ABSTRACT

South Africa has a long tradition of locust research and control. The life history and biology of the Brown Locust, *Locustana pardalina*, are documented, but little is known of the species’ population dynamics. To understand the mechanisms driving population fluctuations of the Brown Locust, a model for simulating plague events was developed using MATLAB (MATLAB, 1992). A rule-based model that determined the transitions between stages of the locust life-cycle, contingent on daily rainfall and temperature records, was enhanced by migration probability functions based on distance between stations, wind speed, locust flight duration and wind heading.

In order to test simulation effectiveness, simulations for specific stations were compared with data on swarms eradicated in each magisterial district. This information had been collected to pay locust control officers and was used despite the limitations of its accuracy. Rainfall, temperature and wind data were supplied by the South African Weather Bureau.

It was assumed that incorporation of wind-facilitated migration into the basic model would increase the accuracy of predictions. The inclusion of migration tracking routines improves the simulation of outbreak events with respect to timing.

INTRODUCTION

South Africa has a long tradition of locust research and control. The life history and biology of the Brown Locust, *Locustana pardalina*, are documented, but little is known of the species’ population dynamics.

The research described here was part of a collaborative project between various departments of the Agricultural Research Council, namely the Locust Research Unit of the Plant Protection Research Institute (PPRI), the Institute for Soil, Climate and Water (ISCW), the Directorate: Land and Resource Management (DLARM) and University of the Witwatersrand (WITS). The project aims included the development of an early warning system for the Brown Locust. The broader aims of the collaboration were to:

- collect and collate locust data in the outbreak region
- carry out retrospective analysis and mapping of locust outbreaks
- improve locust monitoring systems
- analyse weather data for the outbreak region
model locust outbreaks
• develop an early warning system using weather data, vegetation indices and locust data, integrated into a Geographic Information System (GIS).

The specific aim of the work presented here was to build a locust life-cycle model from information derived from the literature and from the practical experience of staff of Wits and the Locust Research Unit of PPRI.

The Brown Locust is restricted to the more arid regions of southern Africa, to which it is well adapted. Features of the life cycle have recently been reviewed by Price (1988) and Hanrahan (1988). A resident population of the solitary form provides a constant base from which swarming populations can develop, apparently with little warning (Lea, 1958). Eggs are particularly well adapted to arid conditions. They can survive long periods in the dry sandy soils (Mattheé, 1951; Price, 1988) and over-winter. The eggs have a complex diapause, which allows a small proportion of them to remain unhatched even after the normal diapause period is broken and ideal hatching conditions have been experienced (Mattheé, 1951). This allows large populations of eggs to build up in the soil over several seasons (Du Plessis, 1938). The eggs can begin embryonic development but suspend the process and survive up to 45% dehydration and later re-hydrate to continue development when the next rains occur. The process of dehydration and re-hydration can be repeated several times (Mattheé, 1951). Embryos have survived for as long as 3 years in this way (Lounsbury, 1910), but in the field viability declines with time (Botha, 1967).

Extensive marching of hopper bands occurs, but this has been ignored as only short distances are covered. Adult gregarious Brown Locusts undertake largely low altitude flight, 10–20 m above ground. Migration generally starts after sunrise and is temperature-dependent, but night flying also occurs. Factors causing cessation of flight are not clearly established. The important features for the model are locust readiness for flight and wind conditions on a particular day.

The area in which outbreaks are common has an erratic rainfall, and is thought to be influenced by El Niño effects on the Southern Oscillation. Efforts to show a direct correlation between deviation in rainfall and locust ‘boom and bust’ patterns have not been successful.

MATERIALS AND METHODS
Information on swarms eradicated in each magisterial district, collected to pay locust control officers, were used despite the limitations of its accuracy. Data were accumulated into monthly totals for each magisterial district. Rainfall, temperature and wind data were supplied by the South African Weather Bureau. The rainfall and temperature data are recorded daily figures whereas the wind data are generated from wind model data used by the Weather Bureau. Records were searched to find reasonably uninterrupted data series for particular stations that matched a particular locust outbreak. Data from 1986–89 were used, when the last severe outbreak occurred. Efforts were concentrated on four areas namely Douglas, Pofadder, Graaff Reinet and De Aar (Figure 1).

The model consists of two fairly independent sections. The first part is based on the locust life cycle and is derived from an earlier version of the model (Nailand and Hanrahan, 1993). The second section deals with migration (Tilch, 1998).
Modelling Brown Locust Outbreaks

Figure 1  Map of South Africa showing main locust outbreak area 1910–91. Locust control data are catalogued according to magisterial district and weather data according to weather station, mainly located in towns and on specific farms.

Figure 2  The model of the Brown Locust life cycle set out as a block diagram. The shaded area represents the egg stages of the life cycle, showing the complexity of two levels of diapause as well as the cycling between quiescence when eggs dehydrate during dry spells, and turgidity when eggs rehydrate after rain. Eggs only hatch once diapause is broken and they have acquired enough moisture to remain turgid while they complete embryonic development. The clear section on the left of the diagram represents post-hatching instars. Males are noted but not modelled further. Females are shown laying a maximum of four egg packets at fixed time intervals.
The first section of the model uses a rule-based system, dependent on life-cycle parameters to track locust population changes driven by rainfall and temperature at a given site (Starfield et al., 1994). Adequate rainfall is used as the trigger to stimulate egg development. The model updates all individuals at increments of one day on the basis of the rules set. Much of the update of development through the life cycle is dependent on equations for calculating degree-days.

The migration section of the model is constructed differently. On the basis of other studies, it was decided that the following were important considerations.

- Migrations occur predominantly in a down wind direction.
- They only occur if the temperature is sufficiently high.
- The insect flight speed is irrelevant and the rate of movement is that of the prevailing wind speed.

The model therefore takes into account wind speed, wind direction and air temperature and immigration and emigration are calculated on the basis of probability equations. At present the work has considered migration between two stations but could be enlarged to incorporate more (Figure 3).

The model has been developed in MATHWORKS MATLAB (MATLAB, 1992) and can be run on a personal computer with 16 Mbytes of memory. The model now operates through a standard WINDOWS graphical interface with menus and dialogue boxes, with all data input and output in spreadsheet format with graphical and statistical tools.

RESULTS AND DISCUSSION

Figure 4 shows the outbreaks recorded at the four chosen magisterial districts for the period 1985–92. These are expressed as locust swarms eradicated per month. There is no measure of other swarms that may not have been recorded and no measure of effectiveness of control measures. It can be seen from these graphs that both the timing and the intensity of swarming varied between stations.

Model simulations were compared to real data with the migration activity disabled and while no comparison can be made between locust numbers, the model does yield a reasonable matching in timing of the outbreak events (Figure 5).

The model was then run with the migration activity included and a notable improvement in matching of events occurred (Figure 5).
Figure 4  Outbreaks recorded at four magisterial districts for 1985-92, expressed as locust swarms controlled per month.
Figure 5  Locust swarms controlled compared to swarms generated by the simulation model. (a) without migration and (b) with migration.
Figure 5 Continued.
We can assume that the model represents a reasonable match to the true driving forces of the Brown Locust population numbers. It obviously needs more testing and refinement and could be used to test the limitations of environmental factors such as high rainfall levels.

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REFERENCES


