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Editors

Climate Change and Food Security in West Asia and North Africa

Springer

Chapter 7
Climate Change and Locusts in the WANA Region

Keith Cressman

Abstract The Desert Locust is probably the oldest and most feared migratory pest in the world, plaguing farmers in Africa and Asia since Phaoronic times. Under optimal conditions, locusts increase rapidly and form swarms. A single swarm, larger than Paris or Cairo, can contain billions of insects, migrate across continents, and eat enough food for 2,500 people in 1 day. During plagues, vulnerable households can find themselves in debt, limited national resources are rapidly depleted and food security can be at risk in affected countries. It can take several years and hundreds of millions of dollars to bring a plague to an end. Changes in the climate during the remainder of this century will affect Desert Locust habitats, breeding, migration and plague dynamics in West Asia and North Africa (WANA). Although it is widely acknowledged that WANA will become warmer, there are differing views about changes in precipitation under the various climate change scenarios. General trends may contain hidden variations within the regions and countries. Certain areas will become more prone to extreme events such as flooding and droughts. Regular assessment of climate change impacts is a component of the locust early warning system operated by the Food and Agriculture Organization (FAO) of the United Nations to monitor the global situation and alert locust-affected countries and international donors. The latest scientific evidence is reviewed to postulate potential effects on the Desert Locust. It is probably reasonable to assume that this ancient pest, which is particularly well suited for survival under difficult conditions in arid areas and has successfully endured previous changes in the climate, will adapt to climate variability in the foreseeable future.

Keywords Temperature effects • Locust migration • Locust breeding • Wind effects

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M.V.K. Sivakumar et al. (eds.), *Climate Change and Food Security in West Asia and North Africa*, DOI 10.1007/978-94-007-6751-5_7,

7.1 Introduction

The Desert Locust (*Schistocerca gregaria*, Forskål) is a pest well known to farmers, nomads and locals in West Asia and North Africa (WANA). It is probably the oldest and most feared of all migratory pests in the world. Its presence in Egypt has been documented during Phaoronic times, some 5,000 years ago, and is mentioned in the Bible and the Koran. Under normal conditions, low numbers of individual solitary adults are present within a vast desert area of some 16 million km^2, extending from West Africa to India. When good rains fall, females lay eggs in sandy soil that normally hatch after about 2 weeks into wingless larvae or nymphs called hoppers. Hoppers undergo a process of moulting in which they shed their skin five or six times, each time growing in size. The final moult from the wingless hopper to the winged adult is called fledging. The new adult, known as a fledgling, has soft wings that must dry and harden after a few days before it can fly. Adults are initially immature but eventually become sexually mature and, after about 1 month, they are ready to lay eggs. The entire lifecycle takes about 2–6 months, depending on temperature and habitat conditions. Favourable maturation conditions are usually associated with rain and warm temperatures. Locust eggs, hoppers and adults will mature faster under warmer temperatures. Immature adults can survive for 6 months or more under cool dry conditions but adults cannot survive for long under hot dry conditions with little to eat.

Desert Locusts have the ability to change their behaviour, physiology, colour and shape in response to a change in locust numbers. At low numbers, they behave as individuals (solitary phase) and at high numbers they behave as a single mass (gregarious phase). This process is referred to as *gregarization* and the intermediate phase between solitary and gregarious is called *transiens*. Three processes are involved in phase transformation: concentration, multiplication and gregarization. Scattered locusts will concentrate in green vegetation in response to habitat conditions and as a result of convergent winds and, as locust numbers increase, they form small groups. Grouping can be considered as an intermediate step in the change from solitary hoppers and adults to gregarious hopper bands and adult swarms. If sufficient numbers of locusts are present or if good rains fall and there is another generation of breeding, then locust numbers can increase rapidly and hopper bands and swarms can form.

Locust adults migrate with the wind as passive fliers flying downwind at roughly the wind speed up to about 1,800 m above the ground. Solitary adults fly at night while swarms migrate during the day. Downwind displacement of up to about 200 km per day tends to bring locusts into seasonal rainfall areas. Locust movements often take place during periods of particular winds rather than coinciding with the prevailing wind flow. Furthermore, rare and even unprecedented movements can occur, for example, migration across the Atlantic Ocean from West Africa to the Caribbean in October 1988.

Desert Locusts are normally present at low densities in semi-arid or arid areas away from major cropping areas. They do not pose a significant threat to agriculture and hopper bands and swarms are rare or completely absent. This calm period is called a recession. The transition from a recession to a plague is characterized by outbreaks and upsurges. An outbreak occurs when there is an increase in locust numbers over several months in a relatively small area. It is localized and restricted to certain habitats in an individual country. Small groups of hoppers and adults, hopper bands and adult swarms may form as the outbreak continues. If an outbreak is not controlled and if good rains fall, locusts will continue to multiply, concentrate and gregarize so that with each additional generation the proportion of the total population in bands and swarms increases. This is referred to as an upsurge. An upsurge may affect several countries within a given region. If an upsurge is not controlled and further rains fall, then a plague can develop on a regional or continental scale.

During upsurges and plagues, Desert Locust hopper bands and swarms can damage subsistence crops, pastures, irrigated agricultural areas and export cash crops, threatening the food security of affected countries and regions. One tonne of locusts, a very small part of average swarm, can consume as much food in 1 day as 2,500 people (Steedman 1990). In most of the recession area, farming systems are already naturally vulnerable and fragile, and cannot sustain additional stress or disruption posed by Desert Locust infestations. This fragility could be exacerbated if temperatures become warmer and rainfall decreases in the recession area.

The Food and Agriculture Organization (FAO) of the United Nations (UN) operates an early warning system that monitors weather and ecological conditions, and locust infestations in the recession area on a daily basis. The Desert Locust Information Service (DLIS) at FAO Headquarters acts as a focal point and clearinghouse for all survey and control data transmitted by national locust field teams. The data are analyzed within a geographic information system to assess the current locust situation and forecast the scale, timing and location of breeding and migration. Alerts and warnings are issued to the international community during periods of increased locust activity as part of the early warning system and the global strategy to prevent plagues.

This paper provides an initial attempt to postulate how potential changes in temperature, rainfall and wind associated with climate change and variability might affect Desert Locusts by the end of this century.

7.2 Temperature Effects

Several general circulation models using data collected by the Intergovernmental Panel on Climate Change (IPCC) Data Distribution Center (DDC) indicate that Africa will face future warming, ranging from 0.2 °C per decade (B1 low scenario[1])

[1]The B1 scenario is one of an integrated world that is more ecological friendly, characterized by rapid economic growth, rising population to 2050 then declining, reductions in material intensity and the introduction of efficient technologies, and an emphasis on global solutions to economic, social and environmental stability.

to more than 0.5 °C per decade (A2 high scenario[2]) (Christensen et al. 2007). The warming is expected to be greatest over the interior of the semi-arid margins of the Sahara. Hence, by 2100, temperatures could be as much as 4 °C higher than today.

7.2.1 Locust Breeding

The effect of warmer temperatures could cause Desert Locust maturation to occur more rapidly, leading to an overall shorter lifecycle of the insect. Warmer temperatures could also potentially allow breeding to commence earlier and last longer in each seasonal breeding area if there is rainfall, or end earlier if there is no rainfall. A prolonged season of favourable breeding conditions could allow for a possibility of at least one extra generation. This, in turn, would cause Desert Locust numbers to increase much more rapidly than at present under current temperature conditions. On the other hand, increased temperatures without a corresponding increase in precipitation would cause ecological conditions for breeding and survival, that is moist soil and green vegetation, to deteriorate faster than under current conditions. This would reduce the length of possible breeding within a given season and the likelihood of extra generations. Consequently, locust numbers would not increase very much. Nevertheless, rapid drying of ecological conditions would encourage gregarization as locusts crowd into those few areas that remain green; however, the scale of this gregarization would be limited due to lower than normal numbers of locust.

A model was used to estimate the potential effect of future warming on the maturation rate of locust eggs and hoppers. The model, known as the *Desert Locust Egg and Hopper Simulation Programme*, estimates the egg and hopper development periods of the Desert Locust using long-term monthly mean temperatures from weather stations in the Desert Locust recession area (Reus and Symmons 1992). It calculates the daily mean temperature and the daily-related amount of development. Egg and hopper development rates are assumed to be zero when the daily mean temperature is below 10 °C. When the mean temperature is below 20 °C, model results are interpreted with caution as there may be an overestimate of the actual egg and hopper development periods.

For this study, the model was used to estimate egg and hopper development rates under normal (current) conditions and under future extreme warming conditions. In order to use the model for the latter situation, it was modified by increasing the long-term monthly mean temperatures of the weather stations by 4 °C. Three breeding seasons were examined: (a) summer (May to December) in the Sahel from

[2]The A2 scenario is of a more divided world characterized by independent operating, self-reliant nations, continuously increasing population, regionally oriented economic development, and slower technological changes and improvement to per capita income.

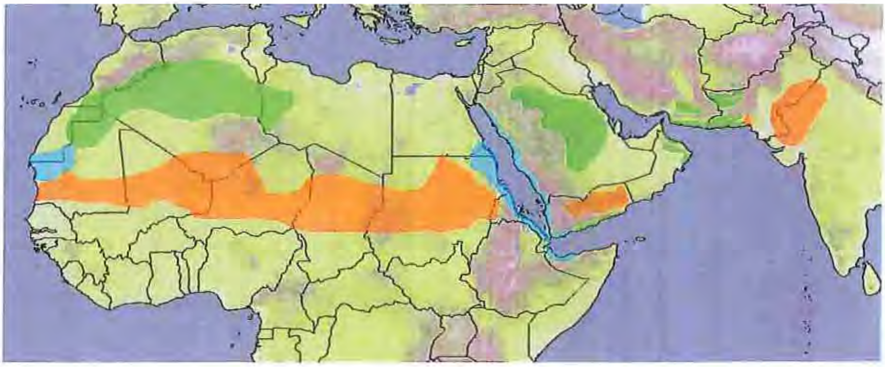

Fig. 7.1 Seasonal breeding areas of the Desert Locust – orange (summer, May/Jul to Oct/Dec), blue (winter, Oct/Nov to Mar/May), green (spring, Jan/Mar to May/June)

West Africa to Sudan and along both sides of the Indo-Pakistan border, (b) winter (October to May) along both sides of the Red Sea, the northern coast of the Horn of Africa and in northern Mauritania, and (c) spring (January to June) in northwest Africa south of the Atlas Mountains, in the interior of Saudi Arabia and in Baluchistan of western Pakistan and southeastern Iran (Fig. 7.1). Each season consisted of different temperature regimes. The summer period corresponded to declining temperatures as the season progressed; the winter to an initial decline, then increasing temperatures; and the spring to increasing temperatures throughout the season. Seven to eight representative weather stations were used in each season. The time period for each breeding season was extended by one or more months before and after the current breeding period to allow for any effects of increased warming. The model was run on the 15th day of each month within the breeding season period forward in time from egg laying to hopper fledging. The outputs of the model consisted of the estimated dates of egg hatching and hopper fledging. The minimum, maximum and mean number of days for hatching and fledging under normal and future extreme warming conditions were compared and contrasted with each other for each of the three breeding seasons.

The results suggest a number of trends for each season (Figs. 7.2–7.4):

- *Extended spring period* (January to June). Under warmer conditions, hatching was on average up to 2 weeks shorter and fledging was 1–3 weeks shorter than normal conditions. The greatest differences occurred at the beginning of the season when temperatures were still low while as the season progressed and temperatures increased, the differences became less. In January, hatching was up to 27 days faster and fledging was 35 days faster under warmer conditions. In both normal and warmer temperatures, the theoretical maximum number of generations during the extended spring from 1 January to 30 June remained as two although this occurred about 1 month faster under warmer conditions.
- *Extended summer period* (May to December). There was no significant effect of warmer conditions on the time required for hatching except at the end of the

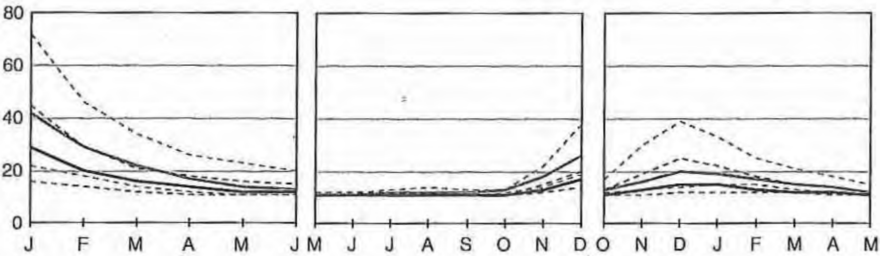

Fig. 7.2 The average number of days required for egg development under normal (*gray line*) and warmer (+4 °C) (*dark line*) conditions in the spring (January to June), summer (May to December) and winter (October to May) breeding areas. *Dashed lines* represent minimum and maximum values

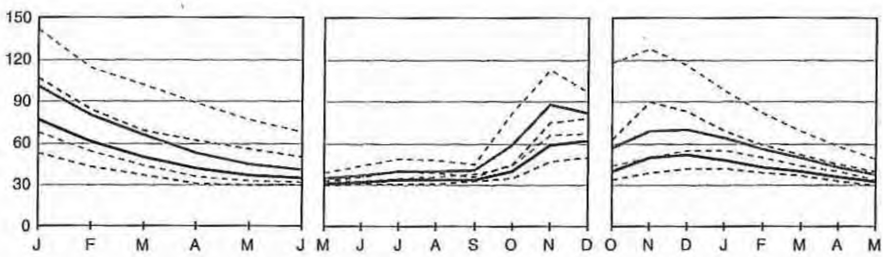

Fig. 7.3 The average number of days required for hopper development under normal (*gray line*) and warmer (+4 °C) (*dark line*) conditions in the spring (January to June), summer (May to December) and winter (October to May) breeding areas. *Dashed lines* represent minimum and maximum values

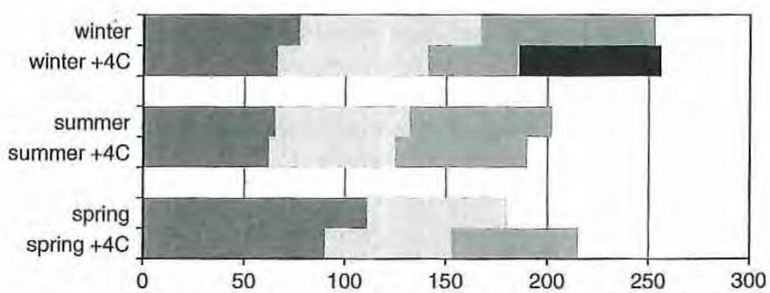

Fig. 7.4 The theoretical potential number of Desert Locust generations and their length (days) during the extended summer, winter and spring breeding periods under normal and warmer (+4 °C) conditions

season (December) when on average it was about 9 days shorter than under normal current temperature conditions. On the other hand, the length of time required for fledging decreased by about 1 week throughout the season under warmer conditions, and up to 2–4 weeks by the end of the extended season when temperatures are declining from October onwards. In both normal and warmer temperatures, the theoretical maximum number of generations during the extended summer from 1 May to 31 December remained as three. Under warmer conditions, summer breeding finished about 2 weeks earlier than under normal temperatures, assuming no temperature effects on adult maturation.

- *Extended winter period* (October to May). Under warmer conditions, hatching was generally only a few days shorter while fledging was 1–2 weeks shorter than normal conditions. As temperatures were initially declining, hatching was on average about 5 days faster in December and fledging was up 2 weeks faster from October to February under warmer conditions. There is a possibility that four generations of breeding could occur under warmer conditions compared to three under normal temperatures.

The reliability of the model results may be affected by differences in the relationship between air temperature and the temperature experienced by locust eggs and hoppers (Reus and Symmons 1992).

7.2.2 Locust Migration

During recession periods when the majority of Desert Locust populations are solitarious in low numbers, adults migrate at night, normally taking off about 20 min after sunset and flying for up to 10 h, or an average of 2 h per night (Symmons and Cressman 2001). Swarms, on the other hand, fly during the day, taking off about 2–3 h after sunrise in warm weather and 4–6 h after sunrise in cooler weather. Swarms will take off in temperatures of 15–17 °C under sunny conditions and 23–26 °C under cloudy conditions, and fly for 9–20 h. Swarms normally settle on the ground for the night about 2 h before sunset to a half hour after sunset. Adults and swarms are passive fliers, moving downwind at or near the wind speed. Swarms can easily move up to 200 km in a day while adults may move anywhere from 1 to 400 km in a night. The limiting temperature for both day and night flights is about 20–22 °C.

Warmer temperatures could potentially affect locust migration by allowing adults to fly longer during nights, especially during the autumn and spring when nighttime temperatures are usually cooler. Consequently, adults may arrive at destinations sooner or reach new areas further away. Warmer temperatures could allow swarms to take off earlier in the morning, allowing for a longer period of flight and a greater displacement distance. Under future warming, swarms could perhaps reach areas quicker than in the past.

Locusts normally fly up to about 1,800 m above ground. Assuming that the height limits are temperature dependent, then warmer temperatures could allow adults to theoretically fly higher. If this is the case, then some of the natural barriers to migration such as the Atlas Mountains in northwest Africa, the Hoggar Mountains in the Algerian Sahara, the mountain ranges along both sides of the Red Sea,

Fig. 7.5 Natural barriers to Desert Locust migration in the recession area

the Jebel Akdar in northern Oman and the mountains in the interior of Iran may no longer be effective (Fig. 7.5). This could permit new migration routes, allowing swarms to reach southern Europe and central Asia, assuming that the winds are favourable.

7.3 Rainfall Effects

Warming generally increases the spatial variability of precipitation, leading to a decrease of rainfall in the subtropics and an increase in higher latitudes and in parts of the tropics (Christensen et al. 2007). Increased rainfall may arise from enhanced moisture convergence associated with monsoonal circulations. Although increasingly reliable regional climate change projections are becoming available with improved resolution, predictions of how climate change will affect rainfall in the Sahara Desert remain varied and lack consensus.

The fourth assessment synthesis IPCC Report (2007) indicates that annual rainfall is likely to decrease in the northern Sahara by up to 18 % with a greater likelihood of declining rainfall (up to 30 %) as the Mediterranean coast is approached (Fig. 7.6). This area includes Mauritania, Western Sahara, Morocco, Tunisia, and the northern portions of Algeria, Libya and Egypt. It is unclear how rainfall in the Sahel (Mali, Niger, Chad and Sudan) and the southern Sahara in Algeria, Libya and Egypt will evolve as the various models are in disagreement. Prior to this report, it had been suggested that rainfall might increase in the Sahel as a result of increasing carbon dioxide levels leading to an increase in vegetation growth and moisture levels (Claussen et al. 2003). Other researchers hypothesize that increasing land-ocean temperatures and decreasing surface pressures over the Sahara may contribute to increased rainfall in the Sahel (Biasutti et al. 2009; Haarsma et al. 2005) or may not (Schepanski and Knippertz 2011).

In Northeast Africa, annual rainfall is likely to increase during December–February in Ethiopia and Somalia. One study suggested that mean precipitation

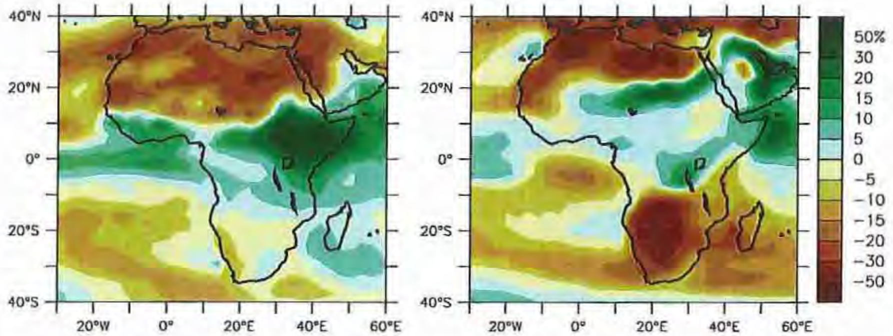

Fig. 7.6 Precipitation changes from the MMD-A1 simulations between 1980–1999 and 2080–2099 over Africa and the Near East during the winter (December–February) and summer (June–August) averaged over 21 models (Christensen et al. 2007)

would decrease in Sudan and the Ethiopian Highlands in June and July, and increase in September and October (de Boer 2007).

Desert Locusts normally breed during the winter along both sides of the Red Sea and occasionally in northern Mauritania. During the spring, breeding usually occurs in Baluchistan in western Pakistan and southeast Iran, and occasionally in the interior of the Arabian Peninsula, and along the southern side of the Atlas Mountains in Morocco and Algeria. Spring breeding is most pronounced during periods of increased locust activity and during upsurges and plagues. During the summer, locust breeding takes place in the northern Sahel between Mauritania and western Eritrea, and along both sides of the Indo-Pakistan border. Relative changes in precipitation for 2090–2099 compared to 1980–1999 under the A1B climate change scenario[3] indicate up to 20–30 % decrease in rainfall in northern Mauritania and along the Red Sea coast in Egypt, Sudan and Saudi Arabia (Fig. 7.6). For the same period, a 5–20 % increase in rainfall is projected for the Red Sea coast in Eritrea and Yemen and the Gulf of Aden coast in southern Yemen and northern Somalia. In the summer breeding areas, a 10–20 % decline in rainfall is projected for Mauritania while a 5–20 % increase is estimated over the northern Sahel in Mali, Niger, Chad and Sudan as well as in the interior of Yemen (Christensen et al. 2007). There is not a clear indication of rainfall effects along the Indo-Pakistan border or in the spring breeding areas.

It is worthwhile to note that none of the model-simulated current or future rainfall in the Desert Locust recession area is similar to that observed in recent decades. Perhaps some of this can be explained by the absence of land cover and atmospheric (dust and biomass aerosols) processes in the models (Hulme et al. 2001).

[3]The main characteristics of the A1B scenario include low population growth, very high GDP growth, very high energy use, low-medium land use changes, medium resource (mainly oil and gas) availability, and rapid pace and direction of technological change favoring balanced development.

Limited research on extreme rainfall events suggests that there may be a general increase in the intensity of high-rainfall events in Africa (Christensen et al. 2007). The importance of extreme rainfall events and their link to Desert Locust plagues should not be underestimated. For example, a cyclone in Oman in 1968 led to a plague and widespread unusually heavy rain from Dakar, Senegal to Morocco in October 2003 caused a regional plague in North Africa in 2004–2005.

7.4 Wind Effects

Since Desert Locust are passive fliers and fly with the wind, then shifts in wind direction and speed due to climate change and variability could affect locust migration routes and daily displacement speed. If wind patterns or the geographic distribution of wind change, then adults could be carried to new areas; however, if ecological and weather conditions in the new areas differ significantly from those in the semi-arid and arid habitats, then locusts are not likely to survive and become established. For example, the species did not become established in the Caribbean after Desert Locust swarms migrated from West Africa in October 1988 because of ecological and weather conditions (Ritchie and Pedgley 1989).

Climate change may affect the geographic distribution and the annual variability of winds but only very limited research has been conducted in this field. There is some evidence that, by the end of the twenty-first century, there will be small magnitude changes in winds with potential increases of extreme winds over northern Europe and a general decline in average wind speeds in northern latitudes, depending on the time of year (Pryor and Barthelmie 2010; Ren 2010). There is also a possibility that coastal winds might increase while interior winds could decrease by up to 12 % (Harley et al. 2006). If climate change alters the jet stream and completely rearranges global air circulation and ocean currents, then local wind patterns, those that affect the Desert Locust, will certainly change. However, the potential impact of global climate variability and change on wind remains unclear, especially in the Desert Locust recession area.

7.5 Conclusions

The bulk of this study concentrated on temperature effects because, of the three parameters important to Desert Locust, there is the greatest agreement on potential impacts of climate change and variability. In contrast, there is much less certainty about the impact on rainfall in certain areas and on winds in general.

Under warmer conditions associated with climate change and variability, Desert Locust eggs and hoppers could potentially develop faster during the coldest time of each seasonal breeding period. The greatest impact was seen during the extended spring breeding period when the time required for fledging decreased by 35 days and that for hatching by 27 days in January, the coldest month at the beginning of the season. A similar trend was noted during the summer (fledging shortened by 26 days and hatching by 10 days at the end of the season in December) and the winter (fledging shortened by 14 days and hatching by 5 days in December, the coldest month). Changes in the development rate of eggs and hoppers during warmer periods of each season (i.e. the beginning of summer, and the end of winter and spring) did not vary so much; eggs still required at least 10 days to hatch and hoppers at least 24 days to fledge. However, there is a possibility for an extra generation of breeding during the winter under warmer temperature conditions.

During the winter, a 20–30 % decrease in rainfall in the locust breeding areas in northwest Mauritania and along both sides of the central and northern Red Sea would be expected to reduce the scale of breeding. Reduced breeding would affect the number of locusts present at the end of the breeding season that would then move to the summer breeding areas in the northern Sahel of West Africa and Sudan, and the interior of Yemen. In this case, fewer locusts would be present to take advantage of summer rainfall for breeding. A further 10–20 % decline in expected summer rainfall in Mauritania would exacerbate this situation, potentially causing a significant and dramatic decline in locust activity within the country. The only exception to this could be along the Red Sea coast of Yemen and southern Eritrea and along both sides of the Gulf of Aden. Here, a 5–20 % increase is projected that could cause an increase in locust numbers that could eventually move into the summer breeding areas in the interior of Sudan and Yemen.

During the summer, rainfall is projected to increase in the northern Sahel from Mali to Sudan and in the Yemen interior by 5–20 %. This could allow the initially low populations in Mali, Niger and Chad to increase to normal levels, and the potentially higher than normal populations in Sudan and Yemen to increase further. If increased rainfall was to continue beyond August in these areas, then another generation of breeding could occur, potentially causing a substantial increase in locust numbers. These populations could act as a source for winter breeding.

Nevertheless, the combined effects of both temperature and rainfall must be evaluated together since successful breeding requires both components. In this case, locust activity could potentially increase during the summer in the interior of Sudan and Yemen and during the winter along the coastal plains of the southern Red Sea in Eritrea and Yemen and along both sides of the Gulf of Aden in southern Yemen and northern Somalia. Increased locust activity in both the summer and winter breeding areas within the region could lead to a progressive buildup of locust populations in Sudan, Eritrea, Yemen and northern Somalia. In the northern Sahel of Mali, Niger and Chad, locust activity is likely to remain at normal levels; that is, neither increasing or decreasing significantly because populations produced during the summer in increased rainfall areas would be kept in check by poorer than normal rains and subsequent breeding in northwest Mauritania during the winter. Potential locust activity in Mauritania could decline dramatically given the anticipated decreases in rainfall during the summer and winter under warmer conditions.

The effects of temperature and rainfall in the summer breeding areas along the Indo-Pakistan border and in the spring breeding areas of Arabia, Baluchistan and

Northwest Africa could not be assessed due to inconclusive estimates of rainfall changes under warmer conditions. The effects of wind are less certain but any changes in wind speed, direction and circulation flows are likely to affect Desert Locust migration and could allow adults and swarms to reach new areas. Whether they will be able to become established, survive and breed in these new areas will depend on ecological and habitat conditions.

Further research is required to better understand the impacts of climate change and variability on the Desert Locust. For example, Desert Locust outbreaks and upsurges should be cataloged and correlated with drought indices and rainfall anomalies to gain further insight into the relationship of droughts and extreme rainfall events with increases in Desert Locust activity. Potential areas at risk by Desert Locust under warming conditions should be investigated to identify any new threats to national and regional food security. Lastly, the data required to operate global and regional climate change models need to be improved, more accessible and shared amongst the various stakeholders. Integrated models should be developed to test different climate change scenarios. Policy makers should be made aware of the uncertainty of the potential impacts of climate change and variability on agricultural production and food security, and the need to expand contingency planning to include different climate change scenarios and include these in national locust programmes.

References

Biasutti M, Sobel AH, Camargo SJ (2009) The role of the Sahara low in summertime Sahel rainfall variability and change in the CMIP3 model. J Climate 22:5755–5771. doi:10.1175/2009JCLI29969.1

Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli RK, Kwon WT, Laprise R, Magaña Rueda V, Mearns L, Menéndez CG, Räisänen J, Rinke A, Sarr A, Whetton P (2007) Regional climate projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK

Claussen M, Brovkin V, Ganopolski A, Kubatzki C, Petoukhov V (2003) Climate change in Northern Africa: the past is not the future. Clim Change 57:99–118

de Boer B (2007) The impact of climate change on rainfall extremes over Northeast Africa. Royal Netherlands Meteorological Institute (KNMI). De Bilt (The Netherlands), 46 pp

Haarsma RJ, Selten F, Weber S, Kliphuis M (2005) Sahel rainfall variability and response to greenhouse warming. Geophys Res Lett 32:L17702. doi:10.1029/2005GL023232

Harley CDG, Randall Hughes A, Hultgren KM, Miner BG, Sorte CJB, Thornber CS, Rodriguez LF, Tomanek L, Williams SL (2006) The impacts of climate change in coastal marine systems. Ecol Lett 9:228–241. doi:10.1111/j.1461-0248.2005.00871.x

Hulme M, Doherty R, Ngara T, New M, Lister D (2001) African climate change: 1900–2100. Clim Res 17:145–168

Pryor SC, Barthelmie RJ (2010) Climate change impacts on wind energy: a review. Renew Sust Energy Rev 14:430–437

Ren D (2010) Effects of global warming on wind energy availability. Renew Sust Energy Rev 2:052301. doi:10.1063/1.3486072

Reus JAWA, Symmons P (1992) A model to predict the incubation and nymphal development periods of the desert locust, *Schistocerca gregaria* (Orthoptera: Acrididae). Bull Entomol Res 82:517–520

Ritchie M, Pedgley D (1989) Desert Locust across the Atlantic. Antenna 13:10–12

Schepanski K, Knippertz P (2011) Soudano-Saharan depressions and their importance for precipitation and dust: a new perspective on a classical synoptic concept. Q J Roy Meteor Soc 137:1431–1445. doi:10.1002/qj.850

Steedman A (ed) (1990) Locust handbook. Natural Resources Institute, Chatham, p 204

Symmons P, Cressman K (2001) Desert locust guidelines I. Biology and behaviour. FAO, Rome, p 43

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Climate Change and Food Security in West Asia and North Africa

The countries of West Asia and North Africa (WANA) have long had the challenge of providing sustainable livelihoods for their populations in the fragile ecosystems of semi-arid and arid areas. Climate change is already a reality in WANA and it places additional constraints on the already fragile ecosystems of dry areas and limited natural resources in WANA. Hence there is an urgency to develop, and strengthen further, research and technology transfer on adaptation, mitigation and production system resilience. A comprehensive and integrated approach to planning and implementing the climate change adaptation strategies across the wide range of agro-ecosystems in different countries in WANA could help both the planners and the local communities to deal effectively with the projected impacts and also contribute to overall sustainability of agricultural production systems.

This book addresses the important issue of climate change and food security in West Asia and North Africa and presents perspectives from different sub-regions in WANA. The mitigation and adaptation options for different agroeconomic sectors in WANA as well as policy, financial, institutional and cooperation issues are discussed. These could help in the development of new policies to better adapt agriculture production systems and enhance food security in WANA.

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ISBN 978-94-007-6750-8

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