**CROP PROTECTION PROGRAMME**

# Forecasting outbreaks of the Brown Locust in southern Africa

**R7779**

# FINAL TECHNICAL REPORT

**1 July 2000 – 31 June 2003**

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# CROP PROTECTION PROGRAMME: FINAL TECHNICAL REPORT

| | |
|---|---|
| **Title of project:** | Forecasting outbreaks of the Brown Locust in southern Africa |
| **R Number:** | 7779 |
| **Project leader:** | Dr Jane Rosenberg |
| **Institution:** | Natural Resources Institute, University of Greenwich |
| **CPP Production System:** | Semi-Arid |
| **CPP Purpose:** | Purpose 4: Benefits for poor people generated by application of new knowledge to control migrant pests in semi-arid systems. |
| **Commodity base:** | Not commodity specific |
| **Beneficiaries:** | Directorate Land and Agricultural Resource Management, South Africa; District Locust Officers, South Africa; Regional (IRLCO-CSA) and national plant protection services in southern Africa. |
| **Target Institutions:** | Agricultural Research Council (ARC)-Institute for Soil, Climate and Water (ISCW); ARC-Plant Protection Research Institute (PPRI); Southern African Development Community (SADC); International Red Locust Control Organisation for Central and Southern Africa (IRLCO-CSA). |
| **Geographic focus:** | Angola, Botswana, Lesotho, Mozambique, Namibia, South Africa, Zambia, Zimbabwe |

| | ***Planned*** | ***Actual*** |
|---|---|---|
| ***Start date:*** | 1 July 2000 | 1 July 2000 |
| ***Finish date:*** | 30 June 2003 | 30 June 2003 |
| ***Total cost:*** | £232,003 | £232,003 |

## 1. Project purpose (= production system output addressed), and specific objectives of this project:

Output A: Strategies developed to improve forecasting and reduce the impact of migrant pests in semi-arid cropping systems for the benefit of poor people.

The specific research objective of the project is to improve the forecasting of outbreaks of the Brown Locust in southern Africa by identifying the relationships between environmental factors and processes and changes in Brown Locust population numbers and distribution.

**2. Project outputs and achievements:** *(relate to final version of the logframe, emphasise conclusions and impact, and give sufficient details of results to support independent review)*

*Output 1: Spatial and temporal patterns of Brown Locust population fluctuations classified*

The Brown Locust is endemic to the semi-arid Karoo areas of South Africa and southern Namibia and population fluctuations are closely related to climatic and habitat variability. In order to determine the factors that lead to Brown Locust outbreaks and to identify the areas with the greatest incidence of breeding, the first phase of the research involved examining historical data records of Brown Locust occurrence, collected since the start of the Twentieth Century and environmental data for the same period.

The high outbreak frequency zones of the Brown Locust in South Africa were first defined in 1937 and subsequently confirmed by Lea in 1958, using the amounts of money spent by magisterial districts (MDs) on swarm control. Lea's boundaries were set according to the number of MDs that had >=9 years of outbreaks between 1933 and 1958. The current project analysed the number of first generation hatching and frequency of occurrence of hopper bands per MD for a 16-year period from 1984 onwards. The final map of the outbreak area (Figure 1 Kieser (2001)) was based on the distribution of MDs that had >= 5 years of first generation hatching (Figure 1). There has been a significant westward shift in the eastern boundary between 1937/1958 and 2001. This decline in outbreak frequency in the east was reflected by the closure of the Middelburg locust control depot in 1997 and its relocation to Upington in the northwest. At the same time, the southwestern limits of the outbreak area appears to have expanded while elsewhere, boundary changes are more irregular. The reasons for these shifts still need to be investigated fully, but preliminary work suggests that changes in rainfall and vegetation cover probably play a role. Using a GIS, the outbreak area maps were superimposed on interpolated monthly rainfall maps for 1933 onwards, derived from daily rainfall station data held in the ARC-ISCW climate archive.

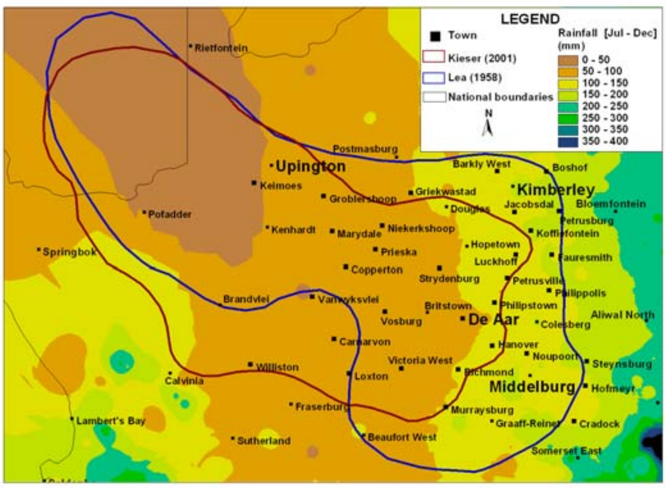



Figure 1a Mean early summer rainfall 1933-1958

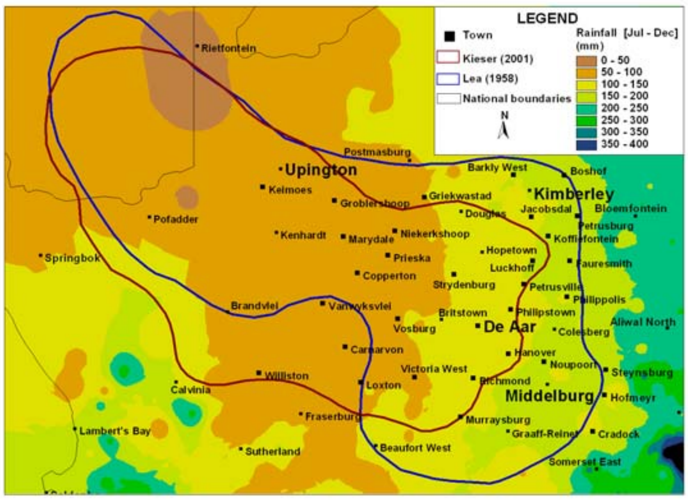



Figure 1b Mean early summer rainfall 1984-2000

The analysis found that during the last century, there was a general increase in annual rainfall across the Karoo. At the same time, there was a westward shift in the early summer 150mm isohyte that corresponded almost exactly with the shift in the eastern boundary of the locust outbreak area between 1958 and 2001. This suggests that early summer rainfall above 150 mm is unsuitable for breeding, possibly because increased vegetation cover reduces the availability of suitable oviposition sites. In contrast, the expansion of the Brown Locust outbreak area in the drier southwest, may reflect enhanced breeding success due to improved soil moisture conditions for egg hatching and better vegetation cover for hopper and adult development.

Over the same period, fluctuations in the grass cover of the Karoo have occurred in response to shorter term changes in rainfall and these may have influenced Brown Locust seasonal breeding success. Re-analysis of the numbers of first generation hatching from 1984 to 2000, based on smaller Locust Control Districts instead of MDs, showed that there were considerable inter-seasonal variations in the location of outbreaks, which reflect spatial variations in the distribution of seasonal rains and suitable breeding habitats (Figure 2 shows the distribution of hopper bands at the start of two large-scale outbreak seasons). These climate induced seasonal changes in vegetation cover have been enhanced by the impact of grazing management. Census data from the 1880s shows a reduction in stocking rates in the Karoo, probably resulting in increased grass cover and hence, changes in the distribution and availability of suitable breeding habitats

Spatial variability is matched by temporal variations in Brown Locust occurrence. The analysis of numbers of swarms controlled over the past 50 years or so, showed that the frequency and intensity of locust outbreaks appears to be increasing and since 1989/90 breeding season, there have been only two seasons when no locust control was required in the outbreak area (Table 1).

| Season | No. Swarms controlled | Outbreak Classification | No.Bands controlled |
|---|---|---|---|
| 1989/90 | 1392 | **Large scale** | 36,553 |
| 1990/91 | 357 | **Serious** | 1,142 |
| 1991/92 | 1603 | **Large-scale** | 18,131 |
| 1992/93 | 0 | **-** | 72 |
| 1993/94 | 9565 | **Plague** | 34,581 |
| 1994/95 | 663 | **Large scale** | 20,895 |
| 1995/96 | 6577 | **Plague** | 24,489 |
| 1996/97 | 8081 | **Plague** | 75,890 |
| 1997/98 | 80 | **Small scale** | 1,018 |
| 1998/99 | 0 | **-** | 2 |
| 1999/2000 | 9021 | **Plague** | 40,115 |
| 2000/2001 | 1101 | **Large scale** | 29,553 |
| 2001/2002 | 137 | **Moderate** | 1905 |

Table 1 Brown Locust outbreaks classified by the number of ADULT swarms controlled. Small-scale outbreak: 50 to 100 swarms; Moderate outbreak: 101 to 250 swarms; Serious outbreak: 251 – 500 migrant swarms; Large-scale outbreak: 501 to 5000 swarms; Plague: >5001 swarms

The results of this study highlight how successful control of the pest depends on having a management system that can take account of seasonal variations in the distribution and numbers of locusts in the outbreak area. Changes in outbreak frequency and distribution also have livelihood implications for Karoo farmers in terms of competition for pasture between grazing stock and locusts and competition for the resources needed for on-farm locust control.

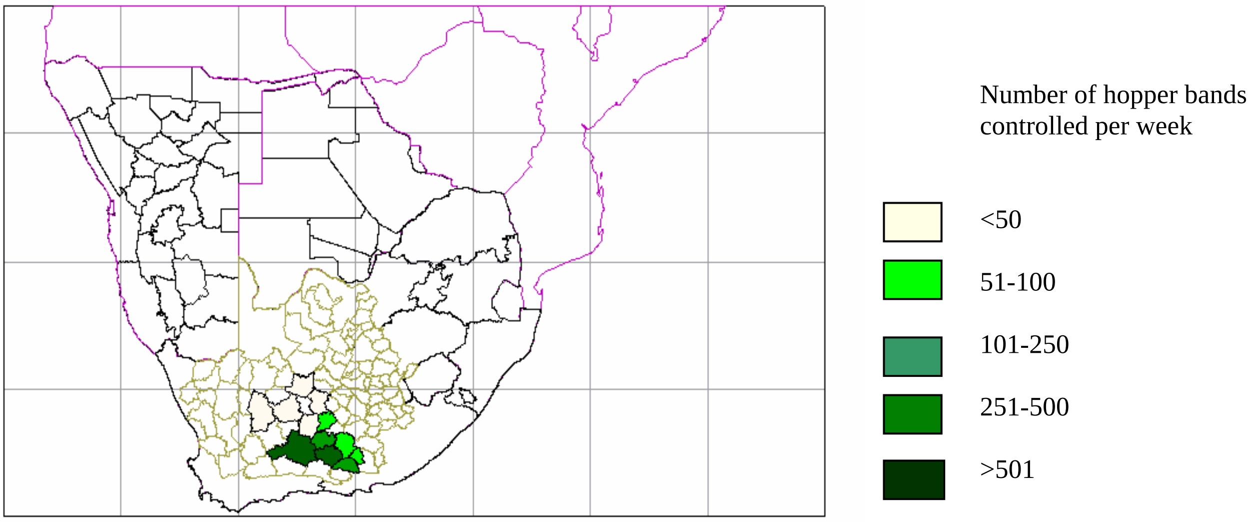



Figure 2a Distribution of Locust Districts with hopper bands in the first 4 weeks of 1991-92 season

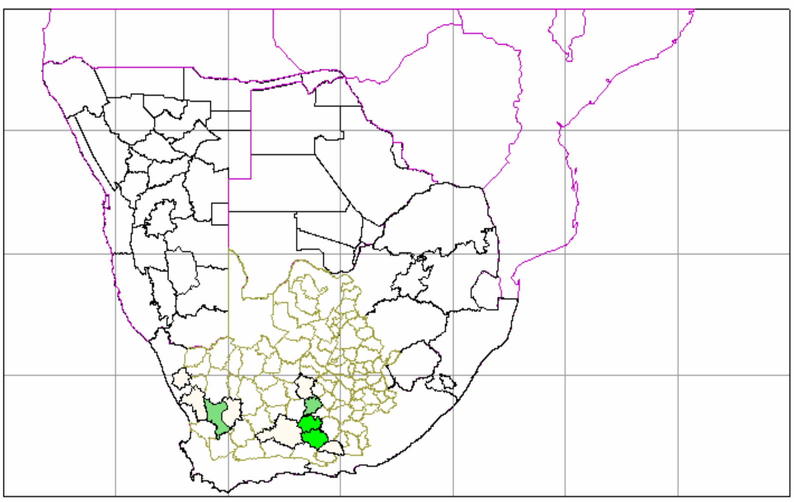


Figure 2b Distribution of Locust Districts with hopper bands in the first 4 weeks of 1994-95 season.

*Output 2: Seasonal changes in vegetation conditions identified*

Monitoring and forecasting for Brown Locusts require continuous assessment of breeding conditions throughout the outbreak area. Satellite imagery, supported by field observations, has the advantage of offering spatially continuous monitoring over varying time scales. The aim of this component of the research was to assess different satellite imagery to derive objective and quantitative estimates of changes in habitat status throughout the outbreak area in relation to different scales of Brown Locust population development.

The work focused on deriving breeding indicators prior to the actual locust outbreak (i.e. inter-seasonal or long-term forecasting) through an examination of the relationship between the temporal and spatial pattern of breeding habitats and the history and scale of subsequent locust outbreaks. The seasonal patterns for two years preceding each outbreak were examined since previous work (e.g. Matthee, 1951) had shown that Brown Locust eggs can survive in the soil for several seasons, although viability declines after about two years (Figure 3).

| Sept-Dec 1998 | Jan-Apr 1999 | May-Aug 1999 | Sept-Dec 1999 | Jan-April 2000 | May-Aug 2000 | Sept-Dec 2000 | Jan-April 2001 |
|---|---|---|---|---|---|---|---|
| Early Summer (a) | Late Summer (b) | Winter (c) | Early Summer (A) | Late Summer (B) | Winter (C) | **OUTBREAK** | |

Figure 3 Example of the definition of seasons used to derive a "breeding indicator" prior to a locust outbreak in 2000-2001 season

Normalised Difference Vegetation Indices (NDVIs) are commonly used as a measure of vegetation "greenness" or photosynthetic activity and in this study they were used as a proxy for breeding habitat suitability. An analysis of NDVI data from 1982 onwards for the entire outbreak area, established that in general, a vegetation index threshold of about 0.2 provided the best discrimination between habitat conditions characteristic of a plague/large-scale outbreak season and those for a season with smaller scale/no outbreaks. The percentage of the outbreak area recording vegetation index values =>0.2 for each season (Figure 3) showed that the separation between plague/large-scale outbreaks and smaller scale/no outbreaks is most significant in Late Summer two years before the relevant outbreak season (b). A simple rule could then be devised based on the area covered by suitable habitat conditions as represented by percentage coverage (NDVI%) =>0.2 threshold. This rule predicted the possibility of plague/large-scale outbreak conditions at the end of Late Summer two years in advance as:

- If (b) NDVI%>20<threshold, then plague/large-scale outbreak
- If (b) NDVI%>20>threshold+0.05, then no plague/large-scale outbreak

This relationship between Brown Locust population build-up and the availability of suitable habitats for breeding, supports classic locust outbreak theory in that the scarcer the breeding resource, the more locusts are compelled to come into contact, concentrate, multiply and gregarise. The result also supports earlier Brown Locust work (e.g. Smit, 1941) which suggested that plagues and large-scale outbreaks resulted from the build-up of populations over more than one year (Figure 4). It should be noted, however that the analysis was based on data covering a period of more or less continuous plagues and large-scale outbreaks and further verification over a longer time span with more variable outbreak conditions will be required to assess the validity of the relationship.

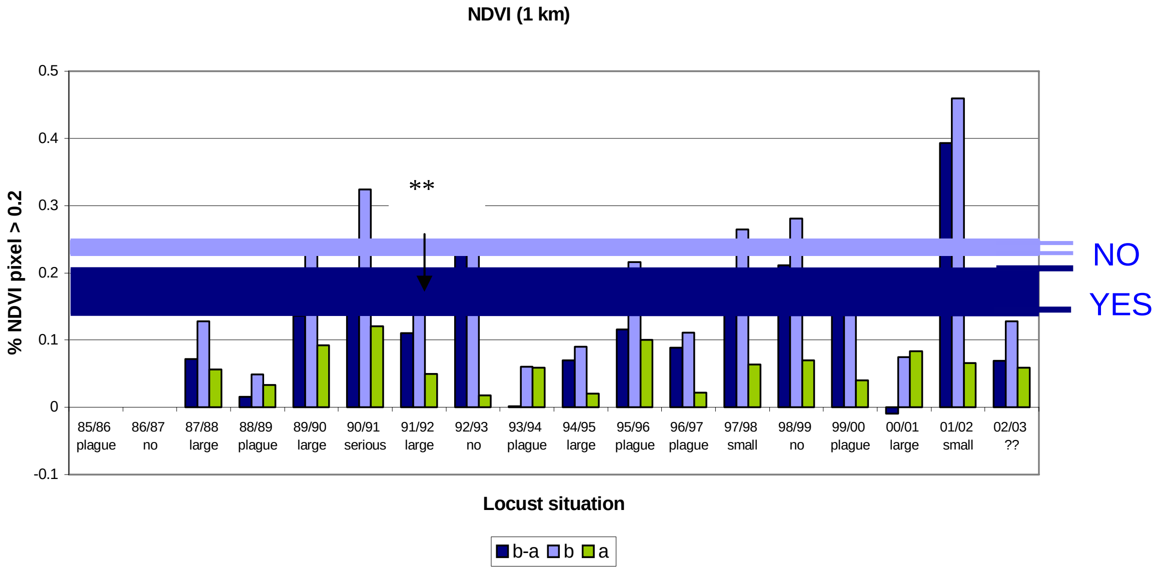
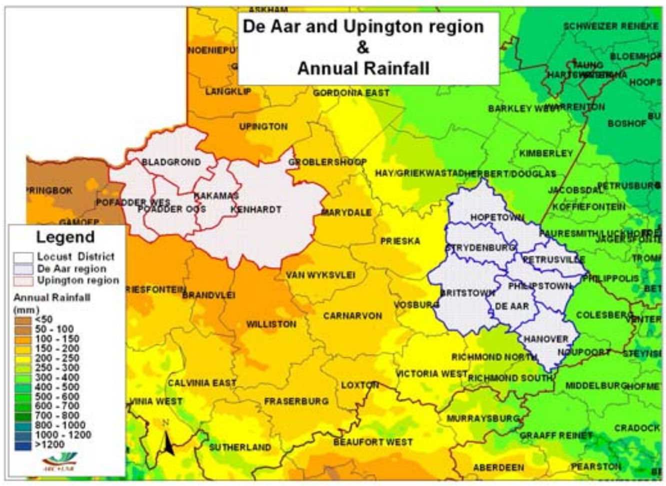



Figure 4. Graph showing outbreak size in relation to percentage area <> threshold for late summer (b) and early summer (a) two years before the outbreak. The years represent the year of the outbreak. (e.g. the value of NDVI 16% for (b) for the 91/92 large-scale outbreak (**) corresponds to the level of suitable habitat cover in Jan-Apr 1990). YES = plague/large outbreak; NO = serious, small and no outbreak

A similar analysis of data from different parts of the outbreak area showed a much more complex relationship between predicted outbreak size and NDVI values.




| | Whole Region | | Upington | De Aar |
|---|---|---|---|---|
| 1982/83 | no | no | | |
| 1983/84 | no | no | | |
| 1984/85 | small | no | no | no |
| 1985/86 | plague | yes | yes | yes |
| 1986/87 | no | no | no | yes |
| 1987/88 | large | yes | no | no |
| 1988/89 | plague | yes | yes | yes |
| 1989/90 | large | yes | yes | no |
| 1990/91 | serious | no | no | no |
| 1991/92 | large | yes | no | no |
| 1992/93 | no | no | no | no |
| 1993/94 | plague | yes | yes | yes |
| 1994/95 | large | yes | no | yes |
| 1995/96 | plague | yes | no | yes |
| 1996/97 | plague | yes | yes | yes |
| 1997/98 | small | no | no | no |
| 1998/99 | no | no | no | no |
| 1999/00 | plague | yes | yes | yes |
| 2000/01 | large | yes | yes | yes |
| 2001/02 | small | no | yes | no |

Figure 5 The De Aar and Upington Outbreak Areas and the sizes of outbreaks each season in each area in comparison to the entire outbreak region.

When the high frequency outbreak areas of De Aar and Upington were compared, it was found that there was temporal and spatial variability in the occurrence of different size outbreaks (Figure 5). There were also differences in the threshold vegetation index values for each area, which probably reflect differences in vegetation cover between the wetter eastern parts of the outbreak area (De Aar) and the sparser vegetation in the drier Upington region (Figure 5). There was no clear evidence of any influence by previous seasons on outbreak size, which probably reflects the difficulty of detecting small changes in vegetation using NDVIs in restricted areas of very low vegetation cover.

The analysis showed that daily and dekadal changes in vegetation cover and soil moisture in a semi-arid area such as the Karoo are very small, particularly in the drier western parts of the outbreak area. Preliminary analysis of data from the SPOT-VEGETATION, a satellite dedicated to the detection of land-cover and growth cycles, showed that even in the driest areas of the Karoo, some level of greening/moisture increase could be identified over a 10-day interval, although background soil conditions could interfere with the vegetation indices following recent rain.

Brown Locust control currently relies on the temporary recruitment of an army of farmers and labourers during a locust outbreak. This system encourages spending, particularly on pesticides and travel, and costs are increased since supplies and control teams have to be mobilised quickly in response to the emergency once farmers report the locusts. Also, the system is becoming inefficient due to high transport costs and the increased numbers of absentee farmers on the Karoo. The key to developing a more cost-effective (and more environmentally sound) control strategy is the ability to allow more time to allocate control resources both between and within locust breeding seasons in response to successful predictions of changes in the occurrence Brown Locust populations. The preliminary findings clearly indicate the potential for visually interpreting SPOT-VEGETATION images for vegetation distribution at a sub-seasonal time-scale (i.e. every 3 to 4 months) to provide forecasters with information on the spatial extent of low levels of vegetation cover before and during the breeding season. Used in conjunction with the coarser resolution, but more frequent NDVI data, such maps would provide some longer-term (i.e. one year or more in advance) guidance as to the possible seriousness of the outbreak and where extra control might be required.

*Output 3: Seasonal changes in key weather variables identified*

Previous work on locusts has established that changes in climate regime, particularly rainfall frequency and amounts, have been principally responsible for changes in the frequency and duration of outbreaks and plagues. In this part of the project, the research concentrated on identifying the main weather features (synoptic and larger scale) affecting the outbreak area, the rainfall and temperature regimes associated with different sequences of population development and the different migration patterns that occur according to synoptic weather conditions.

Satellite derived climate indices, which provide spatially continuous coverage throughout the outbreak area, were analysed in order to derive a tool for monitoring changes in breeding conditions. In order to calibrate the satellite derived indices, rainfall data from 625 stations in the outbreak area were used to compare field conditions with satellite data at different spatial and temporal scales. Ten day rainfall estimates (RFE) grids were obtained from NOAA (8km scale) for the period 1961 to 1998 and the Southern Africa Regional Remote Sensing Unit (RRSU) (10 km scale) for 1995 onwards. Using spatial interpolation routines, which included the effects of altitude, both were found to be suitable for deriving rainfall estimates for the outbreak area when correlated with the rain gauge data. Hence RFE could be used to determine where moisture conditions were suitable for hatching, fledging, maturation, egg-laying and migration and to support the interpretation of habitat changes indicated by satellite derived vegetation indices.

An analysis of RFE values for the entire outbreak area, established that an average RFE threshold of about 35mm discriminated between a plague/large-scale outbreak season and those for a season with smaller scale/no outbreaks. The percentage of the outbreak area recording RFE values =>35mm (Figure 3) showed that the separation between plague/large-scale outbreaks and smaller scale/no outbreaks is most significant at the end of Winter (Figure 3(c)) two years before the relevant outbreak season, but that rainfall conditions during the actual outbreak season itself had a large influence on affecting the scale of the locust outbreak. A simple rule for the long-term prediction of the possibility of plague/large-scale outbreak conditions at the end of Winter two years in advance could then be written as:

- If (c) RFE%>30-35>threshold (35mm), then no plague/large-scale outbreak

Previous studies had concluded that high winter rainfall resulted in high levels of egg mortality due to disease and parasitism and subsequently, to small locust population growth (e.g. Nailand & Hanrahan, 1993). This research confirmed the earlier work, but also quantified the threshold rainfall amounts and the proportion of the outbreak area needed to register the threshold values in order to provide a long-term prediction of outbreak size. However, the research also found that if the summer rains during a forecasted plague/large-scale outbreak failed, then there would be only small-scale or no outbreak, suggesting that changes in environmental conditions during the breeding season were more important in determining population developments.

Brown Locust breeding is affected by environmental conditions, particularly temperature and rainfall, which influence the rate and extent populations develop and spread. The effects of within-season changes in rainfall and temperature on population developments of the Brown Locust were analysed for a plague (1995/96) and a large-scale outbreak (1994/95). Ten-day moving averages of daily temperatures and rainfall totals per dekad were calculated for 240 climate stations scattered across the outbreak area in order to define breeding zones in the outbreak area where conditions were suitable for hatching, hopper development, fledging, maturation, egg laying and migration at different times throughout the breeding season.

Both breeding seasons were found to be characterised by several recurring periods of widespread rain, which affected different parts of the outbreak area at different times (Table 2). The net effect of this was that breeding was asynchronous throughout the outbreak area and separate inferred breeding zones could be delimited each season (Figures 6 and 7). Periods of heavy (>50mm per dekad) to moderate (25-50mm per dekad) rainfall recurred throughout both breeding seasons (19 periods of rain in 1994/95 and 18 in 1995/96) and were mostly associated with synoptic scale troughs, and mobile cold fronts.

The within-season analysis showed that different parts of the outbreak area have “suitable” breeding conditions at different times. From visual estimates, only a small percentage of the total outbreak area (about 25-30%) appeared suitable for breeding at any one time during a season, thereby promoting movement between habitats. Successful Brown Locust breeding depends on a high degree of coincidence between locusts and suitable environmental conditions and this is achieved through downwind migration by adults. The flight behaviour and migration patterns of the Brown Locust are poorly understood since due to political isolation, South Africa did not benefit from the extensive field and laboratory studies carried out on other locust species in the latter half of the Twentieth Century.  Instead, in this study estimates were made of Brown Locust flight parameters based on measurements of specimens in the British Museum Natural History collection and an analysis of daily weather charts covering a period when Brown Locusts were captured in light-traps on the Karoo (Botha & Jansen, 1969).

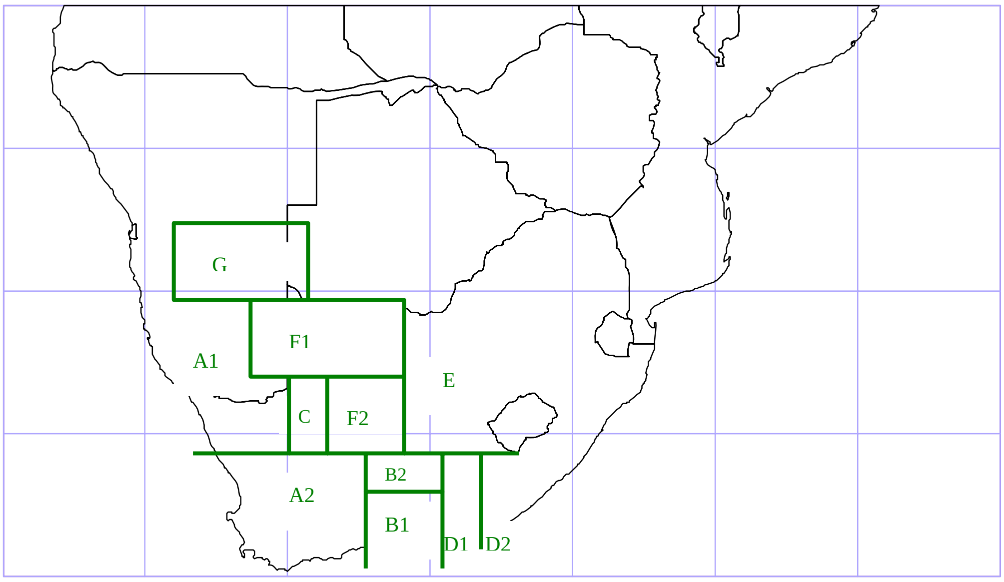



Figure 6 1995/96 breeding zones

| DATE | DKD | BREEDING ZONES | DATE | DKD | BREEDING ZONES |
|---|---|---|---|---|---|
| JUN 1994 | III | **A** | AUG 1995 | I | **A1** |
| JUL 1994 | III | **B** | AUG 1995 | II | **A2,B1** |
| AUG 1994 | I | B,**C** | AUG 1995 | III | **B2** |
| AUG 1994 | II | **D2,D3** | SEP 1995 | III | A1,A2,B1,**C,D1,D2,F2** |
| SEP 1994 | II | D3 | OCT 1995 | II | D2,**E** |
| SEP 1994 | III | B,C,**D1**,D2,D3 | OCT 1995 | III | A2,D1,D2,E |
| OCT 1994 | I | A,B,D1,D2,D3,**E3** | NOV 1995 | I | B1,D1,D2,E |
| OCT 1994 | II | B,C,D1,D2,E3 | NOV 1995 | II | A2,B1,B2,E,**F1**,F2 |
| OCT 1994 | III | C,D3 | NOV 1995 | III | A1,A2,B1,B2,C,D1,D2,E,F1,F2 |
| NOV 1994 | I | D1,D2,**E1,E2**,E3 | DEC 1995 | I | B2,D1,D2,E |
| NOV 1994 | II | B,E1,E2,E3,**E4** | DEC 1995 | II | A1,A2,B1,B2,C,D1,D2,E,F1,F2 |
| | | | JAN 1996 | II | B2,C,D2,E,F1,**G** |

Table 2 Parts of the outbreak area affected by rainfall to start of first generation breeding (**in bold**) during 1994/95 and 195/96 breeding seasons (see Figures 6 and 7 for location of breeding zones)

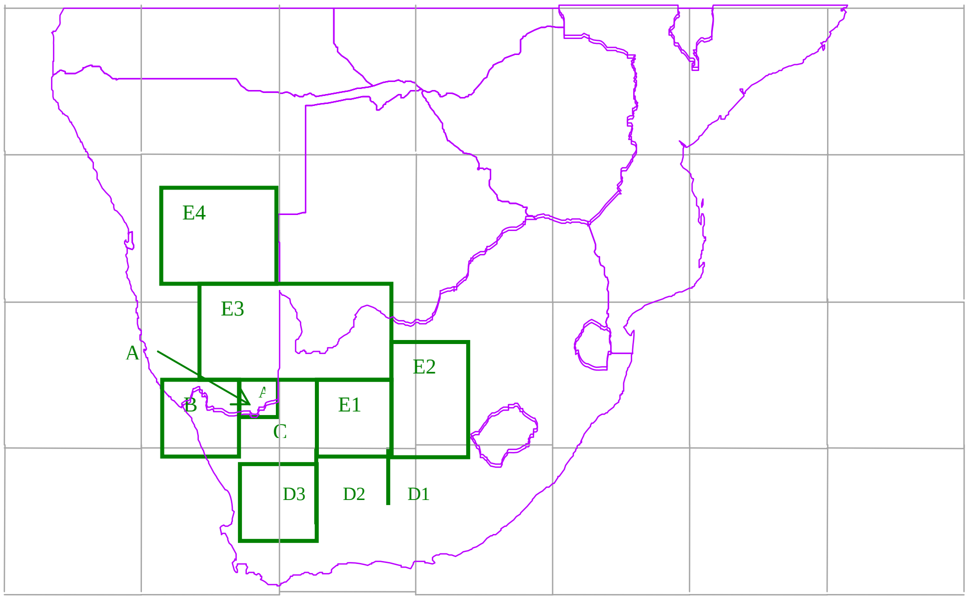



Figure 7 1994/95 breeding zones

Although swarms of Brown Locusts have been observed moving at low levels in contact with the ground during the day, the evidence from this study suggests that high density Brown Locust populations migrate at night at high levels above the ground for <10 hours. Their flight is downwind, providing the wind speed exceeds the locust's air speed of about 11-12 kmh$^{-1}$. Analysis of the weather associated with light-trap captures of Brown Locusts showed that migrants frequently arrived at the traps after fronts had moved eastwards across the catching sites, with the locusts migrating <400 kms downwind in a single night.

The results from this component of the research suggest that a combination of satellite derived vegetation indices (NDVI) and rainfall estimates (RFE), can be used to provide a long-term forecast aimed at the Central Government (DLARM) in South Africa, in order to obtain contingency funding for control resources one to two breeding seasons in advance of a predicted plague or large-scale outbreak. However, since weather events occurring over a few days or weeks clearly have considerable impact on population developments and migration patterns once breeding is underway, shorter term forecasts, based on weather conditions within the locust breeding season are still essential, to enable Locust Control Depots to deploy their control resources to where they are most needed.

*Output 4: Case studies of historic Brown Locust population developments produced*

An understanding of the distribution and numbers of Brown Locusts and their development in space and time during outbreaks and plagues is important to the successful control of the pest. A crucial element of locust forecasting is building-up a picture of locust population dynamics and movements by using sequences of population developments and analogies with past situations. In this section of the research, different locust population development sequences were examined during a plague (1995/96) and a large-scale outbreak (1994/95), with particular attention to the spatial distribution of locust breeding habitats and the links between geographically isolated breeding sites within the outbreak area.

The only field reports of Brown Locust occurrence are of control operations against bands and swarms, so the classical biogeographical approach of mapping and interpreting field reports is not possible since there is no comprehensive survey data and there are usually long gaps in the report record. Instead, from a review of the literature on Brown Locusts and locusts in general, a simple model was developed for the analysis of the seasonal population changes, based on the developmental biology of the locust and using weather data alone to estimate the likely sequences of breeding (Table 3). The inferred breeding sequences were compared to concurrent field reports of band and swarm control.

Table 3 Values of parameters used in the model

| Stage of breeding cycle | Values |
|---|---|
| Egg development at start of season | Assume eggs overwinter at c50-60% stage. Therefore egg development starts from 50% stage once temperatures are 20C. Incubation period 15 days in early summer; 10 days in mid summer<br>provided that:<br>>20mm of rain falls in a month in early summer or >10mm in 48hrs or 25mm of rain falls in a month in summer or >15mm in 48hrs |
| Development & survival of nymphs | %daily nymphal development according to linear relationship between nymphal development rate and daily max temp in range 14-43ºC (20-56day range). Assume moisture that produced hatching is sufficient to ensure hopper survival and fledging |
| Adult development & migration | Fledging to migration is 7-10 days; Fledging to first laying is 14-20 days; Eggs fully developed in female in 14 days; Fledging to full adult takes 10 days.<br>If rainfall <25mm during the 10 days of fledging to adult, immature adults will migrate within the following 10 day period<br>If rainfall >25mm during the 10 days of fledging to adult, adults will remain, sexually mature and lay within 4 days |
| Flight parameters for migration | Temperature threshold for flight >=20C. Maximum number of hours of migration per night = 10 (ss to sr 1900-0500 LT) provided temperature threshold is maintained; Maximum number of hours of migration per day = 8 (0900*-1700 LT (*3 hrs after sr)).<br>Flight direction and speed calculated for wind direction and speed at surface and wind direction and speed at 1km (derive from surface values: minus10 to 20º from surface wind direction (direction changes anticlockwise with altitude in S hemisphere) and surface wind speed @ 1200GMT).<br>Add 3.0-3.3ms$^{-1}$ (11-12kmh$^{-1}$) average flight speed |
| Egg development during the season | Eggs will hatch in 10 days when daily maximum temperatures are >=20C and >=25mm of rain falls except in Autumn (end March-May) when eggs will enter diapause regardless of temperature and rainfall. |

A summary of the results of the analyses of the two outbreak seasons is given below

**1994-1995 Large Scale Outbreak**
Between end of June 1994 and mid-November 1994, inferred breeding started in 10 distinct zones in the breeding area (Figure 7 and Table 3). Inferred breeding started during the winter with the first hatching of over-wintering eggs in the western part of the breeding area in June 1994 (Zone A), although field reports indicated that there may have been an earlier period of hatching. The last hatching from over-wintering eggs was inferred in early summer (November) in the northwest part of the breeding area (Zone E4). The season was characterised by repeated sequences of moderate and heavy rain, which affected different parts of the outbreak area and breeding ended at the end of May 1995, when rainfall diminished and in much of the outbreak area, temperatures were too low for egg or hopper development or migration.

The inferred breeding sequences showed that 3 or 4 generations of locusts were produced because there was sufficient rainfall in different part of the breeding area at different times to enable asynchronous hatching, hopper development, fledging and maturation. The breeding sequences showed that at any one time and place in the breeding area, the populations present may comprise individuals produced locally together with immigrants from breeding elsewhere and that as a result, there may be a mixture of ages and generations at a site. There was also an indication that immigrants arriving in a zone during any one dekad could come from more than one source. Migrations occurred throughout the season from the beginning of September 1994 until the end of May. There was a predominance of migrations from the western sector in association with low-pressure systems. The net effect of the migrations was to enable immature locusts to escape from areas where they could not mature and arrive in places where maturation, mating and egg laying could occur. . At the end of the season, the model also showed that the laying of over-wintering eggs became widespread due to repeated windborne movements by adults as conditions gradually became drier.

**1995-1996 Plague**
Between the beginning of August 1995 and mid-January 1996, inferred breeding started in 11 distinct zones in the breeding area (Figure 6 and Table 3). The first inferred hatching from over-wintering eggs occurred in spring in the western part of the breeding area (Zone A1) and the final over-wintering hatching was in Namibia in mid-summer (Zone G). The season was characterised by 18 periods of widespread moderate and heavy rain, which resulted in asynchronous breeding cycles throughout the outbreak area until the beginning of June 1996 when the breeding season ended. Three or four generations were produced over much of the breeding area between August 1995 and April 1996, except in Namibia where a single summer generation was produced, which emigrated in the autumn and laid over-wintering eggs.

There was a predominance of migrations from the western and northern sectors in association with low-pressure systems and 73% of the movements were associated with frontal depressions and troughs. Considerable mixing of populations from different parts of the outbreak area occurred as a result of repeated movements by adults, with distances ranging from about 180 to 650 kms in a single 10 hour downwind migration.

<u>These findings suggest that similar environmental conditions occur in a large-scale outbreak and a plague. It may be necessary for breeding to start early [winter-spring] in at least part of</u>

the breeding area and for the season to be characterised by repeated sequences of moderate and heavy rain which affect different parts of the breeding area at different times. As a result, in order to produce the successive generations necessary to develop a plague, each adult generation must exploit new "temporary" breeding habitats. Under the current field reporting system in the outbreak area, only controlled bands and swarms are notified and the early stages of an outbreak may be missed. However, the analysis has show that once rain has fallen, populations can spread rapidly and control teams have to be mobilised quickly to cover several different parts of the outbreak area. Outbreaks in different parts of the breeding area can also be initiated or enhanced by the arrival of migrants from elsewhere. In the absence of field surveys, the results suggest that early reporting of the possible start of hatching, based on environmental conditions could be used to initiate warnings of possible locust population developments.

*Output 5: Outbreak localities and timings defined*

Locust forecasters use different types of information according to the time scale of the forecast, which ranges from seasonal (long-term) to weekly (short-term). In this part of the project, a synthesis of the analyses was carried out to define more closely the key factors affecting Brown Locust population developments. As a result of this analysis a more realistic picture could be obtained of the spatial and temporal scale over which forecasts can be issued to meet different user needs (e.g. central government, regional organisations, District Locust Officers, extension services) and surveys and control initiated.

The development of Brown locust plagues and large-scale outbreaks has been found to be a series of interlocking events in which the timing, distribution and amount of rainfall over the entire outbreak area is critical because of the impact on vegetation growth and locust physiology. This relationship between environmental factors and the Brown Locust breeding cycle appears to hold on a general basis even when examined 16 to 20 months in advance of an actual outbreak. Long term correlations between rainfall and vegetation index thresholds and successful summer breeding are only identified with any degree of certainty when the outbreak area is considered as a whole and hence, they can provide only a broad picture of potential outbreak size in the long-term (Figure 8).

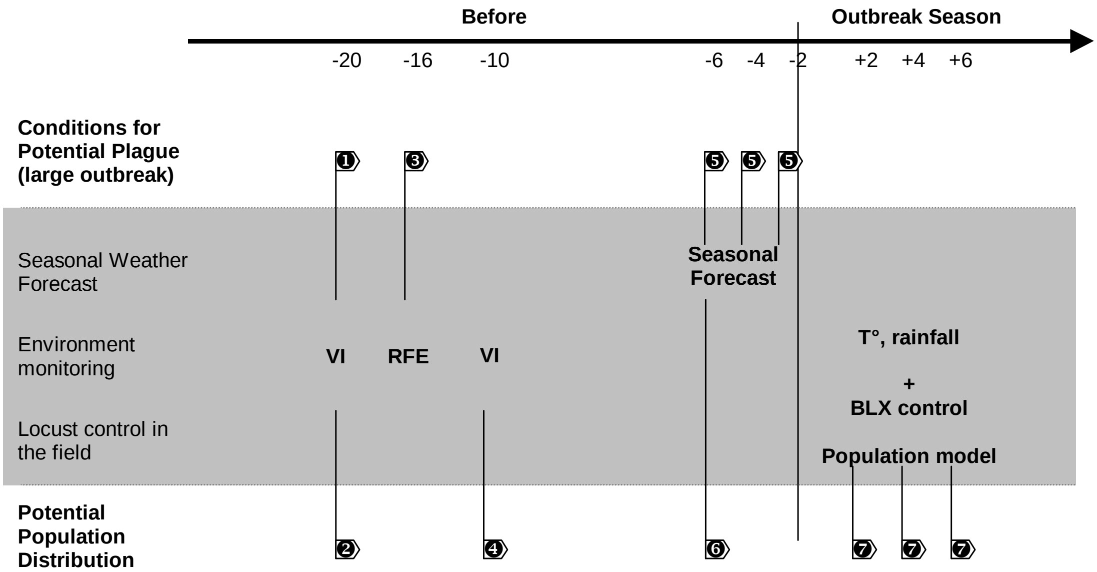



Figure 8 Forecasting time line

The plague and large-scale outbreak modelled in this study were both initiated in the winter/spring, suggesting that any area with temperatures high enough and sufficient rainfall in the winter/spring should be closely monitored. The value of monitoring lies not only in locating areas where plagues could be initiated, but also in identifying the next crucial event in the outbreak development. When the initial breeding is followed by sequences of sufficient rain for one or more summer generations to be produced, a large-scale outbreak or plague can ensue. Control at this stage before emigration from the outbreak area to surrounding agricultural areas would be both cost effective and environmentally sound.

The likelihood of rain occurring at a particular stage during the breeding season can be predicted from the synoptic weather forecast, which also gives a general pointer to the location of the rainfall and to the direction and speed of the wind for migrating adults. The scale of the forecast would be a day or two in advance over an area of several hundred square kilometres. The areas to be monitored are therefore still relatively large and field surveys would be expensive even if such teams existed in the outbreak area. The timing of the surveys, however, could be more closely focused. The location of potential outbreaks may be more accurately defined if NDVI patterns at $1km^2$ scale could be used as a measure of habitat "clumping" (i.e. fractal indices), to indicate where Brown Locust concentration and gregarisation might lead to the development of large swarms that could be targeted for control (e.g. Despland *et al*., 2000).

The results of the study suggest that any decision support system for monitoring and forecasting Brown Locust populations must routinely cover the whole outbreak area throughout the year. The spatial and temporal scales of the monitoring, however, can be refined during the outbreak season. Locust "hotspots" can be identified where the amount and timing of rainfall and the development and distribution of vegetation in relation to modelled locust population dynamics indicate that large-scale breeding or migration are taking place. Some level of field surveys would still be required, however, to verify the modelled predictions.

**3. Publications:** *(give full details and indicate whether subject to peer or equivalent editorial review)*

*Published:*

KIESER, M., THACKRAH, A. and ROSENBERG, J. (2001) Changes in the Outbreak Region of the Brown Locust in Southern Africa. In: International Conference on Orthopteroid Insects. Eighth Meeting of the Orthopterists Society, Montpellier, France, August 19-22 2001 [poster].
Metaleptea. Special Meeting Issue. Eighth International Meeting of the Orthopterists' Society. Part 2. pp 37-38 [online version only]
http://os2001.cirad.fr/E/Metaleptea

KIESER, M., THACKRAH, A. and ROSENBERG, J. (2001) Changes in the Outbreak Region of the Brown Locust in Southern Africa. In: Arid Zone Ecology Forum. 4 - 7 September 2001. Calitzdorp, South Africa. Organised by the Conservation and Management of Ecosystems and Biodiversity Focus Area of the National Research Foundation. [poster].

THACKRAH, A., RAUTENBACH, C.J.deW and FLASSE, S. (2002) Verification of rainfall grid fields for use in locust outbreak research over the western parts of southern

Africa. p 58. In Abstracts of SASAS 2002 Conference 26-28 August 2002. Council of the South African Society for Atmospheric Sciences. World Summit on Sustainable Development. Johannesburg, South Africa.
http://www.up.ac.za/academic/geog/meteo/SASAS2002.htm
Parallel Session 12:T57 - Oral Presentation

**4. Internal reports:**

FLASSE, S. (2001) Brown Locust research project meetings and field visit to the South African Agricultural Research Council 25/02/2001 to 10/03/2001. Natural Resources Institute, University of Greenwich, Chatham, UK. 2pp. (BTOR)

FLASSE, S. and THACKRAH, A (2001) Brown Locust Remote Sensing research. 1 March 2001. ARC-Institute for Soil, Climate and Water, Pretoria. 24pp. (Internal report)

FLASSE, S. and THACKRAH, A (2001) Brown Locust Remote Sensing research. 1 October 2001. ARC-Institute for Soil, Climate and Water, Pretoria. 18pp. (Internal report)

FLASSE, S. and THACKRAH, A (2002) Brown Locust Remote Sensing research. 1 October 2002. ARC-Institute for Soil, Climate and Water, Pretoria. 14pp. (Internal report)

FLASSE, S. and THACKRAH, A (2003) Brown Locust Remote Sensing research. 1 February 2003. ARC-Institute for Soil, Climate and Water, Pretoria. 9pp. (Internal report)

KIESER, M. (2001) Annual Report on Forecasting Outbreaks of Brown Locust in southern Africa. 1 July 2000 – 31 March 2001. ARC- Plant Protection Research Institute, Pretoria. 5pp. (Internal Report)

KIESER, M. (2001) Quarterly Report on Forecasting Outbreaks of Brown Locust in southern Africa. 1 April 2001 – 30 September 2001. ARC- Plant Protection Research Institute, Pretoria. 10pp. (Internal Report)

PENDER, J. (2001) Brown Locust Information Support System (BLISS). 1 August 2001 – 30 September 2001. Natural Resources Institute. 27pp. (Internal report)

THACKRAH, A. (2001) Progress Report on Brown Locust Forecasting Research 1 July 2000 – 31 March 2001. ARC-Institute for Soil, Climate and Water, Pretoria. 15pp. (Internal report)

THACKRAH, A. (2001) Progress Report on Brown Locust Forecasting Research 1 April 2001 – 30 September 2001. ARC-Institute for Soil, Climate and Water, Pretoria. 18pp. (Internal report)

**5. Other dissemination of results, training etc:**

**6.**

N/A

**Contribution of outputs to project goal (= production system purpose):**

The majority of the population in countries affected by the Brown Locust live in rural areas and since on average, only 0.3 hectares of arable land are available per person, improvements to livelihoods and food security depend on better access to benefits from increased crop yields, including reductions in the impact of migrant pests on crop and pasture production. Since locust outbreaks are often associated with major climatic fluctuations such as the occurrence of droughts, they pose a significant additional threat to food security in rural areas that may already be vulnerable to production shocks. Individual farmers or farming communities are totally unable to protect their crops when adult swarms comprising tens of millions of locusts per square kilometre land in their fields.

Current Brown Locust management is based on the principle that populations developing in the outbreak area must be controlled before highly mobiles swarms of adults can form and invade surrounding agricultural areas. This control strategy depends on timely predictions of where and when gregarising populations are developing and a flexible control infrastructure that can increase and reduce its capacity in response to forecasted outbreak developments. The research project has made good progress in improving understanding of the relationships between environmental factors and locust population developments. The outputs of the project will contribute to the development of timely and reliable forecasting strategies for Brown Locusts to prevent swarms developing and escaping from the outbreak area and invading and damaging crops and pasture-land. The research will also facilitate the move away from the current emergency control situation to an informed strategy for the advanced planning of survey and control campaigns. As a result, locust control will be able to move away from the present emergency response to reports from farmers when swarms invade their land, to a more cost-effective and environmentally sound preventative control strategy whereby locust outbreaks are located earlier in the breeding season. The improved knowledge and methodologies resulting from this project will also help strengthen international collaboration in preventing Brown Locust swarms from invading agricultural areas in affected countries. Project outputs will contribute to improvements in South Africa's operational forecasting of changes in Brown Locust populations as a basis for planning control campaigns.

## 7. Pathway whereby present and anticipated future outputs will impact on poverty alleviation or sustainable livelihoods:

The project outputs will contribute directly through the South African Directorate of Land and Agricultural Resource Management (DLARM) in Pretoria, which has responsibility for disseminating information and forecasts about locust population developments to countries in the Brown Locust invasion area. Currently, this dissemination to national pest control agencies is done bilaterally and work is underway to ensure that the SADC Crop Production Sector network will play an important role in promoting the distribution of information about the spread of Brown Locust swarms. The principal regional control organisation in the region (IRLCO-CSA) and FAO, which has a global mandate to provide facilities and assistance to countries during locust outbreaks also contribute to the direct dissemination of Brown Locust information via the ICOSAMP website and the FAO locust website.

Indirectly, through improved Brown Locust forecasts and information, the project outputs will contribute to improving the livelihoods of small-holders and commercial farmers in the

Brown Locust invasion area due to a reduction in swarm invasions. Ultimately, since Brown Locust control in South Africa is wholly publicly funded, a reduction in the extent and costs of control should lead to more effective utilisation of tax payer's money. Greater environmental protection will also result, particularly for non-target species, since control operations should be focused on better defined target populations in the outbreak area.

**8. Attach final version of logframe:** *(include any revisions such as additional outputs and activities from 'add-on' funding/project extensions)*

| **Narrative Summary** | **Objectively Verifiable Indicators** | **Means of Verification** | **Important Assumptions** |
|---|---|---|---|
| **Goal** | | | |
| Benefits for poor people generated by application of new knowledge to control migrant pests in semi-arid systems | Crop yields increased and sustained<br>Food aid reduced<br>Public expenditure on control reduced | National and local level surveys of crop production, expenditure on pesticides, GDP levels; donor evaluations | Benefits invested by national governments for poor people |
| **Purpose** | | | |
| Strategies developed to improve forecasting and reduce the impact of migrant pests in semi-arid cropping systems for benefit of poor people. | Strategic use of pesticides used for control reduced<br>Reduction in crop losses | Campaign reports<br>In-country assessments of control efficiency<br>Annual crop production reports | Regional and National locust control units have access to BLEWS outputs and resources to implement survey and control recommendations |
| **Outputs** | | | |
| 1. Spatial and temporal patterns of Brown Locust population fluctuations classified | Patterns established by July 2001 | Quarterly and annual reports to DFID | Locust control data can be converted into suitable Arcview format |
| 2. Seasonal changes in vegetation conditions identified | Historical data analysis completed by November 2001 | | Appropriate field and satellite derived data available |
| 3. Seasonal changes in rainfall, temperature and windfield identified | Historical climate data analysed by January 2002 | | Meteorological data obtainable at appropriate scale and from suitable stations |
| 4. Case studies of historical Brown Locust population developments produced | Analysis completed by February 2003 | | Relationships between biological and environmental data can be identified |
| 5. Outbreak timings and localities defined | Localities and timings defined by end of February 2003 | | Patterns of population fluctuations consistent enough to identify sources |
| **Activities** | **Inputs** | **Means of Verification** | **Important Assumptions** |
| GIS enabling environment established i.e. compatible hardware and software obtained | **Total Budget here**<br>Staff Costs | **£232,003**<br>£ 94,704 | Appropriate hardware and software available |
| 1.1 Maximum potential breeding area defined from past records | Overheads<br>Equipment | £ 114,269<br>£ 3000 | Environmental and locust data readily available |

| Narrative Summary | Objectively Verifiable Indicators | Means of Verification | Important Assumptions |
|---|---|---|---|
| **Activities** | **Inputs** | | |
| 1.2 Brown Locust control data for the period 1988/89 to 1999/2000 collated and converted into Arcview GIS format | Travel & Subsistence<br>Overseas<br>UK<br>Miscellaneous | <br>£4400<br>£4400<br>£11,230 | Scale of datasets adequate to establish spatial and temporal relationships |
| 1.3 Brown Locust control data for 2000/01 breeding season collated and converted into Arcview GIS format | | | |
| 1.4 Brown locust population fluctuations classified | | | |
| 2.1 Set up archiving system for satellite imagery | | | |
| 2.2 Purchase SPOT Vegetation imagery and set up archiving system | | | Environmental and locust data readily available |
| 2.3 Preliminary identification of vegetation indices | | | |
| 2.4 Redefinition of key vegetation variables | | | Scale of datasets adequate to establish spatial and temporal relationships |
| 2.5 Time series analysis of vegetation indices | | | |
| 3.1 Investigate sources of weather data | | | |
| 3.2 Collation of meteorological data and initial interpretation | | | |
| 3.3 Redefinition of key meteorological variables | | | |
| 3.4 Time series analysis of meteorological factors | | | |
| 4.1 Collate Brown Locust and environmental data for Case Studies | | | |
| 4.2 Work through Case Study population development sequences | | | |
| 4.3 Convert Case Studies into format for BLEWS | | | |
| 5.1 Redefinition of outbreak area | | | |
| 5.2 Duration of outbreak seasons | | | |

## 9. Brief justification for follow-on project: *(indicate any change in partnerships)*

The methodologies for deriving the improved forecasts will have to be tested operationally over two or three breeding seasons to assess their appropriateness in real-time forecasting and control. The current collaborators, ARC-ISCW, ARC-PPRI and NRI will be involved in the proposed adaptive phase of the research. The follow-on project will primarily involve validation of the decision-making tools developed here. In view of the proposed changes to the control strategy in the outbreak area, with a focus on controlling only large gregarious targets, there will be a need to include inputs on the numbers of Brown Locusts occurring during an outbreak as well as the timing and distribution of the outbreaks. Research on this component of the decision-making process has already begun under South African funding at the University of Witwatersrand, but there will be a need to include this University formally in the proposed follow-on project.

## 10. Evidence that stakeholders are satisfied with the outputs and support a follow-on project:

The immediate stakeholders are the users of the system, that is the forecasters working for the Directorate of Land and Agricultural Resource Management (DLARM) in South Africa. Researchers from the project, based at ARC-PPRI in Pretoria are already having discussions with DLARM on ways the project outputs could be used to change the Brown Locust control strategy to one in which only large bands and swarms are controlled, using aircraft. In this strategy, DLARM hopes to reduce the widespread use of broad spectrum insecticides in the outbreak area and target the control more effectively against the most serious gregarious populations. Contact has been maintained between the project researchers and migrant pest control organisations in southern Africa through regular updates of the ICOSAMP website. The SADC Secretariat has obtained sponsorship from the Belgium Crop Development Project for an ICOSAMP Workshop to be run as a parallel session at the forthcoming ESSA (Entomological Society of Southern Africa) Congress to be held in Pretoria, South Africa, from 6-9 July 2003. This Workshop will bring together migrant pest forecasters from the SADC region and be used to assess the future application of the outputs from this project in both the outbreak and invasion areas.

## 11. Proposed purpose, specific objectives, outputs and activities for a follow-on project:

*Purpose:*
Strategies developed to improve forecasting and reduce the impact of migrant pests in semi-arid cropping systems for the benefit of poor people.

*Specific objectives:*
To enhance the operational efficiency of the Brown Locust Early Warning System by developing a Decision Support System to improve locust forecasting and control operations in the outbreak area.

*Outputs:*
A Decision Support System based on a spatial model framework with environmental data integrated with population development models and field information. The DSS will incorporate;

1. verified rainfall and vegetation indices for different scale outbreak seasons and an archive of historical analogues to help formulate forecasts
2. maps of potential “hotspots” for seasonal outbreaks based on fractal indices and thresholds of vegetation indices
3. a simulation model depicting rates of population development and survival between and during breeding seasons.

4. historical analogues of Brown Locust breeding seasons, including short, medium and long-term climate data
5. an archive of trajectory analysis of wind-fields to determine seasonal migration patterns

*Activities:*

1. Verified rainfall and vegetation indices for different scale outbreak seasons and an archive of historical analogues to help formulate forecasts
1.1 Confirm NDVI threshold values 20 months in advance with 2 more years' outbreak data
1.2 Improve monitoring of low vegetation cover areas by comparing SPOT-VEGETATION data with NOAA data
1.3 Confirm RFE threshold values 16 months in advance with 2 more years' data
1.4 Establish long-term VI and RFE operational forecasting rules

2. Maps of potential "hotspots" for seasonal outbreaks based on fractal indices and thresholds of vegetation indices
2.1 Examine relationship between vegetation "clumping" (landscape structure) and Brown Locust population dynamics using

    2.1.1. different spatial scales (determined by scale of satellite imagery)
    2.1.2. different temporal scales (dekad, month, sub-season)
    2.1.3. different VI sources (NOAA AVHRR, NDVI, SPOT-VEGETATION)

3. A simulation model depicting rates of population development and survival between and during breeding seasons.
3.1 Integrate current population model with University of Witwatersrand simulation model
3.2 Verify model and modify environmental threshold values
3.3 Model Brown Locust population sizes for assessment against Output 4

4. Historical analogues of Brown Locust breeding seasons, including short, medium and long-term climate data
4.1 Using Output 3, build up archive of within season population developments from 1989/90 onwards for medium and short term forecasting analogues
4.2 Using GCM and South African seasonal weather forecasts 6 months before the outbreak season, confirm long-term forecasts from Output 1 (what the general conditions for outbreaks are) and Output 2 (where these conditions occur)

5. An archive of trajectory analysis of wind-fields to determine seasonal migration patterns
5.1 Analyse synoptic weather charts for 1989/90 season onwards to establish archive of possible migration patterns from the start to finish of each breeding season
5.2 Compare migration patterns with observations on Brown Locust movements archived at ARC-PPRI.

**12. Name and signature of author of this report and date signed:**

Dr Jane Rosenberg

Signed on behalf of Dr Rosenberg by Hans Dobson