A Method for Detection of Desert Locust, *Schistocerca gregaria* (Forskal) and Estimation of Infested Areas

By

Essam Mahmoud Ibrahim

B.Sc. (Agric.) University of Alexandria, Egypt 1992
Post graduate Diploma (Desert Locust Control) University of Khartoum, Sudan 2003

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Supervisor

Professor El Sayed El Bashir Mohamed

Department of Crop Protection
Faculty of Agriculture
University of Khartoum
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DEDICATION

TO THOSE WHO MADE ME WHO I AM TODAY,
AND HAVE BEEN PATIENT DURING MY ABROAD STUDY,
MY DEAR MOTHER,
MY GREAT FATHER,
MY DARLING WIFE,
AND MY LOVELY KIDS.

WITH HONOUR THIS WORK IS DEDICATED TO THEM.
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Abstract
This study aims to evaluate the current methodologies of ground survey operations of desert locust, and attempts to introduce improvements, which increase the efficiency of the survey process. The general objectives of this study are improving the methods of detecting of desert locust infestations, and upgrading the capacity of desert locust management. The trials of this research were conducted by using computer software and applying principles of geometry to devise an improved ground survey method, and field test the proposed survey method and compare it with the current survey methods.

The field trials were conducted in the Red Sea areas, Delta Tokar and north Kordofan province (in Sudan). Three methods of foot surveys were tested, (current foot transect, the modified foot transect method developed by Ghaemain (2002), and the proposed foot transect), the area unit of these methods for the test was one hectare. Besides, two methods of vehicle surveys were conducted at an area unit of one square kilometre (current vehicle transect, and the proposed vehicle transect). The methods were performed on both natural populations of desert locust and charcoal heaps to simulating stationary locust groupings.

The results indicated that desert locust officers could be able to detect the stationary locust groupings at 5 meters on each side of the transect line, when they perform the foot transect survey, but they should not depend heavily on counting the number of locusts by vehicle, as that method appeared to be less accurate. In addition performing the proposed methods of survey (by foot or
vehicle), enabled the locust officers to cover more area of the surveyed or infested area, than other tested methods. However, the time taken to perform the proposed method was longer when compared with the other methods of survey. However, in most cases, it was found that increasing the number of locust officers or vehicles, leads to increase the detection percentage of locusts. Moreover, locust officers should determine the surveyed areas by using special software tools that to determine the areas more accurately than the visual estimations.

These findings could improve the efficiency of the desert locust survey operations, which are needed to increase the capacity of the current preventive desert locust control strategy.
ملخص الطرح

تهدف هذه الدراسة إلى تقويم الطرق الحالية في عمليات المسح الأرضية للجراد الصحراوي، وتحاول تقديم البدائل التي تزيد من كفاءة عملية المسح. إن الهدف العام للدراسة هو تطوير طرق رصد إصابات الجراد الصحراوي ورفع كفاءة عمليات مكافحة الجراد الصحراوي. استخدم في هذه الدراسة برنامج الحاسوب لتطبيق مبادئ هندسية لإيجاد طريقة مسح جديدة وتطبيق الطرق المقترحة حفلاً بمقارنتها بالطرق الحالية.

أجريت التجارب الحقلية في مناطق البحر الأحمر ودلنا طوكر ولؤلؤة شمال كردفان بالسودان. تم اختيار ثلاث طرق للمسح باستخدام السير بالقدم (الطريقة الحالية وطريقة Ghaemian (2002) والطريقة المقترحة) ، وكانت وحدة المساحة هي هكتار واحد. إلى جانب طريقتين للمسح باستخدام السيارة (الطريقة الحالية والطريقة المقترحة) ، وكانت وحدة المساحة هي كيلومتر مربع. وقد طبقت الطرق على الجراد الصحراوي وأكواب من الفحم لتشابه تجمعات الجراد الثابتة.

ولقد أشارت النتائج إلى أن ضبط الجراد الصحراوي يمكنهم بواسطة طريقة المسح بشيا بالالقدام رصد تجمعات الجراد الثابتة حتى مسافة 5 أمتار على جانب مسار المسح، كما أنهم لا يجب أن يعتمدا كلباً على رصد أعداد الجراد من خلال طريقة المسح بإستخدام السيارة، حيث أن هذه الظاهرة لا تمكنهم من رصد العدد بالدقة المطلوبة.

كما أنه وجد أن تنفيذ الطرق المقترحة (بشيا بالالقدام أو السيارة) يمكن ضبط الجراد من تغطية مساحة أكبر من المساحة المغطاة بالطرق الأخرى المختبرة، إلا أن الزمن اللازم لتنفيذ الطرق المقترحة كان أكثر من الزمن اللازم لتنفيذ الطرق الأخرى.

بالإضافة إلى أن زيادة عدد القائمين بالمسح ساعد في تغطية مساحة أكبر من المساحة المسوحة أو المصابة.

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هذا النتائج تساعد على تطوير كفاءة عمليات المسح وبالتالي زيادة قدرة الاستراتيجية الوقائية المتاحة حالياً ضد الجراد الصحراوي.
CHAPTER ONE
INTRODUCTION

Since times immemorial, the desert locust *Schistocerca gregaria*, has been known as a pest, which causes considerable damage to crops and pastures. The desert locust plague in Algeria that lasted 11 years (1864-1875), caused heavy casualties among the natives. In Morocco during 1954/55, desert locust swarms inflicted damage to market gardens and orchards worth US$ 13 million. In 1958, heavy damage to the predominantly subsistence crops occurred in Eritrea (around 125,500 tones of mixed grains were lost). In Sudan, particularly in Kordofan state, around 55% of the food crops were damaged during the 1988 desert locust plague. During the 1987-1989 desert locust invasion, the international aid was about US$275 million, in addition to the cost of more than 3 million litres of insecticides. The desert locust invasion of 2004 caused significant losses of crops in the Sahel region, particularly in Mauritania, which lost as much as half of its harvest.

Despite these documented losses, it is still extremely difficult to ascertain precisely the crop losses caused by the desert locust. The gregarious phase is the most damaging phase while the solitary phase is almost harmless, because it occurs in such low numbers that hardly cause any damage. The multiplication rate of desert locust during favourable periods is very high (approximately 30 folds in one generation) and there are 2-3 generations per year. The solitarious female lays 3-4 egg pods, each containing 100-160 eggs, and the gregarious female lays 2-3 egg pods, each containing 60-80 eggs. The eggs hatch within 10 to 65 days and the emerging hoppers develop through five to six stages over a period of about 30-40
days, depending on temperature. At the final moult, the young adult (or fledgling) emerges. Under optimal conditions (lush vegetation, maximum day temperatures of 30-36 °C, and sufficient rain for vegetation growth), adults generally mature in about three to eight weeks. If conditions are unfavorable, immature adults can survive for six months or more. Solitarious adults can breed in small areas of green vegetation while immature swarms usually settle in areas where widespread and heavy seasonal rains have fallen. The mature adults, copulate and oviposit in groups. Migration is a striking feature of desert locust behaviour by which immature solitarious and swarming populations can link up seasonally distinct breeding areas, which may be several thousands kilometers apart. Wind systems play a major role in facilitating the long distance downwind displacement of locusts.

The behavioral changes of desert locust leading to gregarization depend on micro-scale environmental factors such as the spatial distribution of food plants, as well as on macro-scale factors such as convergent wind fields that force locusts to concentrate in relatively small areas. This change can take place rapidly, often within a few hours of crowding. The capacity to behave gregariously is passed from parents to offsprings and increases with successive crowded generations. The color of locust also changes from brown in solitary to pink and yellow in immature and mature gregarious adults, respectively. Morphological changes occur following changes in locust behavior.

The breeding areas extend in a broad belt from the Atlantic Ocean in the west, to north-west of India in the east, most of these areas are arid or semi arid, and
receive less than 200 mm of rainfall annually. During recessions (periods of low densities of desert locust), locust occupies a total area of approximately 14.6 million km$^2$, while the invasion area covered by plague populations is around 29.3 million sq. km.

The large area, which is unevenly inhabited by the desert locust, together with the unpredictable migration patterns of this insect, constitute major obstacles in the way of its timely detection and control.

Early detection of gregarizing locust populations and proper location of the infested area are key elements of success for the preventive control strategy. Hence there were great efforts spent in developing surveillance technologies which included the Geographical Information System (GIS), the weather data satellites and modeling. This is in addition to the use of various ground and aerial survey methods and to the development of improved information exchange facilities. However, despite all these major developments, the problems of early detection of foci of locust outbreaks and upsurges and of the proper demarcation of the infested area and the estimation of locust populations remain a formidable challenge.

This study aims to evaluate the current methodologies of ground survey, and to attempt to introduce improvements, which increase the efficiency of the survey process.

The general objectives of this study focus on the improvement of methods of detection of desert locust infestations, and the upgrading of the capacity of the desert locust management.
The specific objectives are: (a) Using computer software and applying principles of geometry to devise an improved ground survey method. (b) Field test the proposed survey method and compare it with the current survey methods.
CHAPTER TWO

LITERATURE REVIEW

1- Economic Importance of Desert Locust

The desert locust invasions are ancient sporadic events. The records of these events were noted in the Bible and The Qur'an. Locust invasions were reported in North Africa about AD 811, but more precise records were not kept until the twentieth century (Showler 1993). Chatelin and Bonneuil (1995) compiled some historical records of desert locust plagues. Thus the Italian locust invasion, followed by the Algerian plague during 1724-1725, and the Moroccan plague during 1813-1815. In 1864-1875, the desert locust invasion in Algeria caused heavy casualties among the natives. During last century, desert locust plagues occurred in the Middle East on different occasions: 1901–1908, 1912–1917, 1926–1933, 1941–47, 1949–1962 and 1968 (Waloff 1966 and 1976). The 1987- 1989 desert locust invasion was the most dramatic in Africa (van Huis 1993). Then there was an upsurge in 1993 and 1996, which devoured the harvests of Ethiopia, Sudan, Eritrea, Somalia and Djibouti (Cressman 1998). The 2004 desert locust invasion was the largest in West and North Africa in more than 15 years and affected a number of countries in the fertile northern regions of the continent (http://en.wikipedia.org/wiki/2004_Locust_Swarm).

Most of these invasions caused great losses to crops and pastures in a number of the affected countries. Joffe (1998) recorded that in Morocco during 1954/55, desert locust swarms inflicted damage to market gardens and orchards worth US$ 13 million. In 1958, heavy damage to the predominant subsistence crops in
Eritrea (around 125,500 tones of mixed grains) occurred over a ten day period, the approximate total value of crops lost was US$12 million, in addition to US$ 400 thousand spent on distribution of food aid. In Sudan, particularly in Kordofan state, around 55% of the food crops were damaged during the 1987-1988 plague.

The estimation of crop losses caused by desert locust has been under critical review, in order to devise comprehensive and realistic methods of damage assessments (Bullen 1969). Extrapolation from estimates of crop losses based on small areas usually results in a very low order of accuracy when applied to damage on large scale. This is partly because on a large scale, the distribution of crop losses caused by locusts is extremely variable in time and space (Bullen, 1972). Krall & Herok (1997) argued that losses caused by desert locust could be devastating, but owing to the insect's mobility, it is never uniformly distributed. For this reason, it is extremely difficult to ascertain precisely the level of crop losses.

2- Biology

Desert locust can exist in two or more phases (Uvarov 1921 and 1977; Johnston 1926). The solitarious phase, and that is when locusts occur in small numbers, and live like ordinary grasshoppers, and the gregarious phase when the numbers increase, thus forming dense populations. The gregarious populations usually form “swarms” when in the adult stage and “bands” when in the wingless form known as hoppers (Uvarov 1921 and 1966). During recessions, desert locusts are found at very low densities, in the solitary form (Hemming et al. 1979 and Magor 1994a), while during the invasion periods they are found in swarms and hopper bands
(Roffey 1994). The gregarious phase may cause great local, regional and/or global damage (Uvarov 1957). That is because desert locusts are polyphagous insects (Evans & Bell 1979), which are very large in size (Uvarov, 1966), and very mobile (Uvarov 1977). Roffey and Popov (1968) estimated the desert locust multiplication rate at 16 folds while Ashall and Ellis (1962) considered it to range between 9 - 36 folds. Ballard, et al. (1932) found that under favourable ecological conditions, desert locust may have three generations in a year. The life cycle commences with the eggs, which hatch to give the nymphs, which develop to the adult stage (Uvarov, 1966). A single copulation is sufficient to fertilize a number of successive egg pods (Norris, 1954). Oviposition starts within two days of copulation, and it takes 3-14 hours (Ashall and Ellis 1962). Popov (1958) stated that the total period for oviposition by a swarm ranges from 7-30 hours. A gregarious female lays 2-3 egg pods and each contains 60-80 eggs, while the solitarius lays 3-4 egg pods each containing 100-160 eggs (Anon 1982). About 20mm of rain in one or several falls over few days or its equivalent in runoff from higher ground, provide sufficient moisture to allow complete eggs development (Magor 1994). Egg pods can remain dormant and continue development after further rainfall; the incubation period also depends upon soil temperature, and ranges between 10-65 days (Wardhaugh, et al., 1969). Gregarious desert locust females usually lay egg pods in groups in the so-called egg fields, and the size of an egg field can be used to estimate the density of the resultant locust population. Gregarious desert locusts pass through five instars while solitarius locusts pass through six instars (Wardhaugh et al., 1969). After hatching, gregarious hoppers first appear in small
numbers, and then join in large groups called "bands". The duration of hopper development is affected by temperature and humidity. Less variation occurs in the duration of the hopper than in the egg stage because hoppers are able to regulate their body temperature by moving in and out of the shade (Roffey, et al 2003). In the summer breeding areas, most hopper development periods lie within the range of 30-39 days, and 28-48 days during the cooler months (Uvarov 1977). Popov (1954) reported that immature adults of gregarious desert locust were usually pink in colour. When conditions are suitable (rainy season), adults may mature in three weeks after fledgling and their colour becomes yellow. Under cold and/or dry conditions, adults can remain immature for up to eight months and their colour becomes brown. The average longevity of desert locust adult is between 40-50 days (Bennett 1976). The main factor, which governs the length of an adult life span, is the length of the immature adult period. Swarms change from migratory flight to reproductive activities over several days. As the number of fully mature adults increases, they form numerous feeding, marching, copulating and later laying groups whilst the less mature individuals continue to migrate. Swarms often break up as they mature but frequently rejoin when they resume migratory flights between laying cycles (Roffey, et al 2003). Norris (1964) concluded that the exact conditions that cause maturation of locusts are unknown, but rainfall appears to play an important role. Moreover, the type of food plants influences development, fecundity, and fertility of desert locust adults (Tauber et al 1954; Abdel Rahman 1999 and Abdalla 2004).
3- **Population Dynamics**

Desert locust has the largest distribution area; this extends from West Africa through the Middle East to South-West Asia (van Huis 1993). The recession area occupies approximately 14.6 million sq. km., while the invasion area covers around 29.3 million sq. km (Waloff 1966 & Magor 1994). These vast areas are characterized by seasonal rainfall averaging between 80-400 mm annually (Magor 1994). Migration takes the immature solitarious adults and swarming populations between seasonally distinct breeding areas by a succession of daily downwind displacements (Roffey, *et al* 2003).

Hoppers of different phases have similar pattern of behaviour; the major exception is the tendency of gregarious hoppers to form mobile and cohesive bands. The daily marching time and distances covered by gregarious hoppers differ according to instar, kind, density and distribution of vegetation, as well as temperature. This distance varied between 100 – 1000 m per day (Kennedy 1945; Ellis and Ashall 1957). When groups of adults are seen in the field, it is an indication that they are becoming gregarious and may form swarms. Other incoming adults, from neighboring areas, may accelerate the process of concentration. Thus leading to an "outbreak" (Waloff 1966), which could be identified as, a marked increase in locust numbers due to concentration, multiplication and gregarization (Roffey and Popov 1968). An outbreak usually, develops into an "upsurge" which means, a period following a recession marked initially by a very large increase in locust numbers and contemporaneous outbreaks followed by the production of two or more successive seasons of transient-to-gregarious breeding in complimentary
seasonal breeding areas in the same or neighboring regions (Waloff 1966). While a "plague" is referred to as a period of one or more years of widespread and heavy locust infestations, the majority of which occur as bands or swarms. A "major plague" occurs when two or more regions are affected simultaneously (Waloff, 1966).

4- Desert Locust Breeding Seasons

Davies (1952) distinguished four breeding seasons for *Schistocerca gregaria* in North-Eastern Africa and the Near East, namely the monsoon, the winter-early spring, the main spring and the pre-monsoon. Monsoon generation swarms migrate north-eastwards and northwards from the monsoon breeding belt in North-East Africa and southern Arabia. Some of these swarms may breed on the Red Sea coasts of Egypt, Sudan, Eritrea, and Western Arabia, over a belt extending across Arabia, and in Oman. The resultant winter-early spring generation swarms join in the northerly migrations to northern Arabia and the Middle East. A south-westerly deflection from the north-western part of the invaded area may result in the invasion of Egypt. Main spring breeding, by swarms of both monsoon and winter-early spring generations, gradually extend northwards through most of the invaded area, and some of the resultant main spring swarms, appearing in central and northern Arabia, may continue to move northwards through Iraq, Jordan and Palestine. Further south, the major migrations of the main spring swarms are south-westwards and southwards towards the monsoon breeding belts in north-eastern Africa and southern Arabia; the tendency to move southwards gradually spreads further northwards, and by June/July it involves swarms which had earlier tended
to move north. The early arrivals to the monsoon breeding belt may breed on rains preceding the onset of the south-west monsoon, and the resultant pre-monsoon swarms in north-eastern Africa, and the pre-monsoon swarms of south-western Arabia, later take part, together with the main spring swarms, in monsoon breeding, which in some years may be sufficiently prolonged for the production of two successive monsoon generations. The cycle is thus in many respects similar to that over most of Western and North-Western Africa, which is discussed by Donnelly (1947), who distinguishes four possible generations per year in that area. It is theoretically possible for five generations per year to be produced by swarms migrating between north-eastern Africa and the Middle East.

Three breeding seasons of the desert locust in south-western Asia have been distinguished by Foulkes (1953), each giving rise to one or two generations of swarms, which may follow a general pattern of migrations from one breeding zone to another. In the eastern part of south-western Asia swarms breed during the season of south-west monsoon, and one or two monsoon generations are produced. Towards the close of the rainy season in this area, swarms of monsoon generations may migrate westwards and north-westwards into areas of winter rain where they breed and give rise to the winter-early spring generation. Both the surviving monsoon and winter-early spring swarms become involved in a northward and westwards movement during which they may breed and give rise to one or two main spring generations. From the spring breeding areas the swarms return in southerly and easterly directions, to breed on the summer rains during the south-west monsoon. It is thus theoretically possible for five successive generations to be
produced during the year in south-western Asia, an estimate which corresponds with the maximum number of generations which might be produced by swarms migrating between North-East Africa and the Middle East. The production of all five generations, however, depends not only on suitable climatic conditions but also on the continuity of swarm displacement between the seasonal breeding zones, and can only be established by a more detailed study of particular seasons and years.

5- Migration Patterns

Waloff (1966) and Pedgley (1981) considered that the migration of desert locust swarms continued for two to four months. Swarms achieve net displacements from 1000 to 3000 km as a result of their cumulative daily displacements. These migrations are more or less downwind. The tracks of an individual swarm or groups of migrating swarms vary, because of the change of the wind direction and speed change with time. Tracks vary from almost straight lines for periods of days, to sharp bends or even loops over one or two days (Gunn, et al., 1948, Rainey, 1963, Johnson 1969 and Pedgley 1981).

For the desert locust there is no evidence that migration is due to the immediate stimulus of lack of food (Gunn, et al 1948). Zolotarevsky (1946) doubted that gregariousness may not in itself be a causal factor in migration, though it may very well be a modifying factor. Rainey (1963) stated that the direction of swarm movements depended on the airflow at the time and place, and that the resulting generalized patterns of migration reflected seasonal regularities in air circulation. However, Wallof (1946a) and Uvarov (1977) concluded that the regular pattern of
seasonal migrations depended on the physiological responses of the locust to weather factors, those patterns change from season to season in regular manner and are not due to cycles of migration inherent in the species.

Generally, downwind migration of desert locust takes locusts towards areas of horizontal wind convergence and rainfall (Rainey, 1951). However, Hosni (1966) who studied the desert locust invasion of UAE during 1960/61 explained that swarms were retained in the Red Sea coastal wadis by the low temperatures and an anabatic/sea breeze semi-permanent convergence zone. Similarly, Pedgley (1972) found that in some years during May and June swarms migrate south-westwards across the Red Sea from north-western Saudi Arabia to Sudan and adjacent regions, a direction which is inconsistent with that of the prevailing sea level winds. He obtained these findings when he released a balloon sounding along the west coast, which indicated that these migrations may occur during spells of north-easterly winds crossing the Red Sea at altitudes of 1.0 to 2.5 km. Steedman (1977) concluded from the data recorded in 1955 and 1968, at the Red Sea area, that the crossings of desert locust over the Red Sea were likely, when easterly winds blew over Arabia and Egypt ahead of a desert depression moving eastwards near 30° N and also with an easterly wind flow along the south-eastern side of an anticyclone situated over the Middle East.

On the other hand, in October 1988 a swarm of desert locust crossed the Atlantic Ocean travelling from Africa to the Caribbean, flying in huge numbers and came in multiple waves, apparently ruling out this “few lucky individuals” hypothesis. Another possibility is that locust flying at the front of the swarm may have become
exhausted and died in the ocean, forming floating mats of dead insects. Other individuals of the swarm could have landed and have fed on these mats, thereby obtaining enough energy to sustain additional flight. Although it seemed extraordinary, this is perhaps the most likely hypothesis to explain how the locusts could cross the Atlantic Ocean, especially when noting that some people observed piles of locusts washed up on beaches for days in Barbados, in 1988 (http://news.nationalgeographic.com/news/2005/12/1228_051228_locusts.html).

6-Desert Locust Surveillance

The desert locust control operations always aim to prevent the development of an outbreak into an upsurge or a plague. Since 1960s, when the preventive control strategy was first adopted, the key element of this strategy has been the early location of the first signs of active gregarization (Krall et al, 1997). Therefore, effective surveillance is essential for a successful preventive strategy. The aim of regular environmental monitoring is to identify as soon as possible areas, which are potentially suitable for locust development and multiplication. Aerial and ground surveys are mounted to assess the locust situation in those areas and control operations are undertaken against any gregarious or gregarising populations with the overall objective of preventing the occurrence of major upsurges. Thus, the strategy depends on the presence of mobile survey teams capable of reaching all potentially suitable breeding areas. However, this is not always possible and so upsurges continue to occur. Therefore, an awareness grew towards the importance of the survey operations and sampling methods, which aim to provide population estimates with the highest degree of accuracy in relation to the amount of effort (i.e.
work or cost) expended. Generally, it is rarely possible to count all the insects in a population and therefore samples must be taken to estimate the population size. Moreover, there is no perfect sampling scheme that will work every time, as each problem, and each arthropod population will require specific sampling method, appropriate to the distribution and life cycle of the pest in question. However, for each sampling method it is necessary to decide upon three things: (i) the size of the sampling unit; (ii) the number of sampling units; and (iii) the location of these sampling units within the area (Youdeowei & Service 1983).

There are a number of methods of sampling of insects in the laboratory and the field, which were presented by Dent & Walton (1997), who stated that the data obtained from the field on insect population size are often based on counts or estimates of the number of insects in different stages. The data are collected from successive samples taken at different points in time at the same location. The sampling methods used might be absolute or relative measures depending on the insect stage, its habitat and mobility. The use of mark-recapture sampling and transect sampling methods has been devised specifically for more mobile species or insect stages. Dent & Walton (1997) emphasized that counts along a fixed route or line have become a standard method for evaluating the abundance of insects. According to these authors, methods used can be classed into three categories: line intercept sampling; strip transect sampling; and line transect sampling. The first considers the numbers of insects crossing a transect line, the second, the numbers of insects within a strip, and the third where an observer moves in a line through the area covered by a population and counts the numbers of insects that are seen.
This latter approach usually involves the 'flushing' of the insects as the observer moves along the transect. If the proportion 'flushed' is constant then the numbers themselves give an index of absolute population and incorporating the proportion and the area covered, an estimate of absolute population density can be obtained. If the efficiency of flushing varies then only a relative measure of abundance is obtained.

For the desert locust, Wolff (1966) drew the attention to the urgent need to develop rapid and reliable methods for assessing the numbers quantitatively when they are distributed (as they often are) over very large areas. Moreover, Pedelgy (1972) described the methodologies used for desert locust survey as slow and incomplete because of difficulties encountered in covering the large areas involved and in detecting the smaller habitats that receive sufficient rain for breeding. Detailed knowledge of the biogeography of *Schistocerca gregaria* helps to delimit these aspects; but the resources for covering an area of several million square kilometers that may need to be surveyed in any one breeding season are inadequate. Popov (1972) recommended the combined use of aerial and ground surveys and showed that aerial surveys within seasonal breeding areas could enable experienced observers to locate the areas of rainfall and likely locust habitats, and ground surveys may focus on potentially important sites. He emphasized that any locust populations found must be assessed both quantitatively and qualitatively in order to forecast the probable course of events and the likelihood of further multiplication, concentration and gregarization. Bennett and Symmons (1972) showed the difficulties of estimating the average numbers in any type of gregarious desert
locust population with confidence, as well as the difficulties of correlating the environmental and physiological factors with variations in locust density. They added that, it was not possible to make generally valid estimates of the densities of non-gregariously behaving populations. Other evidence of the inaccuracy of the ground surveys, was derived by Venkatesh, et al (1982) when they analyzed the locust situation reports from India and Pakistan in 1962, to determine the reliability of the number of swarms and number of individuals of *Schistocerca gregaria* in a swarm. Data provided by ground observers and radar images were compared. This analysis revealed that ground observers often underestimated the size of the swarms as determined by the radar. Further evidence of the low efficiency of the current survey methodology, was shown at the seminar of the EMPRES/CR and the FAO Commission for Controlling the desert locust in the Central Region (CRC) which was held in Borg Al Arab, Egypt (13-20 February 2002), when the participants were able to discover only 10-35% of simulated hopper patches in a field exercise. ([http://www.fao.org/ag/locusts/en/activ/wshops/empres/index.html](http://www.fao.org/ag/locusts/en/activ/wshops/empres/index.html))

Generally, Surveys must assess locust populations for both quantity (number) and quality (kind), (Popov, 1975). For unknown reasons, practically no research has been done on population estimation methods suitable for desert locust populations, although, in practice, estimates are made during field surveys as indicated by Bennett and Symmons (1972). Only few attempts with limited data were made on the methodologies used in desert locust survey operations. Uvarov (1977) showed that the quantitative studies of acridoid populations depended on the understanding of the environmental influences on the daily behavioural cycle. Based on this,
insect numbers could be determined either by counting undisturbed visible insects, or by counting insects visible by disturbance; in the first case by their horizontal and vertical movements within the vegetation, and in the second case by their response to disturbance. The two cases would depend upon time of the day and the weather at the time of count, this leads to behavioral changes, which may cause serious errors during the estimation. Uvarov (1977) proposed a method for counting a night roosting locust population based on a bottomless cage to be randomly placed on populations roosting on different vegetation types. It is relatively easy to determine the size of stationary bands but in the case of hoppers massed on vegetation, it may be preferable to determine the volume of the band taking into account the area and the height of the plants (Stower 1959). Marching bands, with their less definite shape and with a large part of the area in the rear containing scattered hoppers are more difficult to measure. However, Ashall & Ellis (1962) described a method of measuring the marching bands, by walking along the edges of the band, recording the number of paces along each section of the perimeter and noting changes in the compass direction, this method gives approximate values. In order to estimate the size of flying swarms and locust number within them, Uvarov (1977) showed that in this case combined observations from ground and from an aircraft, coupled with the recording of wind (direction and speed), and of thermal convection currents, will provide rational estimations. The estimation of a small settled swarm can be made by ground teams, more easily than that of large ones; the terrain (forest, ravines) may make it impossible to measure their perimeter, or to make the traverses from which the area
can be calculated. But the use of an aircraft partly removes this difficulty, though swarms of low density may not be visible from the air, and even distribution when a swarm is settled on scattered trees is another complication in making accurate estimates. Therefore, the measurements from air are generally more reliable than those made on the ground, but there are great sources of errors common to both settled and flying swarms. Wallof (1966) indicated that in India the locust density was estimated by counting the locust number within strips, the results recorded as number of locust counted per number of paces walked, these strips were 6-7 meters wide.

On the other hand, light traps were also used to collect individuals of solitarious desert locust, in order to estimate the population density within specific time and location (Popov 1971). Gunn, et al. (1948) used a photographic technique to estimate density of both flying and settled swarms. This technique was further developed by Sayer in 1956 when he used a camera with a double-slit shutter, and in 1965 by obtaining four images of the same locust.

In addition, Meinzingen, (1993) presented the following formula to estimate locust density per hectare, using the foot transect method:

\[ \text{No. of locusts/ha=} \frac{[(\text{Total No. of locusts counted} \times 50)}{\text{No. of surveyors}}. \]

With the vehicle transect method the following formula was given:

\[ \text{No. of locusts/ km}^2 = \frac{[(\text{Total No. of locusts counted} \times 250)}{(\text{No. of surveyors} \times \text{distance (km)})].} \]
Cressman (2001) determined the transect width, by estimating the distance in which adults were distributed during walking, (usually about 1-4 meters on either side of the path way, depending on the time of day, temperature and habitat), and suggested that the adult density should be recorded as:

\[
\text{[Number of locusts counted /surveyed area (length x width of the transect)].}
\]

He added that results recorded as locusts per hectare or square kilometer may not be accurate and suggested instead that the exact numbers counted by the surveyors be transmitted to the Locust Unit headquarters without further conversion to individuals per unit area. In addition, estimates of adults can be made from a vehicle by looking out of the windscreen and counting adults that fly up in front of the vehicle in a strip equal to the width of the vehicle, which is about 1.5 meters in most cases. The density of hoppers can be estimated by recording the minimum and maximum number of hoppers seen in the sample area (1 m² for each) as well as the number of samples (e.g. 10) that contained hoppers. These results should not be converted to numbers of hoppers per hectare or square kilometer. For estimating sizes of a large band or settled swarm, the locust officer should walk along two sides of the infested area at right angles while measuring the distance traveled. This may be done by using a vehicle, and then simply multiple the two values to obtain a rough approximation of the area.

Ghaemain (2002) studied a range of different survey patterns to identify the method that gives the best chance of detection of desert locust population at an early stage of gregarization (at the hopper stage). At this stage there are usually scattered small hopper patches (about 1 sq m). He first attempted to determine,
under field conditions the maximum transect width for survey activities. He then
used computer simulation [depending on the software of desert locust Survey
Model (DLSM)] to evaluate different survey patterns and suggest the best one
based on knowledge of desert locust habitat and behaviour. He selected a transect
width of 15 m and attempted to follow a simple survey pattern so that with a little
training all locust officers, regardless of their experience, could use it. Different
survey patterns were evaluated and suggestions made on the best for different
scenarios, which included status of green vegetation, probability of appearance of
patches, time constraints, availability of staff and equipment. He concluded that,
the tested patterns represented practical options that could be used by locust
surveyors.

The use of Geographical Information System (GIS), in the field of desert locust
survey, has been adopted by several specialists, as a new technological approach.
Gill and Howard (1978) discussed how satellite remote sensing techniques can
help improve the survey and control of *Schistocerca gregaria*. Sinha & Yadava,
(1985) used the information that “Acridids generally concentrate in green areas”, to
locate the potential areas of locust habitat, which may then be kept under strict
surveillance. This method of surveillance of breeding grounds of *S. gregaria* is
particularly useful in areas inaccessible to ground survey teams. Sinha & Chandra,
(1985 and 1987) explained that the remote sensing technique depended on the
visual interpretation of false color composite imagery by using tone, texture and
other associated image characteristics and this information was used to locate
suggested that mapping of the habitat of desert locust *Schistocerca gregaria* could be carried out on a large scale using multi-temporal data.

Kellou, *et al* (1990) suggested an integrated acrid-meteorological watch system for the Saharan breeding area to avoid any surprise events in the future. This permanent monitoring system should be built and operated jointly by the meteorological and the plant protection services at the national level. Deveson & Hunter (2002) suggested a geographical information system (GIS)-based on Decision Support System (DSS) to be used to coordinate the collection, processing, analysis and display of a range of spatial data for the forecasting of locust population development and to assist control operations. The resultant forecasts are used to help locate population aggregations early in a breeding sequence to enable effective preventive control of the insect pests. However, the Food and Agricultural Organization (FAO) of the United Nation operates a centralized desert locust Information System (DLIS), which relies on accurate information received in a timely manner, from the countries affected by desert locust, regional centres and meteorological services. This system is based on GIS and is connected to satellite receiving stations and to the internet. The FAO Headquarter’s version is called “SWARMS” (*Schistocerca* WARning Management System). FAO distributed other versions to the affected countries the so called “RAMSES” (Reconnaissance And Management System of the Environment of *Schistocerca* "), in addition to the GPS-connected palmtop computers (e-Locust), which send the information directly to a GIS server via high frequency radio modems (Krall *et al* 1997 & Cressman 2001). Moreover, Reus & Symmons (1992) described a model
developed to estimate the egg and nymphal development periods of *Schistocerca gregaria*. The model uses long-term monthly mean temperatures from a number of weather stations in the desert locust area. The computer program calculates the daily mean temperature and the daily related amount of development. It then accumulates the percentage of development estimated on successive days until the total reaches or exceeds 100. The model can be started on any day of the year at any given development stage and it can calculate development backwards in time as well as forwards. The model should be a useful aid in forecasting population developments of locust and for the planning of surveys. Cressman (2001) showed that the SPOT-VEG remote sensing imagery could be a useful tool for identifying areas of green vegetation. Although it may not provide enough detail to locate favourable habitats precisely, when used in combination with aerial surveys, it could help to delimit the relatively large areas that need to be checked on the ground. Imagery interpretation requires a high degree of skill and experience. The images or their analyzed by-products must be available to users in real time.

On the other hand, a number of scientists have discussed the relationship between plant type and desert locust activities. Guichard (1955) stated that ephemeral vegetation may inhibit gregarization while it remains dense and lush, but would favour it when drying up. Chandra (1984) found only 11 plant species to be attacked frequently by desert locust, of which 7 species were wild and *Pennisetum typhoides* [*P. americanum*] sesame, *Phaseolus aconitifolius* [*Vigna aconitifolia*] and *Cyamopsis psoraloides* [*C. tetragonoloba*] were cultivated crops. Chandra, *et al* (1985) noted that hoppers were frequently and consistently found on *Tribulus*...
terrestris and Aerva persica. Indigofera cordifolia, Cenchrus barbatus and Dactyloctenium sindicum, which seemed to be attractive plants for the hoppers. The Heliotropium plant community can be considered the most suitable for locust development (Woldewahid 2003 and Abdalla 2004), probably because of the higher leaf nitrogen contents of the plant (Suliman 2005). While Suaeda monoica and Panicum turgidum and Acacia tortilis plant community were the least attractive to desert locust. These findings agreed with the findings of Brown (1947), Waloff (1963), Popov (1965) and Roffey (1972), and indicated the most likely habitats for occurrence of desert locust, which should be kept under surveillance for early detection of gregarising desert locust. They also indicated that the food-plant range of the solitary populations of Schistocerca gregaria was much narrower than that of gregarious populations.
CHAPTER THREE

MATERIALS AND METHODS

I. Materials

One *hp* (Hewlett-Packard) compaq laptop, model nx7010, and the computer software AutoCAD 2002, were used to design the best fit of survey routes within selected areas of 1 hectare (for foot transects) and 1 km² (for vehicle transects). The computer software MapSource (ver. 3.02, Garmin) was used to display maps, and measure the distances and angles of the area of work, by transfer of the coordinates from the GPS to the software by a connecting cable. The computer software ArcView GIS (3.2a) was used to calculate the area of work, by transferring the coordinates to the software from an Excel data sheet. The computer statistical software SPSS, ver. 13.5, was used for the data analysis. Charcoal spots (sizes ranging from 0.5 to 1.0 m², the mean size of a charcoal piece was 0.58 cm³, and the depth of the charcoal layer was 1-2 cm) were used to simulate stationary natural populations of desert locust. Flags (25 cm x 25 cm of red pieces of cloth fixed at one end to a wooden stick 1.2 m in length) were used to delimit the areas of work or transects, through which locust officers or vehicles should move. Three to four vehicles (TOYOTA, Land Cruiser, pickup, models 1996/2001/2004, diesel engine) were used. GPS (12XL, Garmin), compass (SILVA, type 3, Sweden), anemometer (Dwyer, M.P.H.), hand tally counter, stopwatch (Q&Q, assembled in China), FAO Desert Locust Survey and Control Form, and adhesive tapes were among the essential tools used.
II. Methods

1- Determination of the width of the transect.

The aim is to determine the width of the foot and vehicle transects, by the naked human eye. Four desert locust officers from PPD (Sudan) were assigned each a vehicle in order to carry out survey along a defined route marked by flags for a distance of 700 meters. The speed of the vehicle was maintained at about 10 km/hr. (Fig. 1 & Plate 1). At the end of the prescribed distance (700m), the locust officer descended from the vehicle and carried out survey on foot along a transect 400 meters long guided by pre-positioned flags. The whole distance (1100 m) was divided into 22 sections, each 50 meters long and at each section four aggregations of charcoal (Plate 2), two on each side of the transect route, were placed randomly at varying distances from the route as shown in Table (1). For the vehicle survey method the distance of the charcoal from the transect route ranged between 5 and 35 meters while in the case of the foot transect it ranged between 1 and 10 meters. However, at each section of 50 meters the four charcoal heaps were equidistant from the transect route. The locust officers were required to record the number of charcoal spots they could see, at each section of the survey route.
Table 1. The distances of charcoal heaps from the transect route, by foot (F) and by vehicle (V).

<table>
<thead>
<tr>
<th>Section No.</th>
<th>No. of Charcoal spots</th>
<th>distance from the route</th>
<th>Section No.</th>
<th>No. of Charcoal spots</th>
<th>distance from the route</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.V</td>
<td>4</td>
<td>10 m</td>
<td>12.V</td>
<td>4</td>
<td>15 m</td>
</tr>
<tr>
<td>2.V</td>
<td>4</td>
<td>20 m</td>
<td>13.V</td>
<td>4</td>
<td>25 m</td>
</tr>
<tr>
<td>3.V</td>
<td>4</td>
<td>10 m</td>
<td>14.V</td>
<td>4</td>
<td>35 m</td>
</tr>
<tr>
<td>4.V</td>
<td>4</td>
<td>5 m</td>
<td>15.F</td>
<td>4</td>
<td>1 m</td>
</tr>
<tr>
<td>5.V</td>
<td>4</td>
<td>30 m</td>
<td>16.F</td>
<td>4</td>
<td>5 m</td>
</tr>
<tr>
<td>6.V</td>
<td>4</td>
<td>15 m</td>
<td>17.F</td>
<td>4</td>
<td>1 m</td>
</tr>
<tr>
<td>7.V</td>
<td>4</td>
<td>25 m</td>
<td>18.F</td>
<td>4</td>
<td>2 m</td>
</tr>
<tr>
<td>8.V</td>
<td>4</td>
<td>30 m</td>
<td>19.F</td>
<td>4</td>
<td>10 m</td>
</tr>
<tr>
<td>9.V</td>
<td>4</td>
<td>5 m</td>
<td>20.F</td>
<td>4</td>
<td>5 m</td>
</tr>
<tr>
<td>10.V</td>
<td>4</td>
<td>35 m</td>
<td>21.F</td>
<td>4</td>
<td>2 m</td>
</tr>
<tr>
<td>11.V</td>
<td>4</td>
<td>20 m</td>
<td>22.F</td>
<td>4</td>
<td>10 m</td>
</tr>
</tbody>
</table>
Figure 1. The layout of the charcoal spots along the route of vehicle and foot transects.
Plate 1. A. The pathway of vehicles in the vehicle transect.

Plate 1. B. A typical charcoal spot simulating a group of stationary hoppers/ adults of desert locust.
2- Design and test of alternatives to the current survey routes.

In order to achieve the highest efficiency of locust detection within reasonable time and affordable resources, 9 patterns (5 patterns of foot transects and 4 patterns of vehicle transects) were drawn (by using the geometrical computer software “AutoCAD 2002”) and tested in the field.

The methods currently used are, the foot transect carried out either by 3 or 4 locust officers, in an area of one hectare, when the locust officers walk upwind for 100 meters, to count the locusts along a path 4 meters wide, (Figures 2 & 3).

The current vehicle transect is carried out by 3 or 4 vehicles, in an area of one km², each vehicle moves upwind for 1000 meters, and locusts are counted along a path 8 meters wide, (Figures 4 & 5).

The method developed by Ghaemain, (2002) (Figure 6); was modified to fit the area of one hectare (Figure 7) and used to assess locust population, where four locust officers were employed in this method. The locust officers walked crosswind at angles -72 °, + 80.5 °, +72 °, and - 80.5 ° from the bearing direction of wind, for 106 meters, 101.38 meters, 101.38 meters, and 106 meters respectively. Due to the shape of letter (M) of this pattern, it is referred to as the M pattern, (Figure 7).
**Figure 2.** Graphical presentation of the current foot transect performed by 3 locust officers in an area of one hectare.

**Figure 3.** Graphical presentation of the current foot transect performed by 4 locust officers in an area of one hectare.
**Figure 4.** Graphical presentation of the current vehicle transect performed by 3 vehicles in an area of one sq km.

**Figure 5.** Graphical presentation of the current vehicle transect performed by 4 vehicles in an area of one sq km.
Figure 6. Graphical presentation of the foot transect, developed by Ghaemain, M. (2002), for a unit area of 1 sq. km. performed by (1-2) locust officers.

Figure 7. Graphical presentation of the M pattern (the modified foot transect, developed by Ghaemain,(2002)) performed by 4 locust officers in an area of one hectare.
In addition, four patterns were designed and tested, as alternatives to the aforementioned patterns. The first of these proposed foot transect was performed by 3 locust officers, who walked along 3 transects. The first transect was a track 96 meters long crosswind, at (+45°) to the wind direction; the second track was 96 meters crosswind, at (-90°) to the first track. The second locust officer walked along a track 135.76 meters long directly upwind. The third locust officer walked along two tracks, the first track was 96 meters crosswind, at (-45°) from the wind direction, the second track was 96 meters crosswind, at (+90°) to the first track, (Figure 8).

The second foot transect was conducted by 4 locust officers, where the first locust officer walked along two tracks, one track was 93.17 meters crosswind, at (+45°) to the wind direction, and the second track was 93.17 meters crosswind, at (-90°) to the first track. The second and third locust officers walked along two parallel tracks of 131.76 meters each directly upwind. The forth locust officer walked along two tracks, the first track was 93.17 meters crosswind, at (-45°) to the wind direction, and the second track was 93.17 meters crosswind, at (+90°) to the first track, (Figure 9).

The third proposed vehicle transect was a vehicle transect performed by 3 vehicles. The first vehicle moved along two tracks, the first track was 920 meters long crosswind, at (+45°) to the wind direction, and the second track (920 meters) crosswind, at (-90°) to the first track. The second vehicle moved along one track...
for 1301.1 meters directly upwind. The third vehicle moved along two tracks, the first track was 920 meters crosswind, at (-45°) to the wind direction, and the second track was 920 meters crosswind, at (+90°) to the first track, (Figure 10).

The forth proposed vehicle transect was performed by 4 vehicles, the first vehicle moved along two tracks, the first was 920 meters long crosswind, at (+45°) to the wind direction, the second was 920 meters long crosswind, at (-90°) to the first track. The second and third vehicles moved along two parallel tracks each 1221 meters long directly upwind. The forth vehicle moved along two tracks, the first is 920 meters crosswind, at (-45°) to the wind direction, and the second track was 920 meters crosswind, at (+90°) to the first track, (Figure 11).

The time taken to cover each of these survey routes was recorded and comparisons were made between different routes.

The different methods were tested under field conditions, both on population of gregarious adults of desert locust and on charcoal aggregations simulating stationary locust groupings. The survey officers were asked to use the different methods and record their findings separately for each method.
Figure 8. Graphical presentation of the proposed foot transect method performed by 3 locust officers, in an area of one hectare.

Figure 9. Graphical presentation of the proposed foot transect method performed by 4 locust officers, in an area of one hectare.
Figure 10. Graphical presentation of the proposed vehicle transect method performed by 3 vehicles, in an area of one km².

Figure 11. Graphical presentation of the proposed vehicle transect method performed by 4 vehicles, in an area of one km².
This applies for both natural populations of desert locust detected and counted and for charcoal spots simulating stationary locust grouping. In the vehicle transect the survey route for each method was predetermined and saved in the GPS with the help of the MapSource software.

The survey officers used the current foot transect method, the proposed foot transect method and M pattern to evaluate the efficiency of each of the three methods in detecting the randomly distributed charcoal spots in each of two hectares. Each method was replicated 4 times (Table 2).

**Table 2.** Layout of plan to test different foot transect methods in detecting charcoal spots simulating groups of locust.

<table>
<thead>
<tr>
<th>Hectare No.</th>
<th>The applied methodologies</th>
<th>Type of simulated population</th>
<th>No. of charcoal spots</th>
<th>No. of replications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M pattern</td>
<td>Group of locust</td>
<td>48</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>current foot transect</td>
<td></td>
<td>48</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>proposed foot transect</td>
<td></td>
<td>48</td>
<td>4</td>
</tr>
</tbody>
</table>

The current foot transect method and the proposed foot transect method were also compared at different habitats namely at the Red Sea coast, at Tokar Delta and at the summer breeding areas of North Kordofan. At each location, the time taken to complete the survey by each of the two methods was recorded, in order to determine the performance time for each method at different habitat types.
It is worth mentioning that the habitats of these locations were quite different from each other, especially as regards vegetation cover and topography.

The current and proposed foot transect methods were compared with respect to the time required by each and to the efficiency of each method in detecting locusts, during a survey journey of 900 km, as shown in Fig (12).

**Figure 12.** A typical area wide desert locust survey route performed by PPD teams at the summer breeding areas of North Kordofan.
3- **Estimation of the size of an infested area.**

An area close to wadi El Diib (N21 41 52.4 /E36 07 10.8) infested with fledgling adults was chosen for this study. The borders of the area were demarcated by 60 GPS coordinates (Fig. 13). Trees and shrubs within this area where locusts were roosting were marked (Plate 3) and their positions saved in the GPS (Fig. 13). The coordinates of the total and the infested areas were transferred using the software MapSource and the software AutoCAD 2002, whereby each area was calculated separately. At the same time, four locust officers were asked each to give an estimation of the total area and of the infested area. Estimates of locust officers were compared with one another and with the calculated areas.

**Plate 2.** The site selected for estimation of total and locust infested areas.
Plate 3. Roosting locusts on trees within the infested area (A), and the demarcated roosting sites (B).
Figure 13. Total surveyed area and area infested with desert locust as determined by the GPS and MapSource software.
CHAPTER FOUR

RESULTS

1- Determination of the width of the transect.

Table (3) shows that surveyors using the foot transect method can detect all charcoal spots scattered up to 2 meters from the survey route. With increased distances of objects from the survey route the efficiency of detection decreased, so that at 10 meters about 16% of the spots were missed. Similarly, in the case of the vehicle transect the percentage of detection of charcoal spots decreased with increased distances. At 5 meters from the survey route, around 66% of the charcoal spots were detected while at 35 meters only about 19% of the spots were detected (Table 4).

2- Evaluation of the different foot transect survey methods for detection of charcoal spots.

Simulated populations of stationary gregarious desert locust were surveyed using three different methods. The highest percentages of detection of charcoal spots were obtained when the surveyors used the proposed foot transect method. The M pattern (the modified method developed by Ghaemain, (2002)) was the second best while the current foot transect recovered the least number of charcoal spots (Table 5). Moreover, when these methods were compared on the basis of time taken to perform each, the current foot transect took the least time followed in increasing order by the M pattern and the proposed pattern respectively (Table 5).
During the preliminary trials it was found that, when the number of surveyors was increased from 3 to 4 and the current foot transect was compared with the proposed foot transect method, there was a slight increase in the percentage recovery of the charcoal spots (10%) with the increase in the number of surveyors, by both methods.

It should be noted that in all cases the time taken to conduct the proposed foot transect method was greater than that of the current foot transect.
Table 3. Percent detected charcoal spots laid out at various distances from a foot transect route.

<table>
<thead>
<tr>
<th>Distances from survey route (m)</th>
<th>Mean percentage of detection</th>
<th>Mean Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1&lt;sup&gt;st&lt;/sup&gt; locust officer</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; locust officer</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>87.5</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>87.5</td>
<td>87.5</td>
</tr>
</tbody>
</table>

Table 4. Percent detected charcoal spots laid out at various distances from a vehicle transect route.

<table>
<thead>
<tr>
<th>Distances from survey route (m)</th>
<th>Mean percentage of detection</th>
<th>Mean Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1&lt;sup&gt;st&lt;/sup&gt; vehicle</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; vehicle</td>
</tr>
<tr>
<td>5</td>
<td>62.5</td>
<td>62.5</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
<td>62.5</td>
</tr>
<tr>
<td>15</td>
<td>37.5</td>
<td>37.5</td>
</tr>
<tr>
<td>20</td>
<td>37.5</td>
<td>50</td>
</tr>
<tr>
<td>25</td>
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<td>30</td>
<td>25</td>
<td>37.5</td>
</tr>
<tr>
<td>35</td>
<td>0</td>
<td>25</td>
</tr>
</tbody>
</table>
Table 5. Time taken and detection percentage, by each of three foot transect survey methods, when performed on charcoal spots, simulating stationary gregarious adults.

<table>
<thead>
<tr>
<th>Method</th>
<th>Replication no.</th>
<th>Locust officer</th>
<th>Detected no. of spots</th>
<th>Total</th>
<th>Mean Percent of Detection</th>
<th>Time Taken</th>
<th>Mean Time Taken (mm:ss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M Pattern</td>
<td>1</td>
<td>1^st</td>
<td>3</td>
<td>16</td>
<td></td>
<td>1:10</td>
<td>1:19 b</td>
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<tr>
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<td></td>
<td>2^nd</td>
<td>5</td>
<td></td>
<td></td>
<td>1:15</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3^rd</td>
<td>6</td>
<td></td>
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<td>1:07</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4^th</td>
<td>2</td>
<td></td>
<td></td>
<td>1:08</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1^st</td>
<td>4</td>
<td>21</td>
<td></td>
<td>1:09</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2^nd</td>
<td>7</td>
<td></td>
<td></td>
<td>1:06</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3^rd</td>
<td>6</td>
<td></td>
<td></td>
<td>1:03</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4^th</td>
<td>4</td>
<td></td>
<td></td>
<td>1:09</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1^st</td>
<td>6</td>
<td>21</td>
<td>34.38 a</td>
<td>1:09</td>
<td>1:00</td>
</tr>
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<td></td>
<td></td>
<td>1:00</td>
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</tr>
<tr>
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<td>8</td>
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<td>1:01</td>
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</tr>
<tr>
<td></td>
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<td>4</td>
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<td>2:03</td>
<td>1:58</td>
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<td></td>
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<td></td>
<td>3^rd</td>
<td>9</td>
<td></td>
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<td>1:59</td>
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<td>4^th</td>
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<td></td>
<td>1:59</td>
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<tr>
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<td>1^st</td>
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<td>21</td>
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<td></td>
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<td></td>
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<td></td>
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<td>20</td>
<td></td>
<td>1:10</td>
<td>1:06 b</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>8</td>
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<td>1:09</td>
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<td>1:04</td>
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<tr>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
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<td>5</td>
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</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td>1:05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1^st</td>
<td>9</td>
<td>22</td>
<td>34.37 a</td>
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<td>2^nd</td>
<td>7</td>
<td></td>
<td></td>
<td>1:05</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>3^rd</td>
<td>6</td>
<td></td>
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<td>1:05</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>4^th</td>
<td>4</td>
<td></td>
<td></td>
<td>1:12</td>
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<td>1^st</td>
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<tr>
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<td>2^nd</td>
<td>2</td>
<td></td>
<td></td>
<td>1:08</td>
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</tr>
<tr>
<td></td>
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<td>3^rd</td>
<td>3</td>
<td></td>
<td></td>
<td>1:07</td>
<td></td>
</tr>
</tbody>
</table>
3- **Evaluation of the different foot transect survey methods for detection of gregarious adult locusts.**

When the proposed foot transect and the current foot transect survey methods were performed on natural populations of gregarious adults, the first method recovered more numbers of locusts than the second method, but it took more time to perform in comparison with the current foot transect method. Also the four locust officers detected more locusts by the two methods, as compared with 3 officers (Table 6). The mean time taken by the two groups of officers was the same in the case of the current foot transect, but there was a slight difference between them in the case of the proposed foot transect.
**Table 6.** Time taken and detection percentage, by each of two foot transect survey methods, when performed on gregarious adults of desert locust.

<table>
<thead>
<tr>
<th>locust officers</th>
<th>Current Foot Transect</th>
<th>Proposed Foot Transect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In the case of 3 locust officers</td>
<td>In the case of 4 locust officers</td>
</tr>
<tr>
<td></td>
<td>Time taken (min:ss)</td>
<td>No. of the counted locusts</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>1:17</td>
<td>11</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>1:30</td>
<td>27</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>1:22</td>
<td>14</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Totals</td>
<td>4:09</td>
<td>52</td>
</tr>
<tr>
<td>Mean time taken</td>
<td>1:23</td>
<td>---</td>
</tr>
</tbody>
</table>
4- **Evaluation of the different foot transect survey methods for detection of different phases of desert locust.**

Generally, the proposed foot transect method needed more time to perform than the current foot transect and M pattern; the differences in the time taken between the last two methods were very little. Moreover, there was a notable increase in the time taken when counting the gregarious groupings than the solitarious individuals, particularly when performing the proposed foot transect survey method, Table (7).
Table 7. Time taken and number of locust counted, by three foot transect survey methods, performed on solitary and gregarious desert locust.

<table>
<thead>
<tr>
<th>PHASE</th>
<th>METHOD</th>
<th>Total time taken (mm:ss)</th>
<th>No. of Locust counted</th>
<th>Mean 2</th>
<th>Std. deviation</th>
<th>Mean 1</th>
<th>Std. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean</td>
<td>Std. deviation</td>
<td>Mean</td>
<td>Std. deviation</td>
</tr>
<tr>
<td>Solitarious</td>
<td>current foot transect</td>
<td>2:18 b</td>
<td>0:17</td>
<td>2.16 a</td>
<td>1.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>proposed pattern</td>
<td>2:57 a</td>
<td>0:22</td>
<td>1.81 b</td>
<td>1.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M pattern</td>
<td>2:18 b</td>
<td>0:07</td>
<td>1.69 b</td>
<td>1.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gregarious adults</td>
<td>current foot transect</td>
<td>2:30 b</td>
<td>0:17</td>
<td>264.84 b</td>
<td>70.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>proposed pattern</td>
<td>3:17 a</td>
<td>0:20</td>
<td>309.74 a</td>
<td>69.37</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>M pattern</td>
<td>2:24 b</td>
<td>0:12</td>
<td>326.21 a</td>
<td>55.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gregarious hoppers patches</td>
<td>current foot transect</td>
<td>2:23 b</td>
<td>0:11</td>
<td>39.15 b</td>
<td>7.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>proposed pattern</td>
<td>3:30 a</td>
<td>0:17</td>
<td>45.44 a</td>
<td>7.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M pattern</td>
<td>2:21 b</td>
<td>0:12</td>
<td>40.79 b</td>
<td>7.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 These data were recorded at different locations and on different population sizes.
2 The total time taken includes time taken for measuring and recording the wind speed and direction (00:23), and filling the Form (00:30).
3 Estimates of hopper density were based on the number of patches. Each patch was approximately 1-3 m².
5- Evaluation of the different vehicle transect survey methods for detection of gregarious adult locusts.

Table (8) shows the number of gregarious adults detected by the proposed and current vehicle transect methods. The proposed vehicle transect method enabled the surveyors to detect more locusts in comparison with the current vehicle transect method, but the latter method was conducted at much less time. When four vehicles were used instead of 3 more locusts were detected by both methods. Moreover, the time taken to perform the survey was always less in the current vehicle transect method than the proposed vehicle transect method.

It is worth mentioning that, during the preliminary trials, which were conducted on the simulated populations (charcoal spots), it was found that when the number of vehicles were increased from 3 to 4 and the current vehicle transect was compared with the proposed vehicle transect method, there was a slight increase in the percentage recovery of the charcoal spots (5%) with the increase in the number of vehicles, by both methods.
Table 8. Time taken and detection percentage, by each of two vehicles transect survey methods, when performed on gregarious adults.

<table>
<thead>
<tr>
<th></th>
<th><strong>Current Vehicles Transect</strong></th>
<th></th>
<th><strong>Proposed Vehicle Transect</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In the case of 3 vehicles</td>
<td>In the case of 4 vehicles</td>
<td>In the case of 3 vehicles</td>
</tr>
<tr>
<td></td>
<td>Time taken (min:ss)</td>
<td>Counted no. of locust</td>
<td>Time taken (min:ss)</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; vehicle</td>
<td>6:00</td>
<td>2</td>
<td>6:00</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; vehicle</td>
<td>5:40</td>
<td>0</td>
<td>5:40</td>
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<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; vehicle</td>
<td>7:07</td>
<td>15</td>
<td>7:07</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; vehicle</td>
<td>---</td>
<td>---</td>
<td>6:15</td>
</tr>
<tr>
<td>Totals</td>
<td>18:47</td>
<td>17</td>
<td>25:02</td>
</tr>
<tr>
<td>Mean time taken</td>
<td>6:15</td>
<td>---</td>
<td>6:16</td>
</tr>
</tbody>
</table>
6- **Comparison of the current and the proposed foot transect methods at different habitats of desert locust.**

When the two foot transect methods were performed at three different habitats (Tokar, Red Sea coast and Kordofan) the time taken to carry out the proposed foot transect method was greater than that needed for the current foot transect, especially at Tokar delta (Table 9). The vegetation at Tokar (Plate 4) was dense and tall and that probably slowed down the survey officer’s movements, hence the increase in the time of survey.

7- **Testing the current and proposed foot transects during a long routine survey.**

Table (10) shows that both of the current foot transect and the proposed foot transect method relatively required the same number of stop points, but the time taken was slightly longer for the proposed foot transects than the current foot transects, the difference was only about 21:45 (mm:ss), during (approx.) 900 km of routine survey.

8- **Estimation of the size of an infested area.**

Visual estimates of areas by locust officers varied from one officer to another. However, when the same areas were calculated using data from GPS enteries and the softwares AutoCAD and ArcView, there were no differences between the two methods of calculations Table (11) & Figures (14, 15).
Table 9. Mean time taken to conduct the current foot transect and proposed pattern by 3 locust officers, at different habitats of desert locust.

<table>
<thead>
<tr>
<th>Methods</th>
<th>Time taken to survey one hectare (mm:ss)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Red Sea</td>
</tr>
<tr>
<td>Proposed pattern</td>
<td>3:05 b</td>
</tr>
<tr>
<td>Current foot transect</td>
<td>2:16 d</td>
</tr>
</tbody>
</table>

Table 10. A comparison of work rate between current foot transect and proposed foot transect.

<table>
<thead>
<tr>
<th>Methods</th>
<th>Current Foot Transect</th>
<th>Proposed Foot Transect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Distance Covered (km)</td>
<td>Distance Covered (km)</td>
</tr>
<tr>
<td></td>
<td>No. of Stop Points/ day</td>
<td>No. of Stop Points/ day</td>
</tr>
<tr>
<td></td>
<td>Time taken for the stop points /day</td>
<td>Time taken for the stop points /day</td>
</tr>
<tr>
<td></td>
<td>(hh:mm:ss)</td>
<td>(hh:mm:ss)</td>
</tr>
<tr>
<td>Covered Distance (km)</td>
<td>505</td>
<td>478</td>
</tr>
<tr>
<td>Total of Stop points</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Total time taken for all stop points</td>
<td>--- 01:45:26</td>
<td>--- 02:06:51</td>
</tr>
<tr>
<td>Average (km/ stop points)</td>
<td><strong>10.98 a</strong></td>
<td><strong>11.12 a</strong></td>
</tr>
<tr>
<td>Work Rate</td>
<td>1 stop point / 10.98 km, at the mean time of 2 min. and 18 sec.</td>
<td>1 stop point / 11.12 km, at mean time of 2 min. and 57 sec.</td>
</tr>
</tbody>
</table>
Table 11. Areas as estimated visually and calculated using software ArcView and AutoCAD.

<table>
<thead>
<tr>
<th>Methods of estimation and calculation</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; locust officer</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt; locust officer</th>
<th>3&lt;sup&gt;rd&lt;/sup&gt; locust officer</th>
<th>4&lt;sup&gt;th&lt;/sup&gt; locust officer</th>
<th>Means area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual estimations of area of survey (ha).</td>
<td>150&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100&lt;sup&gt;b&lt;/sup&gt;</td>
<td>100&lt;sup&gt;b&lt;/sup&gt;</td>
<td>90&lt;sup&gt;bc&lt;/sup&gt;</td>
<td><strong>135&lt;sup&gt;b&lt;/sup&gt;</strong></td>
</tr>
<tr>
<td>Visual estimations of infested area (ha).</td>
<td>30&lt;sup&gt;a&lt;/sup&gt;</td>
<td>20&lt;sup&gt;b&lt;/sup&gt;</td>
<td>20&lt;sup&gt;b&lt;/sup&gt;</td>
<td>20&lt;sup&gt;b&lt;/sup&gt;</td>
<td><strong>22.5&lt;sup&gt;b&lt;/sup&gt;</strong></td>
</tr>
<tr>
<td>Calculated area of survey by AutoCAD (ha).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>73.85&lt;sup&gt;a&lt;/sup&gt;</strong></td>
</tr>
<tr>
<td>Calculated area of survey by ArcView (ha).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>73.42&lt;sup&gt;a&lt;/sup&gt;</strong></td>
</tr>
<tr>
<td>Calculated infested area by AutoCAD (ha).</td>
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<td></td>
<td></td>
<td></td>
<td><strong>5.90&lt;sup&gt;a&lt;/sup&gt;</strong></td>
</tr>
<tr>
<td>Calculated infested area by ArcView (ha).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>6.01&lt;sup&gt;a&lt;/sup&gt;</strong></td>
</tr>
</tbody>
</table>
Plate 4.A. The dense cropping areas at Tokar Delta.

Plate 4.B. The habitats of north Kordofan with short green vegetation and flat plains.

Plate 4.C. Red Sea habitats with flat bare land.
Figure 14. The areas calculated by the software of AutoCAD 2002

Source: AutoCAD 2002.
Figure 15. The areas calculated of surveyed area & infested area, when entering the related coordinates to the system of Arc View 3.2a

Source: ArcView3.2a
CHAPTER FIVE

DISCUSSION

The preventive control strategy of desert locust has been adopted since 1960s. Locust control should occur at or prior to the formation of gregarious populations when locusts have amassed in small patches no more than a few square meters in diameter in the breeding areas. Hence, it is possible to combat outbreaks successfully without using vast quantities of pesticides and without great environmental damage. However, due to the lack of funds and inadequate forecasting and monitoring systems, the control of desert locust in recession areas has never worked satisfactory (Krall et al. 1997). Therefore, there is a need to re-examine the control strategies, develop improved tactics, upgrade the survey methods, and evaluate the economic impact of desert locust invasions. Although there is much discussion about developing alternative environmentally soft control measures, so far the only reliable tactic is the use of insecticides. The use of biocontrol agents against desert locust together with innovations in pesticides application technologies could greatly enhance locust management efforts. In addition, improved forecasting based on efficient survey methods and adequate sharing of information between all stakeholders are essential for the formulation of sound desert locust control strategies. It is worth noting that in recent years new survey and forecasting tools, which include Geographical Information System (GIS), remote sensing devices, satellite imageries and computer softwares packages, have become available. These devices have helped a great deal in
defining some aspects of the complex locust habitat but they are by no means a substitute for experienced locust survey officers. Despite the essential role of survey for the success of a sound preventive control strategy, very modest research has been carried out in this field.

During outbreaks or the early stages of upsurge only a certain proportion of the population behaves gregariously, and numerous small gregarious hopper bands are scattered over a large area. Simulated exercises indicate that in potential breeding areas only a very small percentage of these locust infestations could be detected, despite the intensive searching.

The main constraints of survey operations directed towards the prevention of upsurges are the excessive resources needed to effectively monitor early upsurges, insecurity or inaccessibility of remote areas or poor infrastructures, low detection rates of gregarious and gregarizing locusts, incomplete and imprecise field data, poor exchange of information and lack of trained manpower. Accordingly, a proper survey that may result in the prevention of an outbreak in the whole desert locust distribution area has probably never been implemented accurately (Krall et al. 1997).

Further evidence of the low efficiency of the current survey methodology was derived by Wolff (1966) who drew the attention to the urgent need to develop rapid and reliable methods for assessing the locust numbers over very large areas. In addition, Pedelgy (1972) described the methodologies used for desert locust survey as slow and incomplete. Popov (1972) recommended the combined use of
aerial and ground surveys and showed that aerial surveys within seasonal breeding areas could enable experienced observers to locate the areas of rainfall and likely locust habitats, while ground surveys may focus on potentially important sites. Bennett and Symmons (1972) showed the difficulties of estimating the average numbers in any type of gregarious desert locust population with confidence.

It is worth mentioning that, very little research has been done on population estimation methods suitable for desert locust, although, in practice, inaccurate estimates are made during every field survey operation (Bennett and Symmons 1972).

According to Cressman (2001), there are two types of locust surveys, the assessment and search survey. Assessment surveys is undertaken to monitor the situation of desert locust populations, assess the suitability of the ecological conditions for the probability of local breeding, and determine whether significant populations are present that may require control. The vehicle survey could be a more suitable method for the assessment surveys, due to its high work rate and its ability to cover large areas in a short time. It is estimated that a vehicle could travel 200 km/day and search an area of 1000 -10000 km² (Cressman, 2001). However, at the relatively high speed of the vehicle, surveyors may miss a large proportion of locust infestation foci, especially when there are scattered aggregations of early instar hoppers. On the other hand, the foot transect method
The search survey is conducted when significant populations of desert locust are detected and there is need to give an estimate of the area infested and of the level of infestation so that control operations could be successfully mounted (Cressman, 2001). Both types of survey depend on observations of trained survey officers and on the ease of detecting locust along the survey route. Hence in this study an effort was made to determine the most convenient distances at which surveyors can detect locust aggregations. Charcoal spots were used to simulate settled locusts at various distances from the survey route. The obtained results show that walking locust officers could easily detect charcoal spots placed at 1-5 meters on either side of the survey route. This finding supports the recommendation of Cressman (2001) who adopted an average of about 1-4 meters on either side of the survey route. On the other hand, these results are different from those of Ghaemain (2002) who reported foot transect width of 15 meters (7.5 meters on the either side of the survey route) for detection of bands of early stages of hoppers.

In general, detection of simulated locust groupings is relatively more efficient by the foot transect methods than vehicle transect, but the first method is slow and cannot cope with extensive infestations.

To improve the level of detection of locust infestations, the survey routes both in the case of the foot and the vehicle transect were redesigned. The objective of the
new design was to increase the area covered by the surveyors. The area covered by the surveyors in the case of the current foot transect was 12% and 16% of the hectare when the numbers of surveyors were 3 and 4 respectively. However, with the proposed newly designed route, the area covered by 3 persons increased to 21% and that covered by 4 persons to 26% of the total area of one hectare. When using the M pattern designed by Ghaemain (2002), the area covered by the surveyors was 17% of the total area of one hectare.

It is evident that with the proposed patterns there is a better coverage, hence more chance for detection of locust. The obtained results seem to support this both in the case of live and simulated settled locusts.

However, the time taken to perform the proposed patterns has always been more than that needed for both the current method and M pattern. This applies for both the foot and vehicle transect methods.

In this connection it is interesting to note that when the current foot transect and proposed foot transect methods were performed on a routine survey journey of about 900 km, the latter method took only about 21 minutes more than the former.

Even experienced survey officers often give estimates of infested areas much different from the actual areas infested. Thus four officers were requested to give estimates of the total area surveyed and the size of infested area. When these areas were calculated using GPS data and the software AutoCAD and ArcView, there were considerable differences between the two. It is therefore advisable to
avoid visual estimates, which seemed to be inaccurate and may result in an increased cost of locust management.
Conclusion & Recommendations

1. Vehicle transect survey methods are less accurate in detecting locust infestations when compared with foot transect methods. Yet because of the vast infested areas and the slow work rate of the foot transect they remain to be the choice for the assessment survey practices.

2. The width of the foot transect is recommended to cover an area of 2-10 meters, within these limits it is convenient to locate locust groupings and observe flying individuals. Accuracy may be hampered with high population of flying gregarious adults.

3. The proposed transect method improves the ability to detect locust, but it is a slow method compared with the current foot method and the M pattern.

4. With an increase in the number of survey officers there is more chance for detection of locust but the cost of additional personnel has to be considered.

5. Visual estimation of total areas to be surveyed and of actual surveyed areas can be misleading because locust officers differ much in their estimates. It is therefore, recommended that more use be made of GPS data and of special software to use such data in calculating the total and the infested areas. This helps to reduce unnecessary effort and to decrease the excessive use of pesticides in the case of control operations.
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