、迁移对策以及重要地点。许多物种可能因气候的变化而灭绝 ,而气候变化所造成的野生物种分布的变化很可能对人类产生长期久远的影响。

关键词 气候变化 ,灭绝 ,全球变暖 ,迁移 ,范围移动 ,野生物种