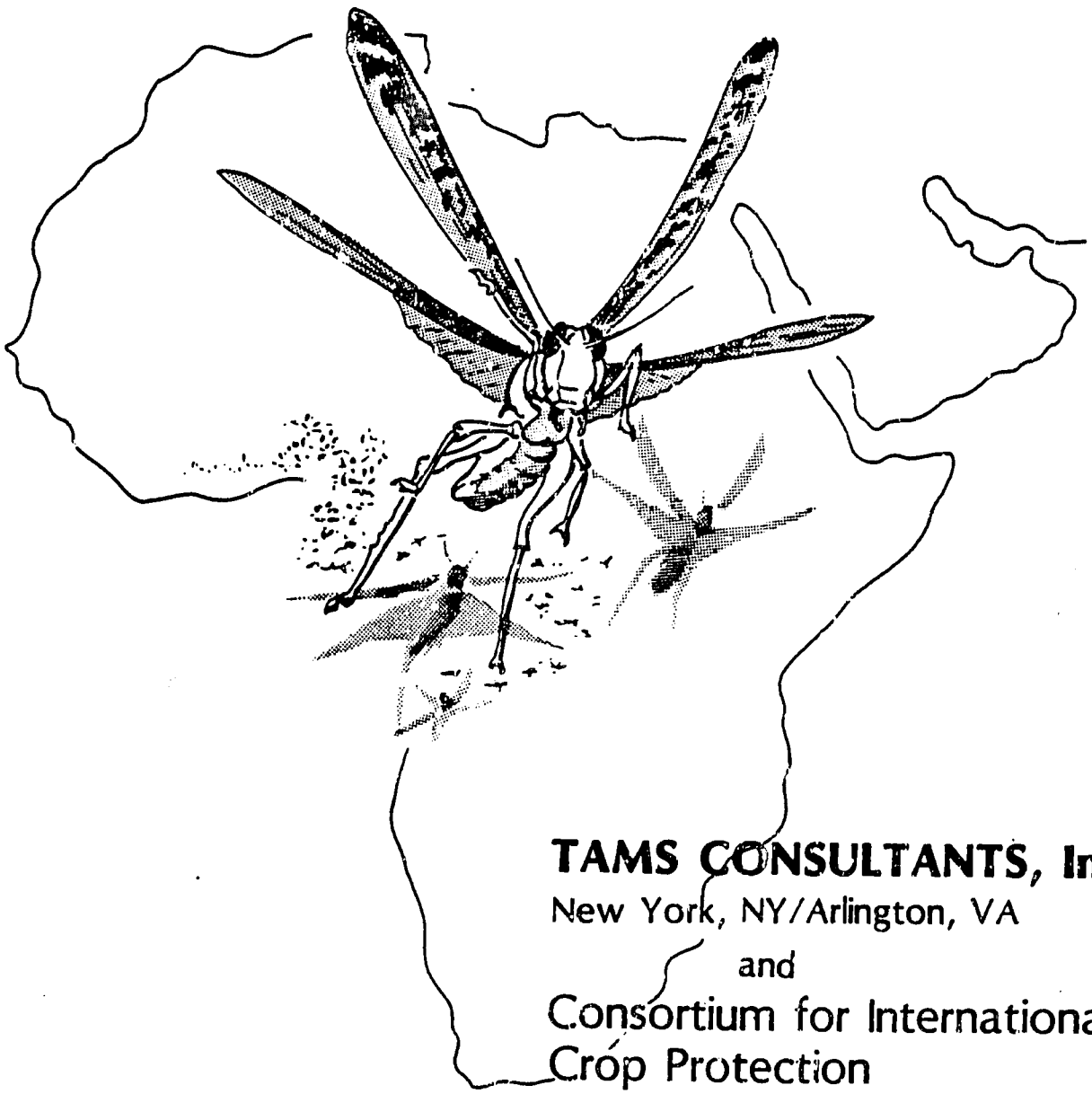
PN-ABD-103

US AGENCY FOR INTERNATIONAL DEVELOPMENT

LOCUST AND GRASSHOPPER CONTROL IN AFRICA / ASIA

A PROGRAMMATIC ENVIRONMENTAL ASSESSMENT



TAMS CONSULTANTS, Inc.
New York, NY/Arlington, VA
and
Consortium for International Crop Protection
College Park, MD

MAIN REPORT

March, 1989

LOCUST AND GRASSHOPPER CONTROL IN AFRICA AND ASIA

A PROGRAMMATIC ENVIRONMENTAL ASSESSMENT

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B. INTRODUCTION

B.1 Purpose of the Environmental Assessment and Need for Action

This section of the Environmental Assessment will briefly describe the AID environmental regulations that require preparation of the Environmental Assessment (EA). It also will summarize the reasons AID has been and continues to be involved in the problem of locust and grasshopper control in Africa, the Arabian Peninsula, and South Asia. This section will be prepared in close cooperation with AID personnel responsible for implementation of AID environmental regulations.

22CRF Part 216, AID Environmental Procedures

These regulations specify procedures by which environmental consequences of AID-financed activities are to be identified and considered by AID and the host country, prior to a final decision to proceed with implementation. Appropriate environmental safeguards are to be adopted. The procedures were developed to ensure that environmental factors were integrated into the AID decision-making process and are consistent with Executive Order 12114 of 1979 and the US National Environmental Policy Act of 1970.

Pertinent to this document are those aspects of the regulations regarding an EA. As required, scoping sessions have been conducted (see Appendix 5). This document follows the specified content and form for an EA and includes an analysis of alternatives to assist in the decision-making process. In accordance with AID policy to conduct assistance programs in a manner sensitive to the protection of endangered or threatened species and their critical habitats, the EA discusses potential impacts and means to avoid or mitigate such impacts.

Foreign Assistance Act, Section 117, Environment and Natural Resources

This amendment to the Foreign Assistance Act addresses the problem of degration of natural resources in developing countries. The amendment authorizes the President to furnish assistance to develop and strengthen the capacity of developing countries to protect and manage their environment and natural resources. Special effort is to be given to maintenance and restoration of resources upon which economic growth and well-being, especially of the poor, depend. An Environmental Assessment or impact statement is to be prepared and taken fully into account.

This EA report fulfills the overall objectives of Section 117 by taking into account comprehensively the relationship of the project to the environment and by developing

mitigative measures to avoid or minimize environmental degradation.

Foreign Assistance Act, Section 118, Tropical Forests

In passing this 1986 amendment, Congress recognized the importance of forests and tree cover to developing countries. Properly managed forests provide a sustained flow of resources to developed and developing countries alike. Of particular concern is the accelerating alteration, destruction or loss of tropical forests. The recommendation of the United States Inter-agency Task Force on Tropical Forests is to be given a priority in formulating programs and carrying out policies with respect to developing countries.

This EA document, while not concerned with tropical forests, addresses tropical conservation and management.

Foreign Assistance Act, Section 119, Biological Diversity

Each country development strategy statement or other country plan proposed by AID is to include an analysis of the actions necessary to conserve biological diversity and the extent to which actions proposed for support by the Agency meet the identified needs. AID is tasked: to cooperate with appropriate international organizations both governmental and non-governmental; to look to the World Conservation Strategy as an overall guide; and to perform other activities to conserve biological diversity. In particular, AID must deny direct or indirect assistance for actions which denigrate national parks or similar areas or introduce exotic plants or animals.

This EA report addresses protection of wildlife and their habitats, national parks, and other reserves and protected areas. Document preparers have drawn upon the expertise of pertinent GOP agencies and appropriate international organizations involved in wildlife preservation.

Policy Determination (PD-6)

Policy Determination (PD-6) regarding Environmental and Natural Resource Aspects of Development Assistance (April 1983) declares that AID policy is to help less developed countries build institutional and scientific capacity regarding critical environmental and resource problems; establish resource management programs; ensure environmental and long-term sustainability of projects; and promote environmentally sound development.

This EA satisfies PD-6 by addressing the environmental sustainability and soundness of improved access, with particular attention to induced secondary development that may occur as a result. The EA makes recommendations regarding resource

managment programs through the list of mitigative measures intended to reduce or avoid impacts.

B.2 History of AID Participation in Locust and Grasshopper Control

AID has a long history of involvement with the underdeveloped nations in the control of grasshoppers and locusts. Between 1951 and 1965 AID provided up to 25 specialists to Africa and Middle Eastern nations to assist in the control of a major Desert Locust plague and to train nationals in modern pest control techniques. Together with British, French and FAO representatives, AID participated in the establishment of the Desert Locust Control Organization for Eastern Africa (DLCOEA).

During the 1967-1969 plague of the Desert Locust, Schistocerca gergaria, AID provided economic support and technical assistance to DLCOEA and the crop protection services of the affected nations. This multi-national effort was the first ever to break a Desert Locust plague before it had run its normal 7 to 8 year course.

AID was quick to assist Pakistan and Afghanistan in 1973 when an upsurge of Desert Locusts in that area threatened to develop to plague status.

Technical and commodity assistance was provided by AID to West African nations between 1972 and 1975 when an outbreak of grasshoppers, principally the Senegalese Grasshopper, Oedaleus senegalensis, and the African Migratory Locust, Locusta migratoria migratoriodes, occured within the region. This participation resulted in the establishment of the AID sponsored Regional Food Crop Protection Project with the aim of strengthening the Crop Protection Services of the West African nations.

Following the severe drought of the early 1980's in the Sahel, the return of normal to above normal rainfall also saw the emergence of major grasshopper and locust infestations throughout much of Africa. This infestation was unusually severe in that it involved the rare appearance, at one time, of the four major African locust species and numerous species of grasshoppers. Again AID responded to a world-wide appeal for assistance. This major international effort reached a peak in 1986 with what was probably the largest insect control effort ever undertaken in West Africa.

Because of the unanticipated major infestations, the US ambassadors in affected countires declared an emergency situation. AID immediately released funding, and prepared a plan of action. Since this plan involved the use of pesticides, it was necessary to consdier an environmental assessment. However, because of the emergency situation, the AID Administrator

authorized a waiver of environmental regulations for the 1986 program. This decision was repeated in 1987. Then AID planned and implemented a contract to prepare this Programmatic Environmental Assessment (PEA) in anticipation of future activities.

AID assistance during this outbreak has been provided to 16 nations in Africa and the Near Eastern Yemen Arab Republic. The control effort extended from Botswana in southern Africa to Morocco and Algeria in the extreme northwest. Morocco and Algeria, the last nations to become involved, entered the picture during the outbreak in the fall of 1987 which has extended into 1988 following a massive Desert Locust invasion brought about by favorable conditions in the sub-Saharan summer breeding belt. AID quickly responded with the provision of aircraft, pesticides, communications equipment and technical assistance. This cooperative effort which has included the additonal donor nations of Portugal, Spain, France and the European Economic Community (EEC), has for the time being at least, alleviated the threat to the extensive, high production crops and pasturelands of northern Africa.

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C. LOCUSTS AND GRASSHOPPERS

C.1 Biology of Locusts and Grasshoppers

Locusts belong to a large group of insects commonly called grasshoppers, which are recognizable by the big hind legs which they use for jumping. Grasshoppers and locusts belong to the order Orthoptera and to the superfamily Acridoidea.

Locusts are grasshoppers, usually large ones, which have a capacity for changing their habits and behaviour when they occur in large numbers. When their numbers rise they become gregarious in habit and stay together in dense groups. These groups are called "swarms" when they are composed of adults and "bands" when they consist of the wingless young stages, which are themselves commonly called 'hoppers'.

The swarms of several species of locust can migrate over great distances, and this and gregarious behaviour are the outstanding characteristics that distinguish typical locusts from other grasshoppers. When locusts are in small numbers they live their individual lives like ordinary grasshoppers.

The life cycle of all species of locusts and grasshoppers comprises three stages:

EGG ---------- HOPPER (NYMPH) ---------- ADULT

The time spent in each stage, the number of nymphal instars and the time required for the adult to become sexually mature vary greatly between species and even show considerable variation within a single species, depending upon the weather.

Most Locust and grasshopper species deposit their eggs in pods just below the soil surface. The number of eggs in a pod and the number of egg pods laid depend upon the species, food availability, and the length of the laying season. Some species have only one generation per year with a long period of egg quiescence or obligatory diapause. Other species, such as the Senegalese grasshopper, have two or more generations per year followed by a period of egg quiescence or diapause. Others, such as the Desert Locust, have continuous reproduction (Fishpool and Popov, 1981).

The young locusts and grasshoppers, (normally called "hoppers" if locusts or "nymphs" if grasshoppers), emerge as miniature versions of the adult. The nymphs moult five to seven times and are incapable of flight until their final moult into the adult stage. In some grasshopper species the adults have only wing pads and cannot fly.

True locusts differ from grasshoppers by their ability to change behavior, physiology, color and shape in response to change in their population density. Individuals of the grasshopper-like form are said to be in the SOLITARIOUS PHASE; whereas those of the swarming, locust-like form are said to be in the GREGARIOUS PHASE. Intermediate forms are said to be in the TRANSIENS PHASE (Roffey and Waloff, 1981).

Unfortunately, these distinctions are not clear-cut. Locusts are known to normally fly during the day while grasshoppers fly at night. However, there are numerous reports of Desert Locust swarms flying well after dark on warm moonlit nights. Likewise swarms of the Senegalese Grasshopper have often been seen flying during the daylight hours.

In the Desert and Migratory Locusts very distinct morphological and physiological changes generally occur when they are moving from solitarious to gregarious phases. These changes include both coloration and relative size of certain body parts. Uvarov found while studying the African Migratory Locust that if the length of the front wing (elytra) was divided by the length of the femur of the hind leg the resulting ratio was greater in the case of locusts taken from a swarm than for those living a solitary existence. However, morphometrics are not always a completely reliable indicator. Changes in behavior and appearance do not always occur at the same rate. The morphometrics of Desert Locusts in some swarms have been shown to be the same as those of the solitarious phase. Nevertheless, the E/F ratio is widely used to detect whether solitary locusts are beginning to show a tendency toward gregariousness.

For other locusts such as the Moroccan Locust, Dociostaurus maroccanus, these changes are not nearly as dramatic. In the case of the Moroccan Locust there is little color change between solitary and gregarious forms. Differences are generally in the size of body parts.

The Senegalese Grasshopper also shows some slight morphological differences between swarming and non-swarming populations. Generally, the body is more slender and streamlined and the elytra slightly longer in the swarming population. Although the Senegalese Grasshopper has two color forms, brown and mottled green, this difference in coloration has not been shown to be associated with phase differences.

Unlike locust outbreaks, grasshopper outbreaks usually involve a complex of species with widely varied biologies.

In the present outbreak (1985-1987) in the Sahel of West Africa, although Senegalese Grasshopper is the dominant species, a large number of other grasshopper species, some with a decidely different life cycle and habitat, are also involved. In the

Sahel and its adjoining areas Popov considers nine groups or complexes in relation to their agro-ecosystems. Complex I consists of the locusts while the other eight are grasshoppers.

The grasshoppers considered of economic importance in the present outbreak represent five of these complexes.

For purposes of this environmental assessment six locust species and three grasshopper species are singled out for primary attention because of their migratory or aggregrating capabilities. These selected species are listed in Figure C.1.

FIGURE C.1 SELECTED LOCUST AND GRASSHOPPERS

LOCUSTS

Common Name	Scientific Name
Desert Locust	Schistocerca gregaria (Forskal)
African Migratory Locust	Locusta migratoria migratorioides (Reiche & Fairmaire)
Red Locust	Nomadacris septemfasciata (Serville)
Brown Locust	Locustana pardalina (Walker)
Moroccan Locust	Dociostaurus maroccanus (Thunberg)
Tree Locust	Anacridium melanorhodon (Walker)

GRASSHOPPERS

Senegalese Grasshopper	Oedaleus senegalensis (Krauss)
Sudan Plague Locust	Aiolopus simulator (Walker)
Variegated Grasshopper	Zonocerus variegatus (Linnaeus)

However, when planning control efforts, the biology and habitat of the more minor species must be considered to obtain maximum control efficiency and eliminate retreatment. These minor species include:

Hieroglyphus daganensis, which is primarily associated with hydromorphic clay soils subject to seasonal flooding, such as the drainage basins of the Senegal, Niger and Gambia Rivers. This univoltine species is a good swimmer, particularly in the nymphal stage. When danger is present it can remain underwater for several minutes.

Kraussaria angulifera, a univoltine, ambivorous pest occupying essentially the same agro-ecosystem as the Senegalese Grasshopper.

Aiolopus simulator, a univoltine species that carries over as an adult in the dry season hidden in the cracks of clay soils within the principal drainage basins.

Catantops axillaris, a univoltine, ambivorous species of wide ecological tolerance and a pest of a wide range of crops. It survives the dry season as an adult. It is a strong flier and has occasionally been recorded at swarming densities in the flood plains of Lake Chad and the central Niger River delta.

The multi-voltine species Kraussella amable, and Oedaleus nigerienses, more characteristic of the savanna grasslands.

The univoltine, hygrotypic Cataloipus sp., more frequent in the riverine communities.

Desert Locust

Distribution (Figure C.2)

Recession area: Across Africa between 14 deg and 20 deg N. and including Ethiopia and northern Somalia; the Near East; Iran; Pakistan; and northwest India (14 million km sq).

Invasion area: Most of Africa north of the Equator, the Near East and across to India and South Asia (29 million km sq).

Habitat of Outbreak Area

Sandy or silty soils in semi-arid to arid regions. Rainfall needs:
20-25 mm rainfall for egg laying, with 15 to 20 mm within a 24 hour period.
Breeding within 50-1000 mm, 50-200 mm in summer is optimum.
Convergent wind systems, barriers, patchy vegetation tend to concentrate populations.

Agro-ecological region of Outbreak Area

Sudano-Sahelian region

Life Cycle

Number of generations:	3-6
Egg development	11-75 days
Eggs per pod:	20-100
Pods per female:	2-3
Hopper development:	20-66 days, average 38 days
Number of instars:	5
Adult longevity:	75-200 days
Immature adult:	45 days - 6 months
Mature adult:	30 days

Natural Enemies

Flies -- Stomorphina lunata and Systoechus Sp.
Beetle Larvae -- Trox and Mylabris

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Food Preference

Graminivorous, but the gregarious phase will feed on a wide variety of vegetation, including crops such as millet, sorghum, maize, wheat, barley, cotton, grape vines and fruit trees.

Remarks

The most dangerous of the locust species worldwide. Crowding for more than one generation is required to produce fully gregarious characteristics. Adult gregarious locusts fly up to 17 hours a day and can migrate up to 5,000 km during their lifetime.

Key Reference

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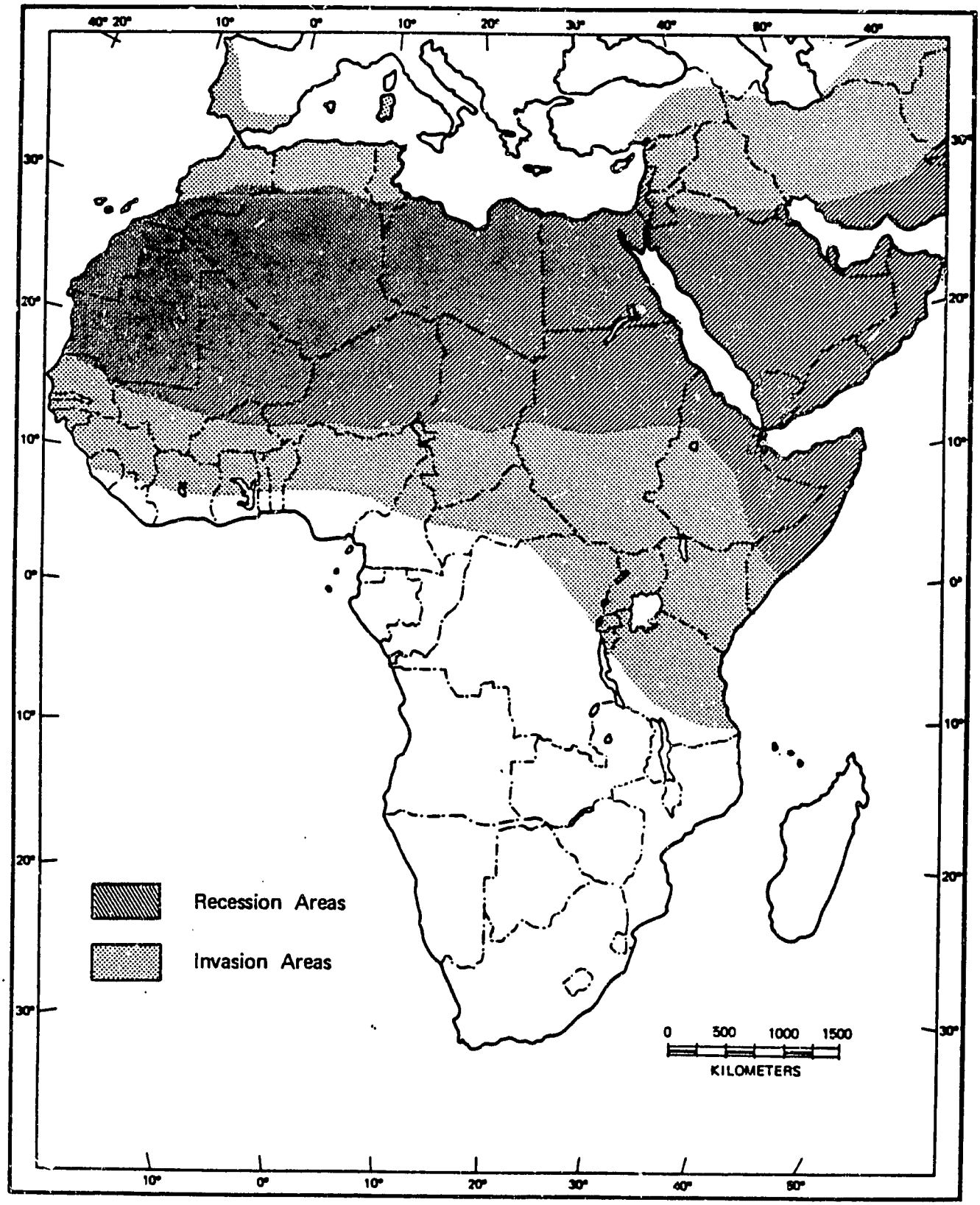

Figure C.2 Invasion and recession areas of the Desert Locust
Source: Waloff, 1976

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African Migratory Locust

Distribution (Figure C.3)

Outbreak area:	Niger Inland Delta, Mali Lake Chad southern part, Chad Blue Nile region, Sudan
Invasion area:	Africa south of the Sahara

Habitat of Outbreak area	seasonally flooded grass plains in semi-arid regions with summer rains
Agro-ecological region of Outbreak area	Sudano-Sahelian region

Life Cycle

Number of generations:	2-4
Egg development:	10-100 days dependent on temperature and moisture
Eggs per pod:	65 for solitarious, gregarious less
Pods per female:	1-2 (cool season); 3-5 (hot season)
Hopper development:	21-40 days
Number of instars:	5-7
Adult longevity:	40-70 days
Immature adult:	10-14 days
Mature adult:	26-55 days

Natural Enemies

Asilid larvae, parasitic Scelionidae
Carabid beetle larvae

Food Preference

Graminivorous

Remarks

In the Middle Niger hopper bands produced from the last retreating rains generation rarely produce swarms.

Key Reference Farrow, R.A., 1975

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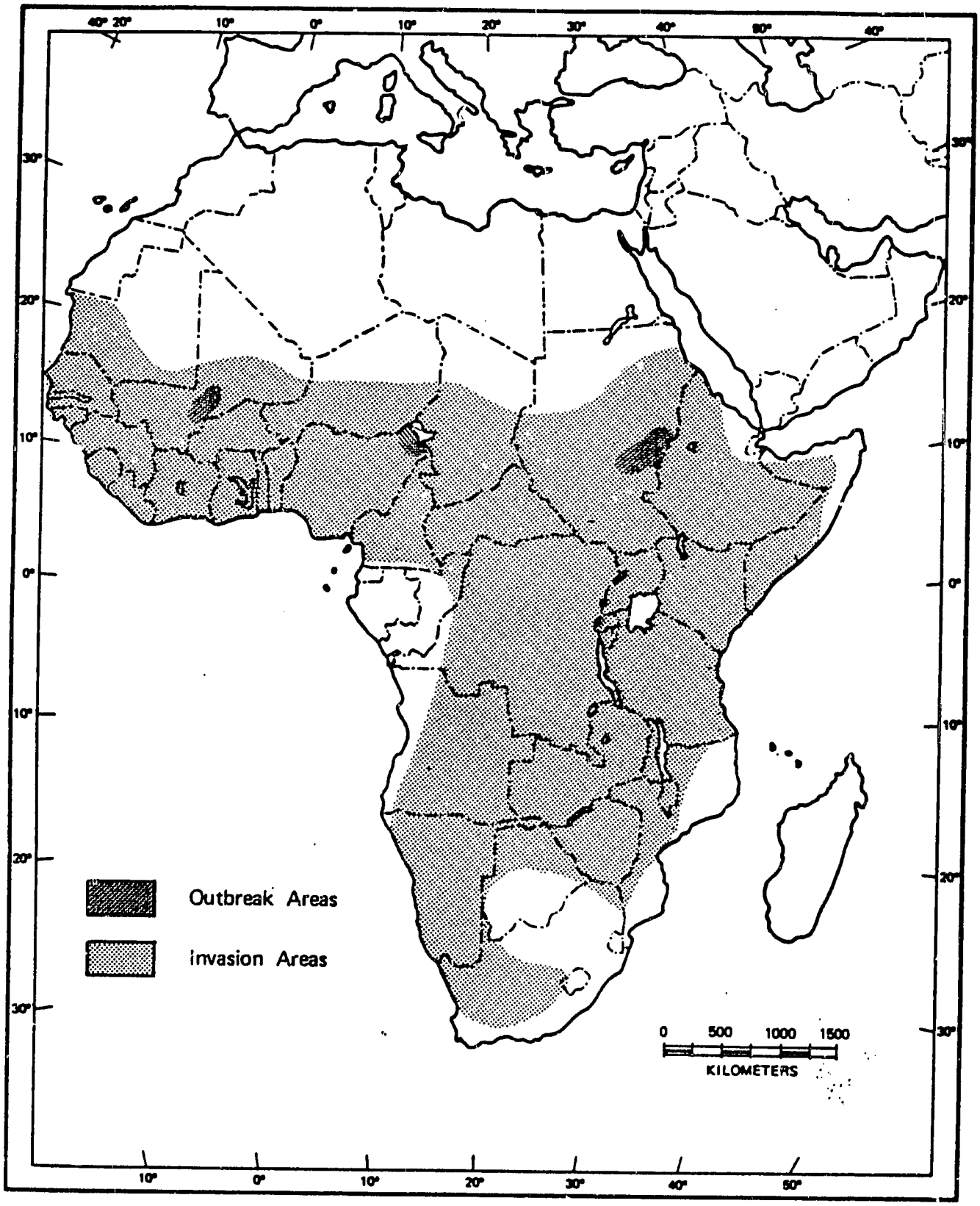

Figure C.3 Outbreak and invasion areas of the African Migratory Locust
Source: USAID, 1987b, and G. Cavin, 1987c

Red Locust

Distribution (Figure C.4)

Outbreak area:	Nine locations in or along the Rift Valley in East Africa: Rukwa, Mweru wa Ntipa, Wembere, Malagarasi, Busi-Gorongosa, Iku, Kafue, and Chilwa
Invasion area:	Mostly Africa south of the Equator.
Habitat of Outbreak area	Completely closed or highly impeded drainage, clay soils, floodplain grasslands with mosaic of tall and shortgrass. No agricultural land use.
Agro-ecological Region of Outbreak Area	Subhumid and mountain East Africa region

Life Cycle

Number of generations:	1
Egg development:	30 days
Eggs per pod:	mean 100
Pods per female:	5 under favorable conditions
Hopper development:	60-70 days
Number of instars:	6-7
Adult longevity:	Southern hemisphere: 150-180 days Northern hemisphere: 240-270 days
Immature adult:	throughout dry season
Mature adult:	20-40 days

Natural Enemies

Same as the African Migratory Locust

Food Preference

Graminivorous

Remarks

Plague persistence is due to a proportion of swarms being confined to retention areas enabling them to survive the dry season. The main retention areas are: eastern Zimbabwe, Lower Zambezi valley and southern Malawi; southwest Uganda and northernmost Tanzania.

Key Reference Symmons, 1977

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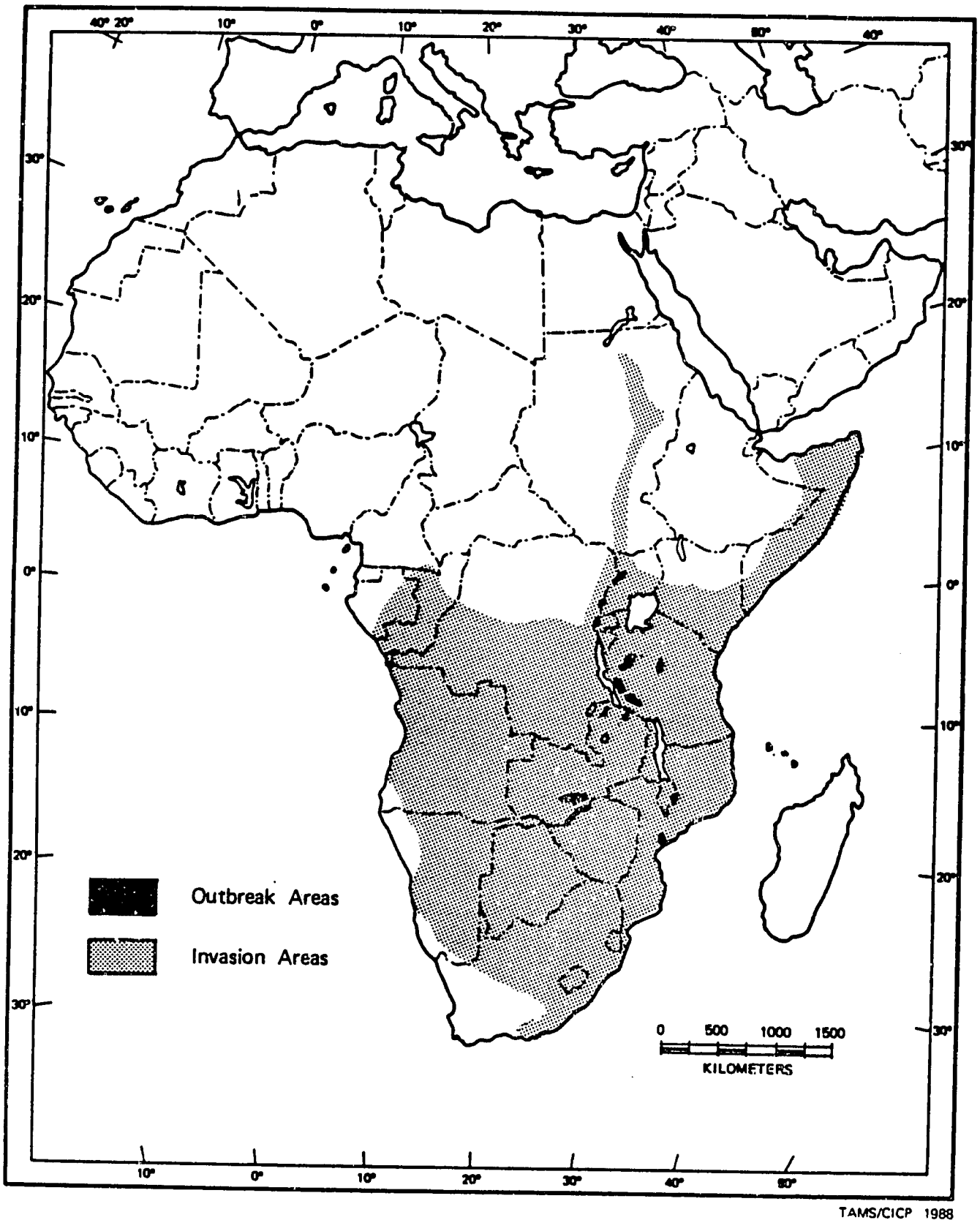

Figure C.4 Outbreak and invasion areas of the Red Locust
Source: Materu, 1984 and Symmons, 1977

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Brown Locust

Distribution (Figure C.5)

Outbreak Area:	Karoo region in South Africa and Namibia
Invasion Area:	Southern Africa, south of about 15 deg S.

Habitat of Outbreak Area

Deposits eggs in dry soils

Agro-ecological Region of Outbreak Area

Sub-humid and semi-arid Southern Africa region.

Life Cycle

Number of generations:	2-4
Egg development:	mean 11.5 days; up to 15 months without rain
Eggs per pod:	mean 37 (solitarious), 47 (gregarious)
Pods per female	average is 4-5, as many as 11 in laboratory
Hopper development:	21-42 days
Number of instars:	solitary males, 4; others, 5
Adult longevity:	6 weeks in summer, 12 weeks or more in cooler months
Immature adult:	15-20 days
Mature adult:	30-75 days

Natural Enemies

Eggs:	Several species of insects.
Hoppers and adults:	Robber flies, scorpions, white stork, white bellied stork, wattled starling. Micro-organism, Malameoba locustae, kills females or weakens stem, preventing egg laying.

Food Preference

Graminivorous

Remarks

Incipient outbreaks have practically all arisen in areas with high solitarious populations two seasons before.

Key Reference Lea, 1964

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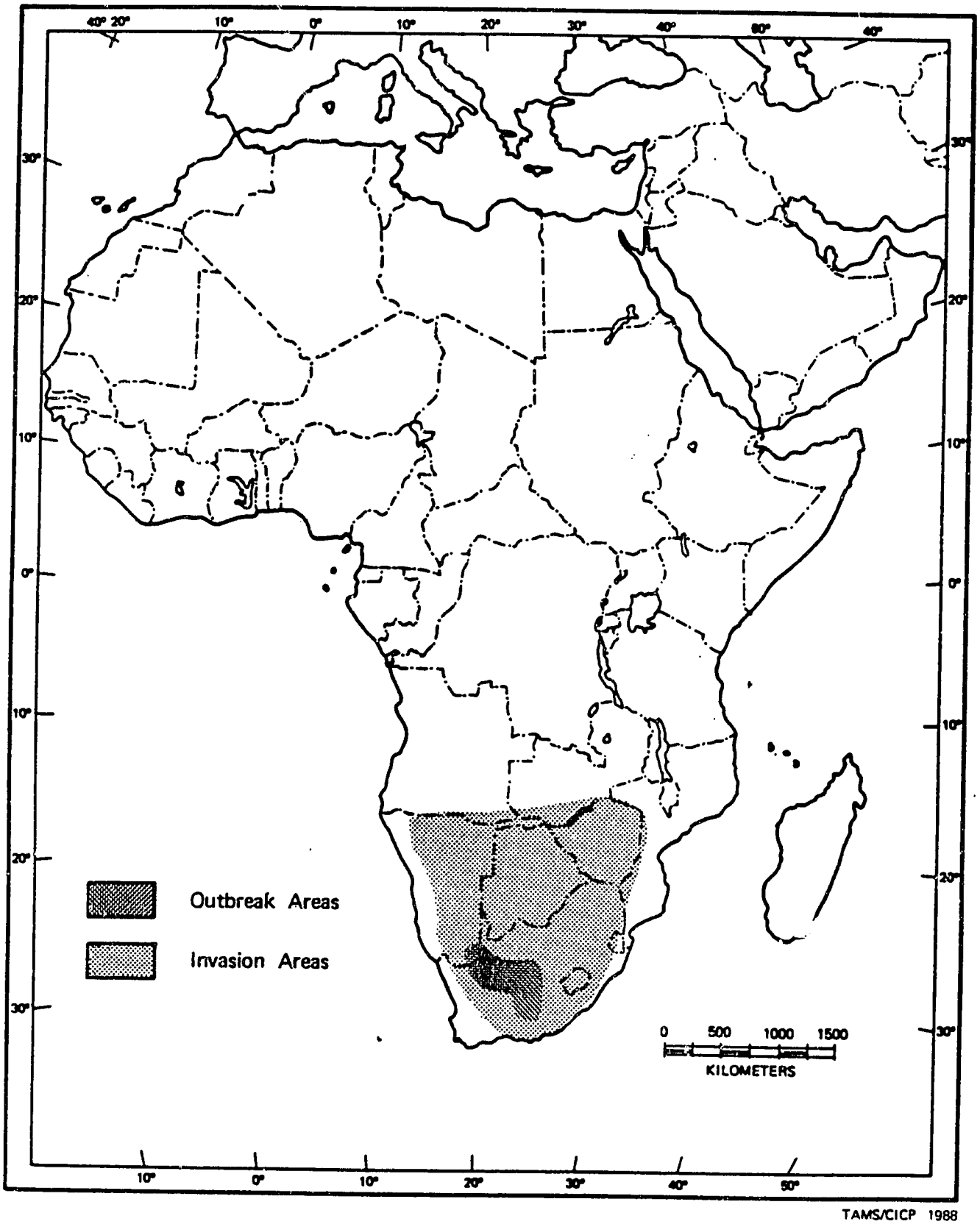

Figure C.5 Outbreak and invastion areas of the Brown Locust
Source: USAID, 1987b, and Botha, 1969b

Moroccan Locust

Distribution (Figure C.6)

Outbreak/invasion area:	A belt from Morocco eastward on both sides of the Mediterranean extending to the Near East and Soviet Central Asia.
Habitat of Outbreak area	Semi-arid steppes with winter rains, with abundant spring grasses and sedges, particularly Poa bulbosa. Oviposition takes place only in undisturbed, moderately compact, almost dry soil, cultivated areas are unsuitable.
Agro-ecological region of Outbreak area	Mediterranean and arid North African regions.

Life Cycle

Number of generations:	1
Egg Development:	9 months -- throughout dry season
Eggs per pod:	20-30
Pods per female:	maximum 2 (solitarious), 5 (gregarious)
Hopper development:	30-45 days
Number of instars:	5
Adult development:	2-4 months

Natural Enemies

Lizards -- Ophiops and Acanthodactylus Sp.
Flies -- Systoechus Sp.
Beetle Larvae -- Trichodes laminatus

Food Preference

Graminivorous

Remarks

Infestations were reported from Morocco and Iran in 1987.

Key Reference Skaf, 1972

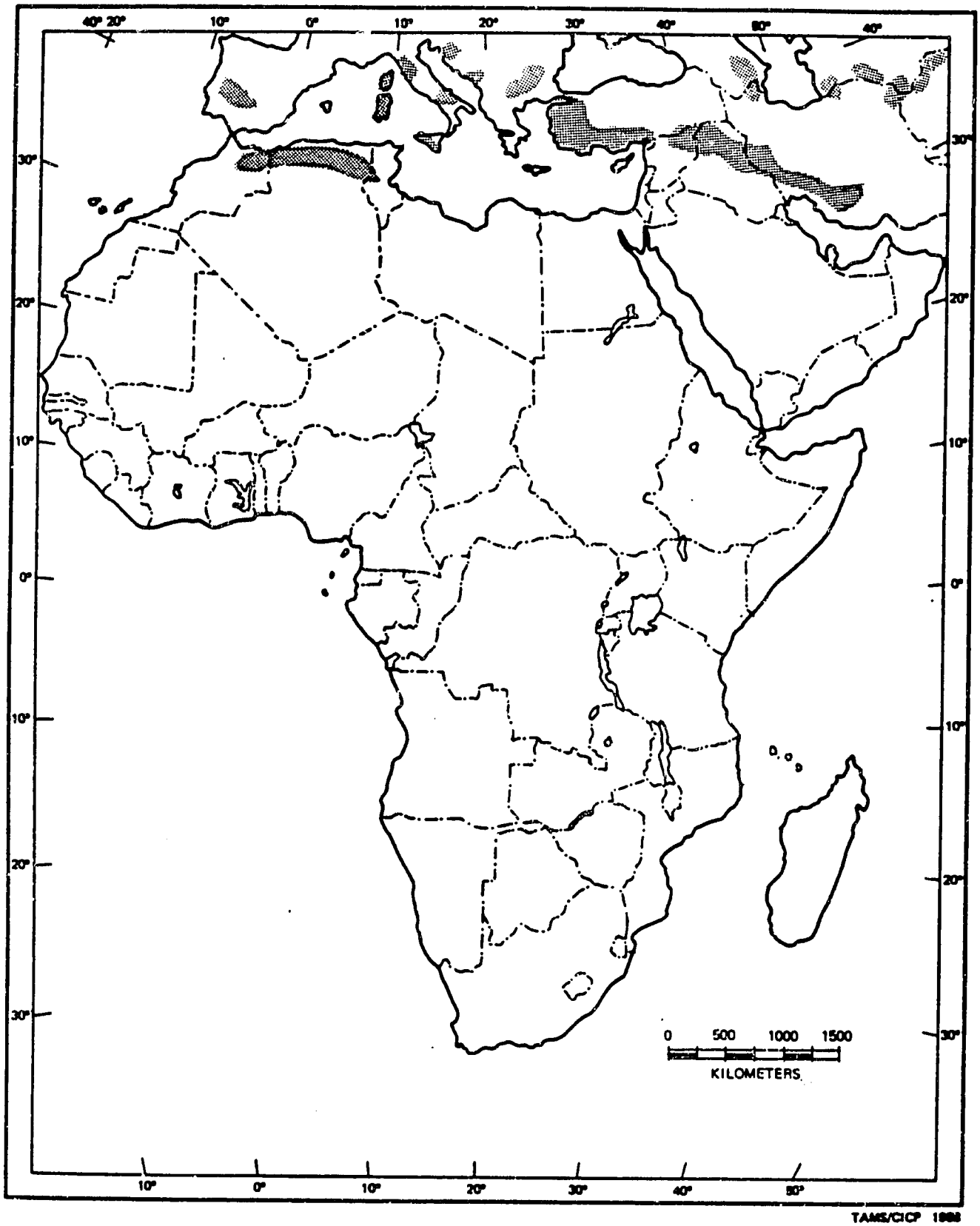

Figure C.6 Distribution of the Moroccan Locust
Source: Uvarov, 1977

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Tree Locust

Distribution (Figure C.7)

Outbreak/invasion area: A belt south of the Sahara, from Senegal to Somalia extending to Saudi Arabia, reaching south to Tanzania.

Habitat of Outbreak Area

Natural thickets of Acacia spp. with rainfall of 300-500 mm, single 3-4 months rainy season, mainly outside agricultural areas.

Agro-ecological region of Outbreak area

Sudano-Sahelian region.

Life Cycle

Number of generations:	normally 1, though 2 are possible
Egg development:	26-53 days
Eggs per pod:	150
Hopper development:	60 days in males, considerably longer in females
Number of instars:	5-6, rarely 7 or 8; females have most
Adult development:	9 months
Immature adult:	throughout dry season

Natural Enemies

Flies -- Stomorphina lunata and Systoechus Sp.
Beetle Larvae -- Trox and Mylabris

Food Preference

Arbivorous

Remarks

Often mistaken for the desert locust. Generally considered a pest only in Sudan where it defoliates Acacia senegal, the tree from which gum arabic is harvested.

Key Reference Popov, G. and M. Ratcliffe, 1968

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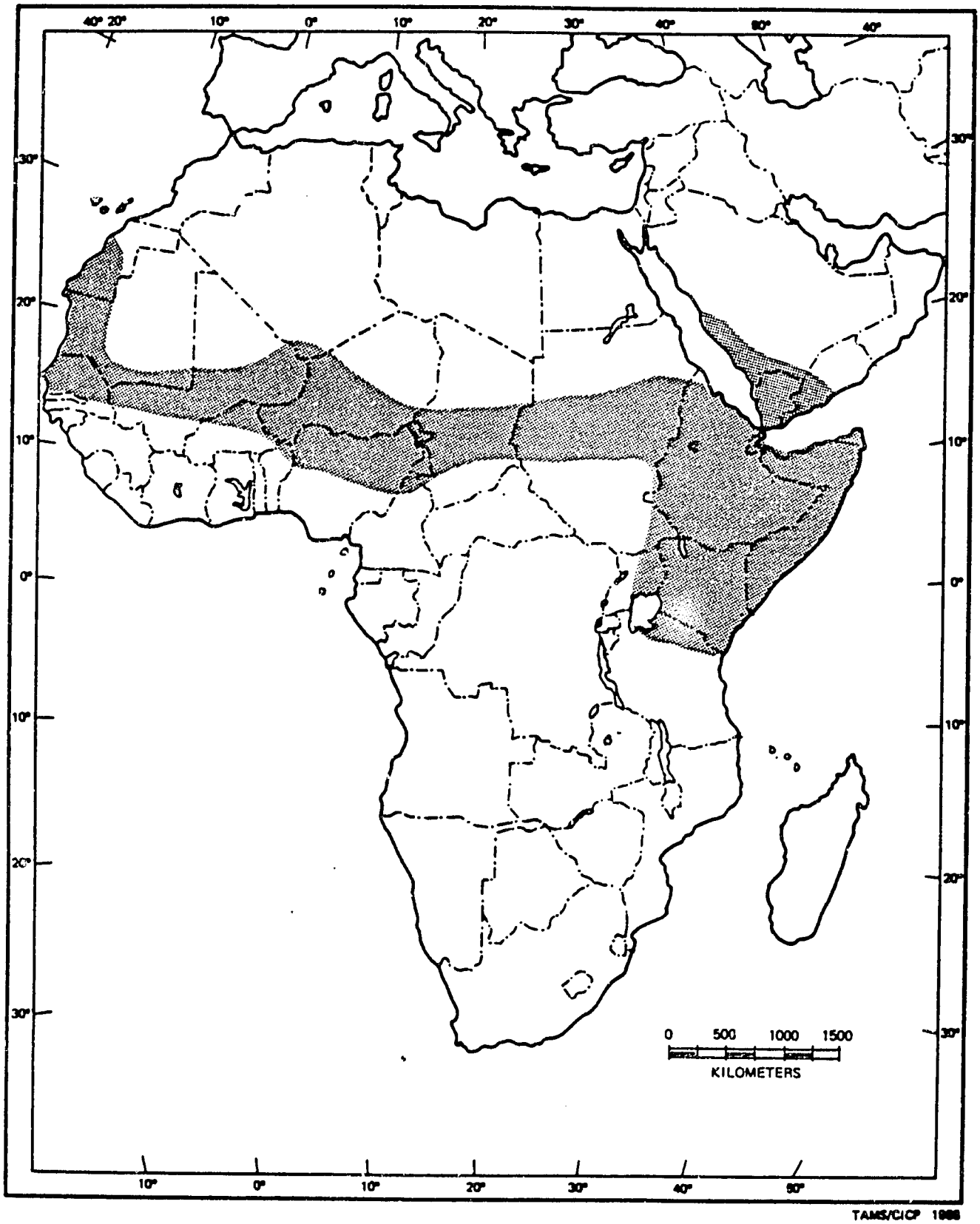

Figure C.7 Distribution of the African Tree Locust
Source: Anti-Locust Research Centre, 1966

Senegalese Grasshopper

Distribution (Figure C.8)

Outbreak/Invasion area: Subsaharan Africa delimited by 200 to 1,000 mm isohyets north of the equator, but extending into Tanzania, southwest Asia, and parts of North Africa.

Habitat

Breeding and seasonal movement are closely dependent on the dynamics of the ITCZ (Intertropical Convergence Zone) and occur during the rainy season. Associated with sandy soil and open steppe vegetation with predominant grasses. Areas in use as rangelands or for shifting cultivation of millet.

Agro-ecological region

Sudano-Sahelian region.

Life Cycle

Number of generations:	2-4, generally 3
Egg development:	8-15 days for non-diapausing eggs. Eggs laid after late August to mid-September enter diapause. Diapause lasts until the next rainy season or several months to several years.
Eggs per pod:	20-30
Pods per female:	1-2
Hopper development:	17-20 days
Number of instars:	5
Adult longevity:	30-120 days

Natural Enemies

Flies- Xeramoeba oophaga and Systoechus Sp.
Beetle larvae- Meloidae, Histeridae, Carabidae, Tenebrionidae

Food Preference

Graminivorous

Remarks

The Senegalese grasshopper shows some of the behavioral and morphological characteristics of locusts including long distance swarming migrations associated with the northward progression of the Intertropical convergence in summer and southerly regression in the fall.

Key Reference Duranton,et al., 1982

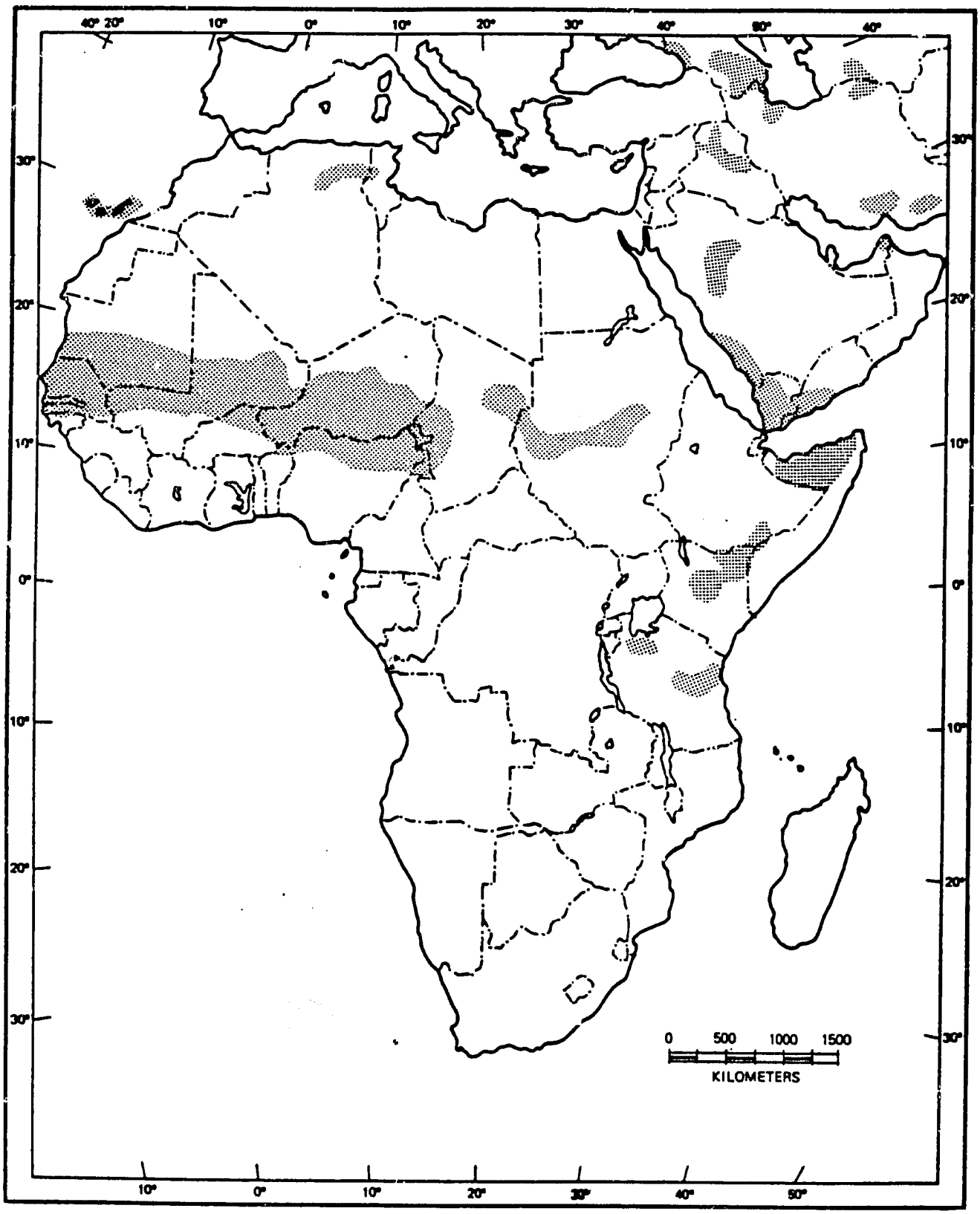

Figure C.8 Distribution of the Senegalese Grasshopper
Source: Batten, 1969, and information from later sources

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Sudan Plague Locust

Distribution (Figure C.9)

The Sahelian zone eastwards to the Sudan and Egypt; southwest Asia to Bangladesh and north to the Tadzhik S.S.R.

Habitat

Vertisols and similar clay soils of the Nile, Senegal, Niger and Lake Chad (former) floodplains.

Agro-ecological region

Sudano-Sahelian region

Life Cycle

Number of generations:	2
Egg development:	18-28 days
Eggs per pod:	20-30
Pods per female:	2-3
Hopper development:	18-28 days
Number of instars:	5
Adult longevity:	6-9 months

Natural Enemies

Flies -- Xeramoeba oophaga and Systoechus Sp.
Beetle larvae -- Meloidae, Histeridae, Carabidae, Tenebrionidae

Food Preference

Graminivous

Remarks

Populations are greatest in the Nile valley because of it north south orientation, whereas the other basins are more east to west and more limited in extent. Thus mortality occurs in these latter basins during northward migration following the ITCZ when adult grasshoppers fail to find suitable breeding sites.

Key Reference Popov, 1982

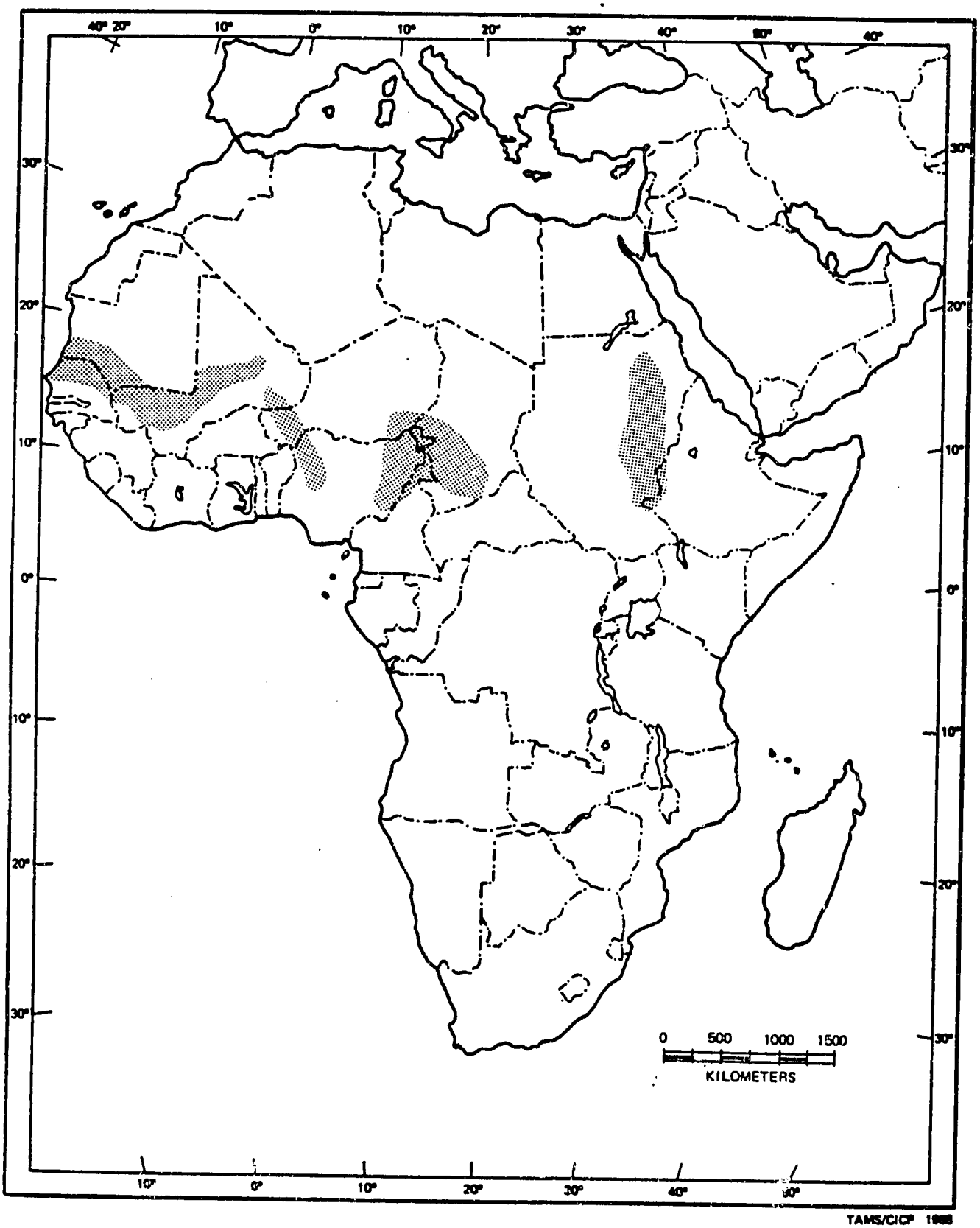

Figure C.9 Distribution of the Sudan Plague Locust
Source: FEWS, 1987a

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Variegated Grasshopper

Distribution (Figure C.10)

Coastal West Africa extending eastwards as far as Uganda and northwards into Sudan.

Habitat

In clearings, and in cultivated, deforested areas of the forest zone, penetrating the savanna principally along drainage systems.

Agro-ecological region

Primarily humid and sub-humid West Africa.

Life Cycle

Number of generations:	1
Egg development:	6-7 months
Eggs per pod:	50-60
Pods per female:	2-3
Hopper development:	75-90 days
Number of instars:	5-6
Adult longevity:	60-90 days

Natural Enemies

Entomophthora gryllii, a pathogenic fungus

Food Preference

Herbivorous. Feeds on a wide variety of plants, showing preference for annual herbs and the flowers and tender shoots of citrus and coffee. Cassava, banana and cotton are less vulnerable.

Remarks

There are two populations, the wet season population and a dry season population which is the largest and most important. As a protective device Variegated Grasshoppers emit an unpleasant smelling liquid.

Key Reference Page, W. W., 1978

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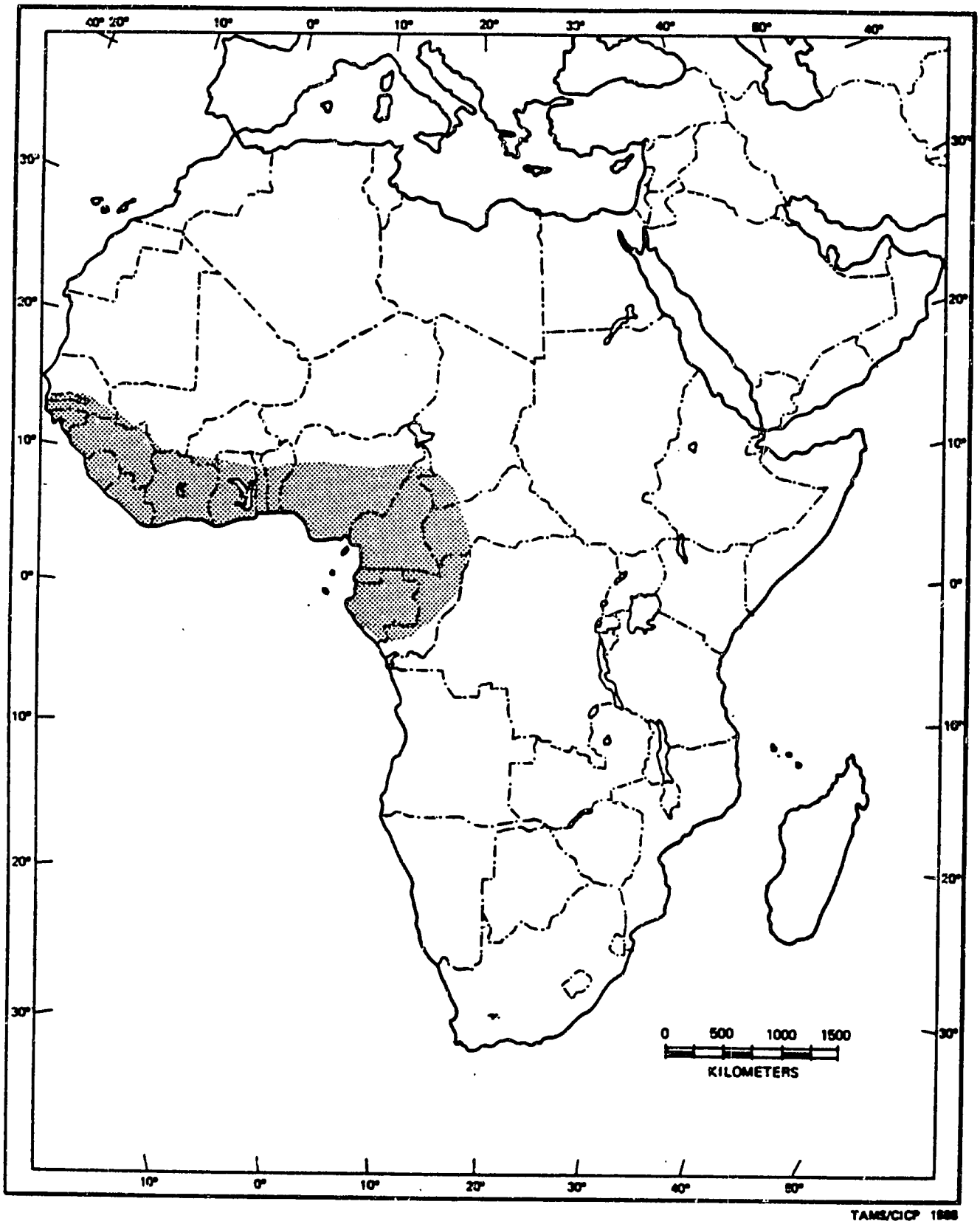

Figure C.10 Distribution of the Variegated Grasshopper
Source: Launois, 1986, and FEWS, 1987a

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C.2 Impact of Locust and Grasshoppers Outbreaks

The impact of locust and grasshopper outbreaks is far better documented for crops than for the natural environment. It is in agriculture that the impact is most obviously felt by the human population. Indeed, for many African governments, locusts and grasshopper tend not to be regarded as pests until they start to feed on crops. This may be due to a disregard for their impact on the natural environment by the population or responsible organization in impacted areas, or it might be because their impact on the natural environment is not that great.

In spite of the popular image of locust swarms; that of devouring all green vegetation in their path, the different species of locusts and grasshoppers are fairly selective feeders with most of them showing a strong preference for grasses, hence the damage they do to grain crops. The one locust that favors trees is the Tree Locust, which is found in the Sahelian zone.

The Tree Locust tends to inhabit wadis where the vegetation is more plentiful. It feeds on trees, shrubs and bushes and only occasionally on grass or other annual vegetation.

Given the relative spareness of the trees within the area of the Sahel it might be thought that the damage to the natural vegetation that the tree locust did was severe. As far as can be ascertained this is not the case. In Sudan, one species of acacia, Acacia senegal, is tapped for gum arabic, and the impact of locust swarms on this acacia are well documented. A swarm setting on Acacia senegal will denude it of its leaves causing a period of dormancy. This dormancy has no lasting impact on the tree. It is probable that the impact on other species of trees, shrubs and bushes is similar and that the predation of locusts does no long term damage to forest, woodland or brush.

The majority of locust and grasshopper species feed on grasses. Natural rangeland is a mixture of different grasses, sedges and forbs -- some annual, some perennial. At any point in time this vegetation will be at different stages of maturity. Being selective feeders it seems probable that locusts and grasshoppers will favor some grasses over others. Some rangeland vegetation will probably be left untouched. The grass that will be most damaged will be the newly emerging shoots which may be eaten down to the ground. More mature grasses will be damaged but will regenerate. Overall the long-term damage to rangeland is not great. Although there will be some obvious short-term loss of vegetation, the natural rangeland, bush and woodland has always had intermittent plagues of locusts sweeping over it.

Together with other grazing animals, the grasshopper and locust is part of the natural ecology of the African continent.

The fact that the natural environment suffers no permanent damage does not mean that there is no economic cost to the damage. Rangeland is a resource that is utilized by cattle herds, and these herds are competing for the same grass as the grasshopper and locust. It is an unequal contest, with the locust being a much more efficient grazer. Given that many of the herds in Africa are nomadic or semi-nomadic, there is at least some possibility that the herds can be driven out of the areas hard hit by locusts or grasshoppers to find grazing elsewhere. In addition, much of the rangeland, especially that of the Sahel, is being over grazed. Any loss of grass under this situation means a direct reduction in the grazing available to cattle.

Within the U.S.A. considerable work has been done to determine whether intervention to control grasshoppers on rangeland is economically viable (Hewitt & Onsager, 1982, 1983; and Onsager, 1984, 1987). To date, no similar work has been done for African rangeland.

It is on crops that locust and grasshopper damage is most obvious. Crops differ from natural vegetation in that we have fields consisting of a single species, all at the same stage of maturity. If a locust or grasshopper swarm alights on a grain field soon after planting they can eat the shoots to the ground making reseeding necessary. Damage to more mature corps is not so dramatic until the milky grain stage is reached, at this time a swarm can cause the partial or total loss of crop. Once the grain has started to ripen it is fairly safe from grasshoppers and locust who favor green vegetation.

It needs to be emphasized that it is only at certain stages of development of a grain, or any other crop, that a locust or grasshopper swarm is going to cause a 100% loss. Generally, the impact on agriculture is not that dramatic. The popular image of a locust outbreak leading to famines seems to have little or no basis in fact. If locusts eat newly emerging shoots and replanting is necessary, there is a cost to the farmer, both in seed and labor, but he will still get a crop. At other stages of maturity the locust and grasshopper can affect yields but little work has been done to determine just what the impact on yields will be for food crops. One of the very few crops in which the effects of an infestation of locusts upon yield have been investigated is sugar cane. Trials and observations in Mauritius (Williams, 1964), South Africa (Anonymous, 1955; Dick 1955, 1958, 1959), the Philippines (Gordon, 1933, 1935) and Mozambique (Dymond, 1934) on the impact of the Red Locust and Oriental Migratory Locust have shown the effect on defoliation is dependent upon the stage of development

of the cane. The highest recorded loss of yield was in Mozambique where swarms of Red Locust reduced yield by an estimated 33%. The other observations and trials showed losses of the order of 12-18% in South Africa and the Philippines, although there was also a case of yield increasing after defoliation.

Just to what extent these results apply to other crops is not clear due to the lack of experimental work and reported field observations. Whatever the losses are, it should be borne in mind that they are intermittent. Locust are a migratory pest, locust swarms do not visit the same fields year after year; indeed for the majority of years we have no locust outbreaks. When there is a swarm it moves through an area and has a major impact on the farmers whose crops are attacked but not necessarily having an impact beyond a localized area.

In order to gain some perspective on the losses due to locusts and grasshoppers it is worth considering the impact of other pests on crop output. A standard work on plant protection gives the figures in Figure C.11.

FIGURE C.11 AVERAGE CROP LOSSES IN AFRICA

	Insect	Disease	Weeds	Total
	(in percentages % of potential yield)			
Millet & Sorghum	10	10	25	45
Maize	20	13.6	35	68.6
Wheat	12	12	15	39
Rice	20	7	15	42

Source: H. H. Cramer, 1967.

* Note including Locusts which are not recognized as a major insect pest in this reference.

Average losses from all insect pests are between 10% and 20% a year although for any one crop in any one year they may be much higher. For example, wheat loss due to aphids can be as high as 40% in some years. Disease causes crop losses of 7 to 14% on average. The really large losses of 15 to 35% occur due to weeds, probably the most controllable of all the pests that cause crop losses.

Overall the average annual crop losses vary from 42% for rice to 69% for maize. There is no compelling evidence that locusts, on a regular basis, do as much damage as, for example,

weeds. Indeed, the above cited reference, looking at the macro picture of crop protection does not even identify the locust as a major pest.

To further keep it in context, there is no area of Africa where either locusts or grasshoppers are such a severe pest that the area has been abandoned by cultivators and, on a countrywode basis, the impact of alocust outbreak does not have the impact on agriculture that say, a drought, does. But at a national level, many African countries are food deficient countries, any loss of crops to pests makes a bad situation worse.

The impact of locusts is compounded because locust damage is most severe on desert margins (Bullen, 1969). It tends to diminish towards the wetter areas. Thus, the most severe damage occurs on areas which are <u>less intensively</u> cultivated, but these are areas that are being <u>increasingly brought under</u> cultivation as the result of population pressure in the Sahelian countries. This would tend to indicate that as agriculture expands -- especially into marginal areas -- the impact from locust attack will increase. This, however, may not be the case. Haskell (1970) suggests that as cultivated areas increase the threat from locust diminishes as the spread of settled agriculture interferes with the mobility of swarming locusts and also reduces their potential breeding area; this causes the population to reduce so that the species exists only in the solitary phase. Haskell cites the example of Mauritius where in the 1930's and 40's the Red Locust was regarded as a serious pest. But, as the island became more and more of a sugar monoculture and more land was taken up by the crop, the conditions became such as to allow only a small stable population, thus leading to its disappearance as a major pest. He cites similar examples from Cyprus and the Philippines, where the spread of agriculture has <u>reduced</u> the locust threat.

C.3 <u>Costs of Locust and Grasshopper Damage</u>

Given the many years of locust control and the numerous organizations involved in this control it might be assumed that information on the damage caused by locusts would be well documented. This does not appear to be the case. The type of data that is typically produced to support funding for locust control is shown in Figure C.12. As can be seen, the data is fragmented and episodic, reflecting outbreaks that were sufficiently large to merit the attention of an international agency or a government.

An attempt to better calculate the potential of locust damage was made by Bullen (1969). He developed a crop vulnerability index to quantify the crops that were potentially

subject to Desert Locust attack and the frequency with which they might be attacked. As a theorectical construct it was useful but its practical application foundered on the broad nature of the cropping data underlying the model and the lack of crop yield information. Nineteen years later the available statistics is no better. There exist no accurate crop yield and/or loss data for most of the area subject to attack by locusts.

This lack of data on crop damage was discussed in a two-day meeting on migrant pests held by the Royal Society in London in 1977. The Chairman, J. W. S. Pringle, F.R.S., summed up the discussion in the following terms:

> "I think it is true that the actual damage done by the pests, as a fraction of the gross national product of the various other African countries has not been assessed..."

One of the participants in the discussion mentioned that a proposal had been made at one time to release a swarm of Red Locust, at a time when substantial resources were at hand, in order to monitor the damage done by the swarm, but that the idea was vetoed by the Red Locust Control Organization (Royal Society, 1979).

FIGURE C.12 ESTIMATES OF CROP DAMAGE CAUSED BY DESERT LOCUSTS

YEAR	NATION	CROPS DESTROYED	VALUE OF CROPS DESTROYED
1926-1934	India		400,000/yr
1928-1929	Kenya		300,000/yr
1953	Somalia		600,000/yr
1954-1955	Morocco		4,500,000/1 season
1949-1957	FAO estimate for		US $1,500,000 /yr
12 of 40	effected countries		US $5,000,000 in 1955
1954	Sudan	55,000 MT grain	
1957	Senegal	16,000 MT millet	
1957	Guinea	6,000 MT oranges	
1957	Ethiopia	167,000 MT grain	
1962	India	4,000 MT cotton	

Source: J. D. Parker, et al., 1986.

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None of this leads us any closer to determining just what damage locusts and grasshoppers do.

One year for which we have some better data on grasshopper damage is 1986 when the international community was alerted and responded to a reported grasshopper outbreak in Africa. Nine countries were reportedly affected by the infestation. They were: Mauritania, Senegal, Gambia, Mali, Burkina Faso, Niger, Chad, Sudan and Ethiopia. The estimated production saved in these nine countries from the control measures mounted was 350,200 metric tons of grain. The output lost, 241,000 tons. Gross production in these countries was 18,226,000 tons so the loss was a little more than 1%. If we add together the loss plus the amount saved we get something above 3%. (All figures are FAO and FEWS estimates.)

In dollar terms the above figures translate to a crop loss of $31.9 million (figure C.13) out of a total output valued at $2,050.4 million.

At present these are the best recent estimates of the cost of locust damage. On a national and international scale it is not a very significant figure. However, such figures can conceal costs of damage that could have been very severe on a local rather than a national basis, rather like flood or hurricane damage, which may make little impact when we look at national figures but which can cause catastrophic damage for the people in the locality that is effected.

The data for 1986 is more complete than data for outbreaks in the 1960's and earlier but there is such a paucity of agricultural data for Africa, and the data from which we have to compute losses is so incomplete, that we have no real basis on which to work or even to make comparisons. It is not clear, for example, whether the cost of locust damage in 1986 was greater or less than the damage for earlier outbreaks. There is no single organization responsible for <u>collecting</u> such data (although FAO <u>collates</u> and disseminates such data as is collected).

Figure C.13

Cost of Locust Outbreaks

	Mauritania	Senegal	Gambia	Mali	Burkina	Niger	Chad	Sudan	Ethiopia	ALL
PRODUCTION (000 metric tons)										
Gross Production	125.0	964.0	144.0	1780.0	1917.0	1807.0	685.0	4300.0	6504.0	18226.0
Product Lost to Grasshoppers	10.0	50.0	1.0	30.0	8.3	108.0	24.0	9.2	0.5	241.0
Product Saved	10.0	70.0	1.0	30.0	91.5	108.0	30.0	9.2	0.5	350.2
Production Directly Affected	20.0	120.0	2.0	60.0	99.8	216.0	54.0	18.5	1.0	591.3
ESTIMATED VALUE OF METRIC TON	$120	$171	$171	$166	$120	$111	$133	$88	$100	$131
VALUE (000 US$)										
Gross Production	15,000	164,844	24,624	295,480	230,040	200,577	91,105	378,400	650,400	2,050,470
Production Directly Affected	2,400	20,520	342	9,960	11,974	22,976	7,182	1,628	100	78,082
Product Lost to Locusts	1,200	8,550	171	4,980	997	11,988	3,192	810	50	31,938
Product Saved	1,200	11,970	171	4,980	10,976	11,988	3,990	810	50	46,135

Source: FEWS, 1987

The cost of damage is not the most important figure when considering locust control. The value of the crop threatened is more relevant in cost-benefit analysis. However, this value is no easier to determine. We simply have no good figures from output from most areas of Africa. What we invariably get in terms of figures of potential locust damage is some aggregate ex-poste figure that may or may not bear some rational relationship to acreages and actual yields within the countries threatened.

The question that needs to be answered is what would be the cost of allowing a locust or grasshopper outbreak to run its course with no attempt being made to control it. We have no answer to the question. No firm set of figures on which an estimate can be based. As recognized in a recent standard work on this subject (Center for Overseas Pest Research 1982), the cost of locust and grasshopper damage, both actual and potential, is still an unknown.

D. CONTROL OF LOCUSTS AND GRASSHOPPERS

Locusts and grasshoppers are a recurring problem in Africa and the Middle East. Damaging populations occur somewhere in the Region each year, but massive upsurges over vast areas by the principal species (species which develop aggregation and migration tendencies) are cyclical.

Desert Locust plagues, in the absence of widespread concerted control efforts, tend to maintain plague status for 7 to 8 or more years, followed by a prolonged recession period.

For localized incipient, grasshopper infestations, FAO, Donor nations and the affected nations generally recognize these as primarily an individual farmer problem. The individual farmer is generally incapable, however, to protect his crops from the ravages of a widespread upsurge, from grasshoppers which develop in the surrounding grasslands and move into his crops when the grassland dries or the grasses cure; or from locusts that migrate into his area from long distances.

The farmer most likely to sustain damage from migrating locusts and grasshoppers in Africa and Middle East, and the one least likely to be able to recover after devastation to his crop is the subsistence farmer.

When AID became involved in addressing Africa's locust/grasshopper problems, operational responsibility was divided among three internal units.

1. Short-Term: Office of Foreign Disaster Assistance (OFDA) has the authority and responsibility to apply its resources to:
   a. Pest emergency situations in a host country when a disaster has been declared by the U.S. Ambassador to that country.
   b. The mitigation of potential disaster situations.
   c. Certain recovery and rehabilitation activities designed to prevent secondary disaster effects.
2. Medium-Term: The Bureau for Africa has the authority and responsibility to:
   a. Implement non-disaster project activities required to put the pest emergency situation back under control.
   b. Implementation of normal, longer-term development initiatives, vis a vis pest control programs.
3. Long-Term: The Bureau for Science and Technology working with the Bureau for Africa has the authority and responsibility to support developmental activities on a regional or bilateral basis, designed to improve the

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capabilities and capacities of national and regional institutions.

AID supports integrated pest management (IPM) as a part of its agricultural program. This includes biological, cultural, physical, chemical behavioral controls and careful use of pesticides to reduce the use of toxic substances (Special Report, The Environment, AID, 1987).

The techniques for dealing with locust/grasshopper pest threats and outbreaks, in the IPM conceptual framework, are divided into four groups:

1. Cultural - which includes crop rotation and planting of new or non-traditional crops that resist locust/grasshopper infestation.
2. Mechanical - which includes flooding ditches with water around crops, or burying or burning pests.
3. Biological - which includes the introduction of pathogens or other diseases that effect pests.
4. Chemical - which is the use of chemical compounds and pesticides to kill the pests.

The first three are more appropriate for use when attempting to control limited infestations in cropland or, in the case of 3, preventing the development of major infestations. Chemical techniques are especially useful in reasserting control after a pest outbreak has occurred.

Grasshopper outbreaks often follow long periods of drought. Some Sahelian grasshoppers can remain in a state of diapause in the egg stage for several years if rainfall is deficient, while their natural enemies do not always have the same survival mechanism.

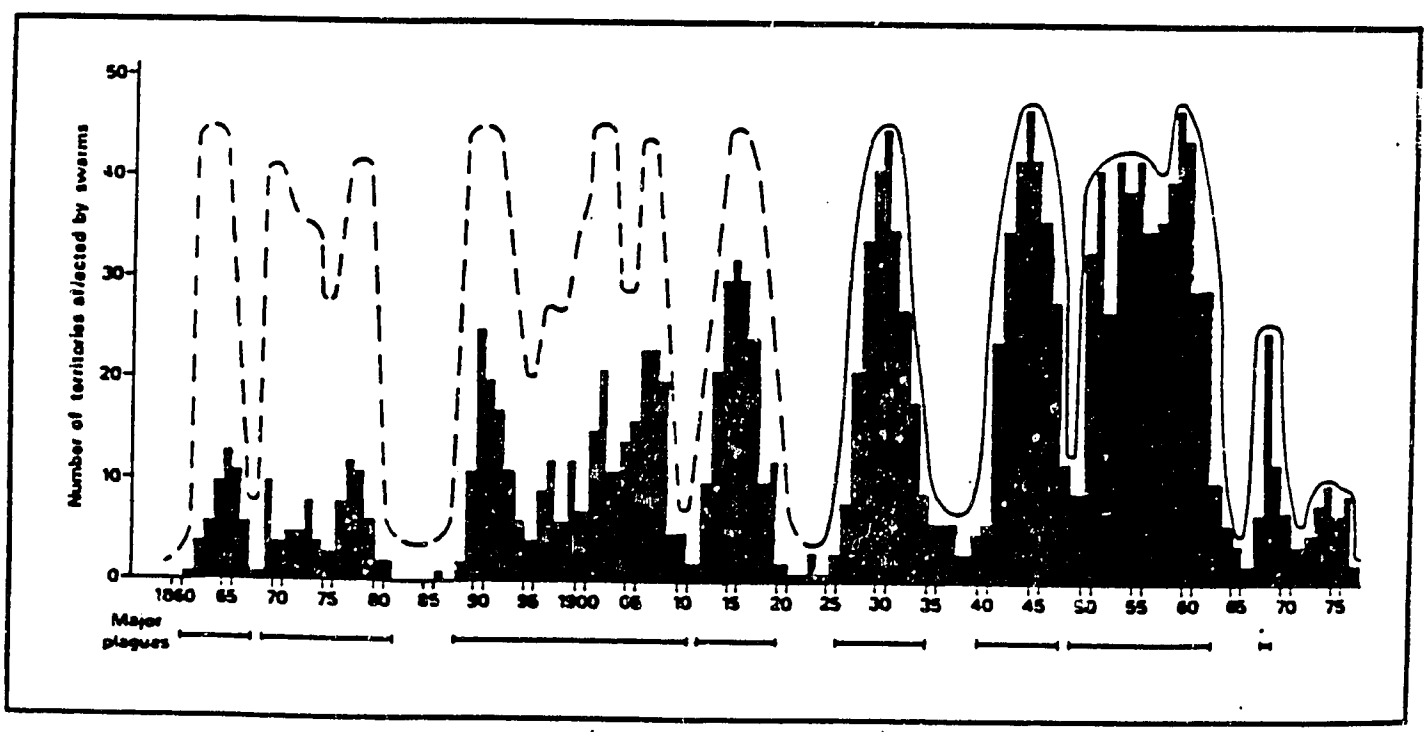
Waloff (1976) tabulated the frequency of Desert Locust recessions of different durations. The average length of recessions was of the order of 7 years.

The Centre for Overseas Pest Research (COPR), London, graphed the major Desert Locust plagues from 1860 onward (Figure D.1). The last major plague ended in 1962. Since then, there have been 3 major population upsurges, 1967-69; 1974-76 and 1988. The two previous upsurges did not reach plague status. It is still too early to determine the final status of the 1988 population upsurge, but because of quick concerted control action having been taken, it is possible that this outbreak may also not reach plague status.

Ashall, C. and Chaney, I. (1979) concluded that it is now clear that knowledge is available which, if properly applied, could guarantee plague prevention. The two most recent upsurges have provided some evidence that control measures can be applied to bring about suppression of an upsurge in one or two years.

Figure D.1

Major plagues of the desert locust. The periods of the plagues are indicated by heavy lines under the graphs. The undulating line above the graph outlines the plagues and recession periods, the broken portion suggesting the extent of infestation during the period 1860-1924 when records were incomplete. (Figure by COPR)



Between 1847 and 1926, recession periods for the Red Locust extended for a high of 39 years to a low of 5.8 years. A long plague period began in 1927 which extended until 1944. No Red Locust outbreaks have occurred since that time. Blackith and Albrecht (1978) suggested that the recession which has extended from 1944 to the present (now 44 years) may have been artificially prolonged by control measures.

D.1 Current Forecasting, Early Warning, Survey and Reporting Systems

Control specialists have been working on more accurate ways to predict the occurrence, location and severity of locust/grasshopper outbreaks in order to achieve cheaper and more effective prevention and control. Survey and reporting systems have provided researchers with data and have attempted increasingly efficient and economical location of infestations that need to be eradicated.

D.1.1 Forecasting

Outbreaks are best controlled by control operations against a previous generation or the nymphs of the threatening generation. Out- break forecasting is necessary for such timely intervention. Weather cannot be forecast far in advance in the geographical areas covered. Since moisture is the single most important factor in locust/grasshopper forecasting, it is possible to foresee with accuracy only the maximum possible size of the present generation or the first filial generation.

D.1.1.1 Use of ground-obtained information for forecasting the Desert Locust

Development of a Desert Locust forecasting system began with the collection and mapping of occurrence data since 1929 by what was to become the Anti-Locust Research Centre, in the United Kingdom. Studies focused on locust flight endurance and physiology, swarm structure, swarm movement and migration in relation to weather systems. These studies found that the occurrence of breeding and outbreak areas depends on seasonally changing weather systems that transport locusts downwind to areas of marked relief in desert regions or weather front convergence zones where flying locusts may concentrate because of rain-triggered plant growth. The detailed distribution of outbreak sites is determined by soil type, soil moisture and vegetation patterns favorable for breeding and oviposition.

Forecasts are based on ground reports of swarms, hopper bands and isolated locusts. This information is mapped with significant weather developments -- rainfall, temperature, wind speed and direction -- to determine when, where and how many new adult populations will appear and be ready to fly. Longer-term forecasts (2 months + ahead) depend chiefly on seasonal

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probabilities derived from historical evidence: of migration routes and breeding areas.

The FAO Desert Locust Reporting and Forecasting Service in Rome prepares a monthly Desert Locust Situation Summary and Forecast which covers meteorology, breeding conditions, locust activity and a distribution map of recent sightings, as well as providing a two-month forecast that is useful for planning the deployment of control resources. Short-term forecasts based on current weather and requiring a quick response from survey/control teams are sent to key countries by cable.

There are gaps in coverage in the various countries and even regions, due to late arrival of field reports. Also, forecasts have generally not been quantitative; available information on sizes of swarming populations is often inadequate and at best qualitative. An evaluation of forecasting success during the period August 1960 - October 1965, found that 64% of all 1280 predictions were correct, including 85% of the predictions of a high probability of swarms or hopper bands. On 15 occasions, there was no warning of actual swarms or impending breeding. Verifications for March 1961 - December 1965 showed that nine of 32 correct warnings came too late -- after the predicted event had already occurred (Betts, 1976).

D.1.1.2 Remote Sensing

One of the primary objectives of using remote sensing on the locust control project is to guide field teams to places where conditions are suitable for locust development, thereby excluding large areas from unneeded air and ground survey and other inessential and costly surveillance operations. Another objective is to provide supplementary information for climatological modelling used to predict locust movement. At the international level, this increased selectivity of information allows better judgement of the potential for important locust activity and the timely initiation of international emergency operations, if needed.

The remote sensing currently being used for early warning is not considered to be totally operational. Heilkema (1987) states that to date, analysis and interpretation of satellite imagery acquired for the FAO's Desert Locust program and Global Information and Early Warning System (GIEWS) has been of a developmental nature and the information extracted has been used in the various programs on an experimental and semi-operational basis. The USAID funded Pilot Project for Seasonal Vegetation Mapping in Support of Grasshopper Control can also be considered semi-operational. The maps have been used to more effectively direct people to "green" areas and avoid the wasted effort of going to dry areas.

Remote sensing specialists interested in locsut control are either working on or proposing to improve the data analysis

and interpretation necessary for the optimal use of satellite information, the definition of the most cost-effective combination of systems, and improving the timely flow of reliable "user-friendly" information and maps to preventive control campaigns which have the training to use them effectively. So, the potential for achieving operational systems is being addressed through advances in technology, training and organizational structure.

The status of remote sensing technology and organizational structure supporting it are briefly outlined below in terms of the remote sensing systems and what kind of information they acquire, information flow from sensor to user, what organizations analyze and disseminate the information, and the possible additional remote sensing prospects in locust early warning. More detailed descriptions of the remote sensing systems described below are found in Appendix 8.

D.1.1.2.1 Remote Sensing Systems

Aerial photographs, multispectral scanner images, thermal images and radar images are all examples of remote sensing products that can be used for locust forecasting and early warning. Aside from using aerial photography to photograph locust swarms in flight and for detailed interpretation and mapping of the different types of biotopes favorable to locust development, satellite borne remote sensing systems are used most in acridid control because they repeatedly cover the extensive geographical areas occupied or invaded by the insects. With their wide area coverage and special sensing capabilities, satellite sensors provide important input to determining information about rainfall, soil moisture and vegetation cover and growth rate - the key ecological parameters governing locust development. The two primary satellites used to monitor these parameters are the European Space Agency's (ESA) Meteosat geostationary orbiting weather satellite and the National Oceanic and Atmospheric Administration (NOAA), NOAA 9 and 10 weather satellites. Two earth resources observation satellites, Landsat, operated by the US firm, Earth Observation Satellite Company (EOSAT), and the French Systeme Probatoire d'Observation de la Terre (SPOT), provide important land cover information in more detail. The operating characteristics of each of these satellites in relation to each other are shown in Figure D.2.

Meteosat is in orbit over a fixed location in Africa and acquires full hemisphere visible and infrared imagery of that continent, Europe and parts of the Middle East. The satellite continually sends digital data to its European data processing center where images can be produced as often as every 30 minutes

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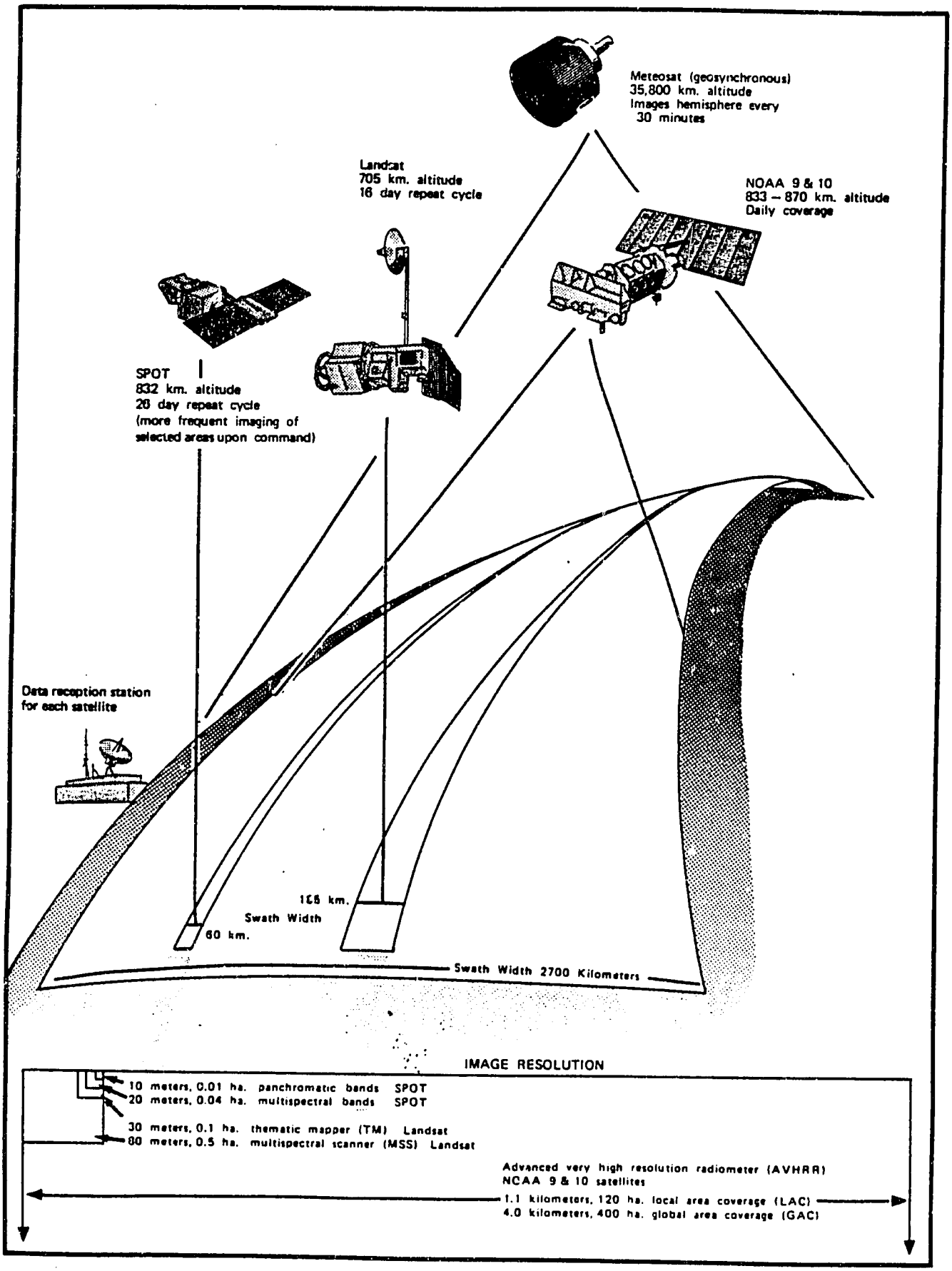

Figure D.2 Principle satellites used in early warning and forecasting -- their image resolutions and areal coverage

over a 24 hour period. Because of this operational capability to continually monitor dynamic phenomena such as cloud movement and cloud top temperatures, Meteosat information is extremely useful for estimating rainfall, wind patterns, and soil moisture.

NOAA 9 and 10 are polar orbiting satellites that provide daily coverage of an area. Their advanced very high resolution radiometers (AVHRR) sensing in the visible and infrared bands also provide important cloud cover information that can be used for precipitation estimation. In addition, the AVHRRs are also useful for land surface mapping and for preparing the vegetation greenness index maps that indicate the potential for locust food and shelter and indicate soil moisture. This NOAA imagery has been the mainstay of the scientists familiar with the locust breeding and recession area environments who wanted to see where vegetation greening up was occurring.

The Landsat and SPOT satellites provide higher resolution imagery than do Meteosat or the NOAA satellites, but each image covers significantly less area and provides less frequent repeat coverage of a location than do the images from the other two satellites. The imagery from these two satellites is used to obtain a more detailed picture of urban, village or agricultural land uses, vegetation patterns, soil associations or drainage networks that might be important for determining specific areas of locust habitat or areas of locust predation. Landsat and SPOT imagery are not always available for analysis in a timely manner (relative to locust development) because of their less frequent coverage and the time it takes to get the imagery.

Scientists often use each of these remote sensing systems in conjunction with each other to make use of the best characteristics of each system. Satellite imagery providing wide area coverage is often interpreted in conjunction with aerial photography of selected areas, the aerial photography providing detailed information that forms the basis of a sampling scheme to be used across the satellite images. Similarly, one type of satellite's imagery may be used with another's to take advantage of each satellite's particular spectral band combinations, resolution capability or return cycle periods. Used in a sampling mode, Landsat or SPOT images can be selected to view environments at various locations throughout locust control areas covered by the coarser resolutioned NOAA or Meteosat images.

This remote sensing information, in turn, is used in conjunction with all other relevant and available printed, mapped or field-acquired soils, vegetation, climatological, infrastructural and historical or current locust location data to increase the effectiveness of locating one's self in the field and in performing data analysis.

This information is being put into data bases that are now being computerized and combine computer mapping with data

management procedures in systems called geographic information systems (GISs). Whatever information is used to describe the map units shown on land cover, vegetation or weather maps is stored in the GIS, and referenced by a particular type of coordinate system so that data analysis can be performed on them, including merging information shown on different maps.

Satellite images themselves are a form of computer map because each image is comprised of a network of picture elements (pixels) arranged in its own coordinate system. Environmental units identified on the imagery can be referenced to this coordinate system and merged with the coordinates of existing maps of other topics. In this context, Landsat imagery, existing topographical and ground survey data and historical locust observations are being used to map Desert Locust habitat in the recession area and establish a digital geographical data base for the monitoring system. By superimposing these habitat maps over current remote sensing-derived vegetation and soil moisture maps, it should be possible to pinpoint even very small potential breeding sites.

So in overview, the satellite inputs improve the quality of locust forecasting, giving a better picture of wide-scale breeding conditions and detecting important rainfall events not recorded and/or reported by meteorological stations.

The spatially continuous, frequent Meteosat and NOAA Satellite cloud images, supplemented by ground observations can indicate the timing and extent of even short-lived rainstorms on a daily basis. They bolster the ground-origin weather and vegetation data that are sometimes inadequate because observations are representative only of often-atypical point locations in a sparse network, and because synoptic data transmitted by the World Meteorological Organization's Global Transmission System (GTS) is consistently incomplete, especially for rainfall.

There are plans to extend monitoring coverage to other migratory pests notably the grain-eating bird Quelea quelea, the African Migratory Locust, the Seneglaese Grasshopper, armyworm and the Red Locust. Information on requirements are generally the same as for Desert Locust, but habitat characteristics differ in spectral terms and the areas to be monitored are smaller.

Finally, remote sensing, primarily aerial photography and imagery from the higher resolution satellites, can be used to identify sensitive environments in areas to be treated for locusts, or to monitor conditions where treatment has occurred. The imagery and aerial photos can be acquired specifically for each incidence should cost and time permit, or it can be obtained from prior projects that have taken place in the region. Several regional remote sensing resource inventory projects throughout Africa have produced reports and documentation centers that contain a significant amount of useful images, aerial photos and

soils, vegetation, land use and water resources information. Information from these inventories and from agricultural, rangeland or forestry development projects can be used for both supplementary early warning remote sensing and for environmental protection purposes as well. Knowing where to find this information should be an important part of each early warning and locust treatment activity.

D.1.1.2.2 Data flow

The rapidity with which the remote sensing data gets to the decision makers and technicians, office or field based, depends on where they are in relation to initial data receiving stations, what kind of data reception the user has and what procedures are necessary to analyze the data that have been received (Figure D.3).

The satellites telemeter digital data back to ground stations where it is put into various formats: stored on magnetic tapes, displayed as computer screen displays or processed as "hard copy" -- paper or film images, computer maps and various types of graphics and statistical data. Some of this information is telemetered immediately back to satellites for relay to other stations around the world that immediately receive it and begin to process the data either as digital or analog (non-digital) information. This information is also transmitted over ground communication lines as well.

Satellite data tapes are sent from main processing centers to other locations that also have the capability to do sophisticated digital analysis. This taped data can also be put on diskettes for use in microcomputer image analysis systems that can be established where the more sophisticated equipment is not available. Depending upon the remote sensing system used, formatting the tapes and diskettes and getting them to the user can take anywhere from a few days to several weeks. (The same is true for images produced from the tapes.)

Analysis of rainfall, soil moisture and vegetation information using the remote sensing and supporting data adds time to that already taken to produce the tapes and images. Rainfall estimations are usually done at ten day (decadal) or monthly intervals, vegetation index maps are usually composites of images that take 7 to 14 days to produce. Less "reliable" estimates of rainfall and vegetation biomass can be made at shorter intervals of from one to several days of image analysis, and the information then forwarded to the appropriate users.

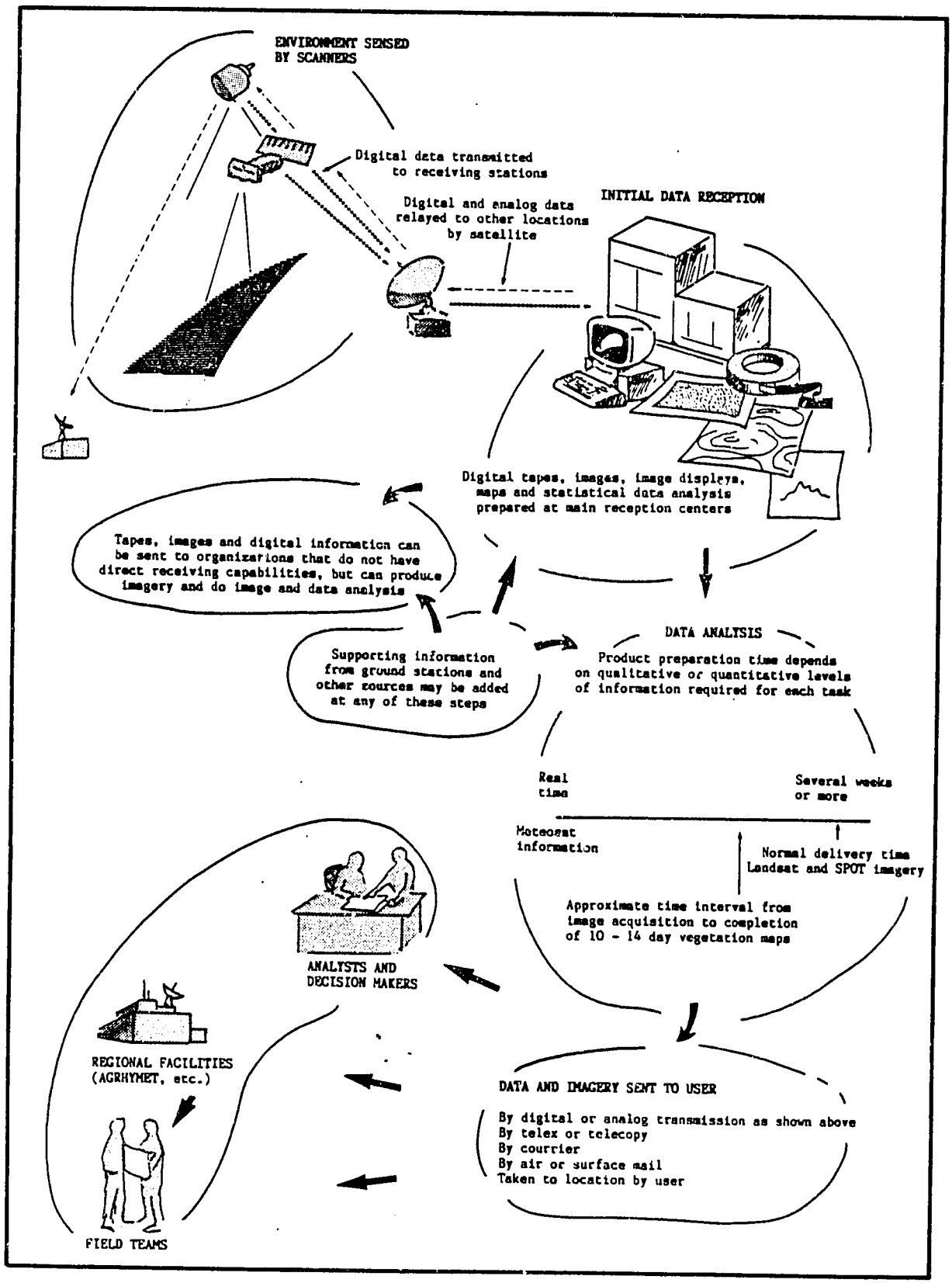

Figure D.3 Data pathways from sensors to users

These time delays are exacerbated because of the primarily U.S., and European locations of scientists and data processing centers and the regional location of the AGRHYMET center in Niamey. This results in delay in getting pest observations from the field to the centers where it can be incorporated into remotely sensed data, and in turn getting images, maps and advisory information to the field. To rectify these situations, steps are being taken to shorten analysis sequences of imagery (where possible), to telecommunicate information from the centers to field locations, to use more satellite relay of digital or analog data remote sensing or communications by satellite where that is possible, and to establish digital data receiving stations in new regional centers.

Remote sensing techniques and their field applications have been tested in Algeria and Pakistan. A remote sensing laboratory was established in Rajasthan, India. NOAA/ AVHRR/Meteosat receiving stations are planned at the Desert Locust Control Organization/East Africa (DLCOEA), Nairobi, Kenya and by late 1988 at the Regional Center for Training and Application of Agrometeorology and Hydrology for the Sahel (AGRHYMET), Niamey, Niger. DLCOEA will also have the capability to analyze and interpret Landsat and SPOT data. Upon installation and testing of these receiving/processing systems, an operational monitoring program will be functional. Field staff training is an important part of the program.

D.1.1.2.3 Organizations

Currently the remote sensing part of the forecasting, early warning and surveying is prepared and analyzed by individuals and organizations affiliated with the FAO, NOAA or NASA, the USGS and USAID, CILSS/AGRHYMET and other organizations.

Although there is certainly redundancy in their operations, these different organizations do not necessarily totally duplicate efforts because each of the units operates under different mandates: research, application, information production and training or a combination of each. What they produce reflects these mandates and may be apropos for a particular areal or time scale or degree of accuracy that may or may not at first be suitable for locust forecasting. In addition, one organization might supply other organizations with data tapes or other information that each respective organization, including the original supplier, might use in complimentary or different ways. AID is aware of this and has discussed data sharing and joint collaborative efforts among organizations, including FAO.

The US does not have any one remote sensing organization dedicated to using remote sensing for locust control operations, per se. NOAA, NASA, the USGS as well as commercial organizations that can subcontract to USAID have the expertise and technology

among them to establish a locust early warning program using the best of each kind of remote sensing and supporting information but this has not been effected yet. This is, in part, because among all of the development uses remote sensing can be put to, the US has not put that much emphasis on locust early warning, and in part because there has not been agreement among US experts as to which methods to use.

D.1.1.2.3.1 FAO

So far the FAO has put the most focused effort into developing an integrated locust forecasting and early warning system. FAO has been doing remote sensing research since 1975 in the framework of its Global Information and Early Warning System of Food and Agriculture (GIEWS), the International Desert Locust Plague Prevention Programs, the assessment of rangeland conditions and long-term monitoring programs such as agroecology zoning, desert encroachment assessment, forest cover mapping, etc. The FAO Remote Sensing Centre's present rainfall estimation technique, using analog Meteosat Secondary User Station (SDUS) imagery, is an operational methodology for qualitative precipitation monitoring of the African continent using thermal infrared and visible image data. It is presently used on an operational basis for Africa as an input to the FAO global early warning and locust plague prevention programs (Hielkema, 1986). The centre has been primarily using NOAA imagery for vegetation greenness estimation.

With funding from the Netherlands, the Remote Sensing Centre is scheduled to install the ARTEMIS (Africa Real T[illegible] Environmental Modeling using Imaging Satellites) system i[illegible]e 1987 or early 1988. Custom-designed for FAO by the National Aerospace Laboratory of the Netherlands, it is a comprehensive operational satellite remote sensing-based system combining Meteosat, NOAA data for monitoring precipitation and vegetation conditions on a continental scale. Tamsat, Admit and Permit are three experimental satellite-based rainfall estimation techniques designed to increase estimation accuracy by using Meteosat or NOAA digital data or both that are being developed and tested by FAO in cooperation with the Universities of Bristol and Reading in the United Kingdom.

ARTEMIS is also proposing to develop better telecommunication data links to field locations in order to get primary data closer to its African users.

D.1.1.2.3.2 U.S. Geological Survey (USGS) EROS Data Center

USAID funded a 1987 USGS/USAID (Africa Bureau) Pilot Project for Seasonal Vegetation Mapping in Support of Grasshopper Control. The project's purpose was to develop, pilot test, and evaluate a near real-time vegetation monitoring procedure using

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satellite data and information system technologies for use in grasshopper control programs and other applications.

The products produced by the Pilot Project consisted of maps of green vegetation conditions and changes in green vegetation cover, derived from composites of NOAA satellite data. The one-kilometer resolution data were used to compute Normalized Difference Vegetation Index (NDVI) values which relate to the amount and vigor of green vegetation. Maps were produced for Senegal, Gambia and Burkina Faso every two weeks from April to November (map production for Niger and Chad began in July). The 14-day maps were shipped by courier while urgent messages were cabled to problem areas. A limited number of Landsat images for more detailed coverage of ground features were provided to field personnel on an as-needed and as-available basis (National Mapping Division, EROS Data Center, US Geological Survey, 1987).

The project evaluation found that the vegetation greenness maps were useful for grasshopper control and other purposes, and recommended that AID continue this work. The evaluation emphasized that delivery time to the field must be shortened to a week or less (USGS EROS Data Center, 1987).

National Aeronautics and Space Administration Global Inventory Monitoring and Modelling Studies group (GIMMS) has been doing remote sensing research on multitemporal vegetation monitoring and vegetation biomass estimatation since 1982. Instrumental in developing NDVI maps, it has applied this research to vegetation monitoring for agriculture, forestry rangeland management and early warning systems, including locust early warning. Some of this research was done with FAO personnel. In addition to the resource assessment research work it does, GIMMS personnel also format AVHRR data received at Goddard Space Flight Center (GSFC) and sends these data to FAO, (until it gets its own reception station), USGS' EROS Data Center and to the FEWS project for their own respective uses of the data.

D.1.1.2.3.3 NOAA

The National Oceanic and Atmospheric Administration (NOAA) operates weather satellites, collects and analyzes information on the weather, climate and oceans, makes weather forecasts and serves as a supplier of this information to other goverment agencies, the public and foreign users. NOAA scientists have also developed vegetation indexing procedures using AVHRR imagery. Until recently NOAA's Assessment and Information Services Center (AISC) provided information to the FEWS project and had proposed to apply some of their efforts to the locust problem, but under a reorganization, the Center no longer is involved in these programs and the climatic assessment is being handled by the USDA's Economic Research Service (ERS)

and Joint Ag/Weather Facility. These facilities are not involved in locust early warning per se.

D.1.1.2.4 Possible additional capabilities

Forecast information from numerical weather prediction models produced at the European Centre for Medium Range Weather Forecasting (ECMWF) can be used to forecast the vegetation index days in advance. These forecasts could also be used to operate a locust population development model and calculate locust swarm trajectories using a model developed at the Royal Netherlands Meteorological Institute. Combined, these tools would form an overall locust forecasting and control optimalization model of development, estimated displacement and the effectiveness of proposed control measures. (MeteoConsult BV, 1987).

The Meteosat, NOAA, Landsat and SPOT satellites now in use will all be followed by successor satellites that will take both the currently used and improved versions of the visible and infrared sensing technology into the 1990's.

Nimbus 7, launched in July 1987 for the Defense Meteorological Satellite Program carries a Special Sensor Microwave Imager SSM/I, that among its capabilities, uses the special properties of microwave frequencies to sense precipitation, soil mositure and land surface temperatures. Proposals to use the microwave sensors for soil moisture estimation in locust areas have already been received by USAID.

The proposed Tropical Rainfall Measuring Missions, starting in 1992, are designed to collect more accurate data on weather, climate and hydrological processes in the tropics. TRMM will do this by flying a satellite in more equatorial rather than polar orbits. The satellites will carry visible, infrared, passive microwave and radar sensors so that by combining the sensor data and at the same time providing more frequent coverage of the region, our ability to estimate rainfall and conduct experiments on soil mositure and vegetation in the tropics will be measurably increased.

There are yet other US Earth Observation and Weather Satellite missions proposed for the long term, and other countries in the European space community, Canada, Japan, India and the Soviet Union will also be launching satellites carrying an array of sensors that have the potential to be used for locust forecasting and early warning.

D.1.1.3 Models

Remote sensing techniques can identify areas favorable for the concentration, breeding and outbreak of locust and grasshopper pests, but as stated above they must be used with actual field observations and predictive models in order to

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forecast, and evaluate the results of various possible interventions.

D.1.1.3.1 PRIFAS Biomodels

The Programme de Recherches Interdisciplinaire Francais sur les Acridiens du Sahel (PRIFAS), a section of Groupement d'Etudes et de Recherches pour le Developpement de l'Agronomie Tropicale (GERDAT), funded by the Ministry of Cooperation of France, has produced "bio-models" of varying complexity for three African locust/grasshopper species. They are a family of models, either descriptive or predictive, constructed from the quantification of observed relationships between variations of environment types and the responses of the insects. The results may be qualitative or quantitative, but are based on tables of correspondence with numerical values (Launois, 1984).

The African Migratory Locust. This model was developed in Madagascar from 1970-73 and then extended to Africa. The most important factor is the soil humidity gradient. Whenever hydrologically optimum conditions (due to rainfall, irrigation, or planting on the edges of shrinking bodies of water) are present in an area for two or three months, there is a danger of population upsurge followed by gregarization. Temperature and vegetation conditions also play a role (Launois, 1984). At least 50% presence of favorable ecological factors indicates areas of possible outbreak.

The biomodel improved the effectiveness of OICMA field surveys in Mali; scouting was confined to favorable areas by overlaying maps of flooded zones, vegetation, temperature isohyets and grasshopper presence. It reduced annual scouting man-months from 144 to 90 resulting in substantial savings in operational costs (Alomenu, 1985).

The Senegalese Grasshopper (the OSE biomodel). Field observations in the Sahel from 1975/76-1987 were used to construct this computerized model. The model depends on rapid reporting of field observations and historical or forecasted meteorological data. On a ten-day basis, it analyzes the interactions between the stages of the grasshopper present and five key environmental factors: photoperiod (diapause), temperature, moisture, vegetation and accessability of the biotope. Each interaction is indexed for its effect on development speed, survival, departure and arrival (Launois, 1979). It can graph grasshopper population structure and immigration/emigration in realtime for a given location starting with the first rains, superimposing this on sorghum and millet growth to describe areas and times of possible severe crop loss. Grasshopper density can be mapped for the entire Sahel and for individual countries on a 10-day basis. Results are qualitative.

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With rapid and adequate inputs, the model could be used to forecast main biological events two weeks in advance. On the medium term (one month), it could give possibilities according to the biological limits of development of the species. 1985 results (obtained from using rainfall weather data only) were compared with FAO field reports and found to be 80% accurate (Launois & Launois-Luong, 1985). On the long term (from the beginning of the dry season to the beginning of the following wet season), it can forecast with reasonable accuracy the worst-case scenario of the threat from diapausing eggs.

The biomodel produced an international alert in late 1985, warning of the possibility of catastrophic grasshopper infestations in 1986. Another warning of heavy infestations was posted for 1987.

The Desert Locust (the SG biomodel). UNDP, FAO AND PRIFAS have been working together on this project since 1983. It is meant to be a computerized quantitative biomodel of Desert Locust population dynamics over its entire distribution area, producing forecasts in terms of probabilities that must be followed up by ground surveys. These will be most useful in remote areas that are hard to cover on a routine basis.

Like the OSE biomodel, this one depends on a table of relationships between environment types and the response of each locust stage, for both the solitary and the gregarious phases (FAO, 1984). Since FAO has mapped suitable Desert Locust habitats in large portions of the Sahel, there is less need for ground data input than with the OSE biomodel. Habitat maps can be overlaid on remote sensing vegetation and rainfall maps to delineate probable breeding areas.

D.1.1.3.3 Trajectory Model of Desert Locust Swarm Movement

A trajectory model for tracking and forecasting Desert Locust swarm movement is being developed and tested at FAO. It is based on a Royal Netherlands Meteorological Institute model for calculating the trajectories of air particles, which behave in many respects like flying locust swarms. Swarm trajectory predictions are produced by combining these calculations with ten-day advance forecasts for wind fields. These predictions are 70% reliable up to three days ahead, and even earlier predictions are more accurate than historical averaging (MeteoConsult BV, 1987).

D.1.2 Early Warning Systems

There is a large array of early warning systems for predicting and assessing potential famine and other emergencies and providing information useful in relief planning and operations. Most of them, including FAO's Global Information and Early Warning System (GIEWS), USAID's Famine Early Warning System

(FEWS) and crop and pasture monitoring project at Agrhymet, monitor and report pest damage only as one of the several major risks to annual agricultural production, which in turn affects food supply and the need for aid. Their reports of locust/grasshopper infestations are neither quantitative nor early and detailed enough to be useful for field use. They are, however, adequate for national or regional scale, medium term donor decision making.

D.1.2.1 FAO Desert Locust Reporting and Forecasting Service

This Rome-based service issues a monthly Situation Summary and Forecast of locust activity during the following two months, which is airmailed to all interested countries and organizations. Short-term, emergency warnings are telexed or cabled to threatened areas.

D.1.2.2 Operation Sauteriaux au Sahel (SAS)

Operation SAS is an information exchange program with potential for early warning, created by PRIFAS in the Sahel in conjunction with development and testing of the OSE biomodel. The resulting semi-quantitative reconstruction of Senegalese Grasshopper population development and movements is disseminated to participants through a biweekly newsletter. It has been difficult to accumulate enough quick, complete and reliable field reports and sufficiently rapid weather data for optimal functioning of this system. The newsletter generally arrives after control decisions have been taken and is most useful as a summary of the grasshopper situation and its possible short-term consequences.

D.1.3 Survey and Reporting

Forecasts and models can provide information on the geographical areas where grasshopper and locust problems are likely to occur, but actual field surveys are necessary to find, delimit and destroy threatening infestations. There are several complementary methods for making useful observations. Effective reporting and communications facilitate appropriate organization and deployment of pest control resources on national and regional levels, and are the basis of subsequent forecasts.

In spite of all the systems available, the forecast as to the extent and intensity of the 1987 Sahel grasshopper infestation was wholly inadequate. The level of infestation overall was far less than projections indicated.

D.1.3.1 Enlisting farmers

In the Sahelian countries, farmers are being mobilized successfully to form village-level pest monitoring organizations with community leader advisory committees. Extension or plant

protection agents pass their reports on to a regional or national headquarters, and plant protection services intervene if the problem is too severe and widespread for farmers to cope with.

D.1.3.2 Ground survey teams

Historically the backbone of survey operations has been the mobile survey and control team in four-wheel drive vehicles. It checks predicted or historically vulnerable trouble spots where locust gregarization or potentially harmful locust/grasshopper population buildups could occur.

It is very difficult to make absolute estimates of the size of a grasshopper infestation or locust swarm, but such information is extremely valuable to forecasters and decisionmakers.

Counting the number of pests present is necessary in order to use economic thresholds for deciding whether insecticide application is justified.

When pest numbers exceed the economic threshold level for the given field situation, insecticides should be applied. Besides pest numbers, other factors to be taken into consideration are the species concerned, their stage(s) and phase (solitary or gregarious, for locusts), development trends, area infested, degree of insect clumping and reason, vegetation attacked and the danger for crops and grazing land, and natural enemy activity.

After the application of insecticides, it is necessary to assess the effectiveness of the treatment by noting knockdown, the duration of action, vulnerable stages and species, and the speed of recolonization of the area by various species.

Besides reporting on the field situation, mobile ground teams sometimes undertake farmer training, distribution of pesticides and supervision of their use. If the magnitude of the problem requires aerial spraying, ground teams are needed for fill-in and mop-up operations, to strengthen the liaison and communications network, and to help assess control results (FAO, 1987j). For all these activities, mobile teams can be usefully complemented by a network of fixed pest observation posts.

An important survey function after the cropping season is counting and mapping end-of-season infestations, locating grasshopper/locust oviposition sites, and carrying out egg pod surveys. These give an indication of where and how many first-generation pests can be expected at the beginning of the following season.

D.1.3.3 Aerial reconnaissance

Aerial surveys are very useful for delimiting likely locust and grasshopper habitats and locating and estimating the size, density and extent of locust swarms and hopper bands. Ground surveys for Desert Locust are inefficient (they miss most bands), expensive and fail to give an idea of the total size of the problem, since ground teams cover only about 15 sq km/day (Joyce, 1979).

Helicopters have been found to be very efficient for survey work, good for rapid detection and definition of targets, liaison between ground units, and assistance with control operations, especially in difficult terrain.

D.1.3.4 Radar

Airborne and ground radar has been experimented with for the investigation of swarm source areas, flight behavior, and areas of deposition of migrating insects, especially at night. A network of locust-detection radar has been proposed for monitoring the Desert Locust recession area (Schaefer, 1970). Because of the expense, problems of maintenance under field conditions, and problems with species identification, this method is unlikely to be widely used in the foreseeable future.

D.1.3.5 Light traps

Light traps can be part of a surveillance system. Counting and recording trapped insects is a skilled, laborious and time-consuming job. Consequently, there has been much criticism of its usefulness for monitoring grasshopper populations. However, it is still thought helpful as a crude measure of night flying activity, being particularly useful for detecting sudden major increases in numbers (Popov, 1984).

D.1.3.6 Communications and Reporting

Excellent radio communication must be maintained between survey teams and their operations headquarters.

Survey teams should be provided with coded reporting forms for noting their observations and activities as well as relevant interview information.

Considerable improvements in data analysis and interpretation are still necessary for the optimal use of satellite information. So are definitions of the most cost-effective combination of systems, and provision for a reliable, timely flow of "user-friendly" information and maps to

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preventive control campaigns which have the training to use them effectively.

The PRIFAS biomodel for the African Migratory Locust improved the effectiveness of OICMA field surveys in Mali. Scouting was confined to favorable areas by overlaying maps of flooded zones, vegetation, temperature isohyets and grasshopper presence.

The GIEWS, FEWS and AGRHYMET early warning systems were designed to predict famine. Their reports of grasshopper and locust infestations are neither early nor quantitative nor detailed enough to be useful to pest control officers in the field. They are, however, adequate for national- or regional-scale, medium-term donor desicionmaking concerning pest control.

PRIFAS' Senegalese Grasshopper observations in the Sahel and the OSE biomodel produced an international alert in late 1985, warning of the probability of catastrophic grasshopper infestations in the following year. But the degree of unpreparedness and disorganization in the countries concerned, combined with the overabundance and lack of coordination of aid and donors, largely cancelled the strategic benefit of the warning. Another warning of heavy infestations was posted for 1987. However, the 1987 warning failed to take into consideration the extent and effectiveness of the 1986 control effort.

Senegalese Grasshopper density mapping provided by the OSE biomodel is general and only semi-quantitative, giving survey teams a rough idea of where to look for large grasshopper numbers, and alerting planners to the relative size of infestations that can be expected. In 1986-87, Operation SAS was created for rapid collection of field observations from network participants all over the Sahel, but data return was slow, sporadic and incomplete. Given these problems, predictions could not be made. The model was, however, able to follow principal field events and their origins.

SAS correspondents received the maps in a biweekly newsletter, but the newsletter generally arrived after controldecisions had been taken and was most useful as a summary of the grasshopper situation and its possible short-term consequences.

D.2 The Availability and Effectiveness of Control Methods Other Than the Use of Broad-Spectrum Insecticides

D.2.1 Presently Available Methods

D.2.1.1 Mechanical control

From antiquity until recent times, farmers have tried to scare off hordes of grasshoppers or locusts with noise and smoke and/or collect them in trenches or corrals to crush, burn or drown them. Flamethrowers and horsedrawn collection machines have both been used. These measures are ineffective in the face of a serious infestation. With insecticides now available and frequently applied by government intervention teams on the farmer's behalf, it also can be difficult to mobilize farmers to apply these traditional, collective methods.

Ploughing or digging up the soil of oviposition sites is useful in some cases although Sahelian acridid eggs are very resistant to dessication. This exposes the eggs to mechanical injury, and depending on the type and depth of ploughing, they are left exposed to dessication and predators at the soil surface, or are buried so deeply that hatching hoppers are not able to dig their way out. Populations of the Variegated Grasshopper in two experimental areas in Nigeria were reduced by 83 and 91% in the following season with this method (Page, 1978). This method is practical only with species or in situations characterized by dense oviposition in small areas.

D.2.1.2 Cultural control

In some areas, planting short-season crop varieties or early seeding can meet late-season grasshopper infestations with a more mature and therefore more tolerant crop. However, proper drying and storage of grain may be hindered if it is harvested before the rains stop. Inflexible planting times and unpredictable grasshopper occurrence patterns, both due to dependence on erratic rainfall, make this method impractical in many parts of Africa and the Middle East.

Good land management, especially reforestation, upgrading range quality and avoidance of overgrazing and burning of wide areas, can suppress grasshopper and locust numbers and decrease suitable breeding sites that are associated with a sparse plant canopy. Since halting overgrazing and desertification is currently a losing battle all over Africa, opportunities to alter the mix of plant species are few, and many farmers and nomads deliberately set annual brushfires to return nutrients to the soil and enhance new plant growth, these control measures are seldom possible to implement.

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Water management through drainage or irrigation has successfully suppressed some locusts, but measures that mitigate one problem can sometimes cause another. Irrigation as well as natural flooding encourage some species such as the Migratory Locust, or can reduce locust/grasshopper numbers by destroying egg fields. Red locust populations are low when water levels rise in recognized outbreak areas in Tanzania and Zambia. Extra flooding of Red Locust outbreak areas by damming normal water outflow was attempted without notable success. Such measures will not always have the desired permanent effect, since the Red Locust and other species may move to different, favorable breeding areas if the usual ones become consistently unsuitable. Pre-seasonal irrigation, where possible, has been suggested for triggering Senegalese Grasshopper emergence when the hoppers will die for lack of food (Duranton, et al, 1982).

D.2.1.3 Biological control

Biological control is the action of predators, parasitoids, pathogens, and antagonists to suppress pest populations below population densities that are economically damaging. It includes both the action of the natural biota unmanipulated by man and the active augmentation, conservation, and introduction of entomophagous organisms.

D.2.1.3.1 Manipulation of Natural, Biotic Mortality Factors

Natural enemies reported by Greathead (1983) which were associated with the grasshopper and locust species which are the subject of this document have been listed in Appendix 9, Table 1. A fairly exhaustive list of microorganisms pathogenic to Acrididae is provided in Appendix 9, Table 2. The bird species observed to consume large numbers of locusts are listed in Appendix 9, Table 3. This literature serves as convincing evidence that the African locusts and grasshoppers have a rich array of natural enemies. At present, neither predators, parasitoids, nor pathogens are being utilized as active control tactics against any of the African locusts or grasshoppers. Likewise, the natural mortality that these acrididophagous species inflict is not being utilized in a knowledgeable manner so as to have predictable or consistent results.

Levels of mortality inflicted by beneficial arthropods cannot be predicted. The reason for this lack of predictability appears to lie in the relatively ephemeral nature of the grasshopper/locust habitat. Because of lack of knowledge regarding the population dynamics and ecology of natural enemies of locusts/grasshoppers, the use of natural control or manipulation of indigenous natural enemies must be relegated to the future.

D.2.1.3.2 Augmentation of Disease With Nolobait

One microorganism, Nosema locustae Canning, has been developed and registered under the name of Nolobait for use in the United States against the grasshopper pests of rangelands. A trial experiment with Nosema locustae was conducted on Santiago Island in Cape Verde and near Kaedi in Mauritania (Henry et al. 1985). This trial demonstrated that Nosema could be applied on wheat bran bait so as to infect the resident population of sedentary grasshoppers. However, no attempt was made to demonstrate population suppression effects. Its efficacy has not been demonstrated against African species of Acrididae.

D.2.2 Potentially Available Methods

D.2.2.1 Biological Control

Each of the three approaches to biological control hold potential in the case of the African locusts and grasshoppers, although all are not equally developed for implementation. The three approaches to biological control are; 1) importation of predators, parasitoids and pathogens from other continents (classical biological control), 2) enhancement of the effect of indigenous natural enemies, and 3) periodic release of commercially propagated species.

D.2.2.1.1 Importation of Natural Enemies

Grasshoppers and locusts are well established within their range, suggesting that they are not pests because of introductions into distant geographical locations devoid of their natural complement of predators, parasites and pathogens.

However, there is good reason to believe that entomophagous arthropods also might be obtained from other geographical locations and utilized against African grasshoppers.

D.2.2.1.2 Enhancement of Indigenous Natural Enemies

In order for the potential of biological control to be realized, it is necessary to develop a species by species understanding of the biologies and the ecological interactions with the physical environment. Many workers have observed high mortality levels due to natural enemies, but these have been isolated and/or unquantified observations. It is clear, however, that if such high mortalities do occur under some isolated conditions, that conditions which led to the high mortality might be recreated if knowledge of the causal factors were available.

Bare ground sought for oviposition and green plants required for food become abundant when man expands cultivation and grazing activities in his agricultural endeavors. For these reasons, the natural environmental constraints of locusts are often negated, such that natural enemy populations no longer can maintain their regulatory action. Grasshoppers have steep survival curves with high mortality early in life, such that differences of no more than 5% survival means the difference between plague status and non-pest status. This characteristic and the mobile nature of grasshoppers are not highly favorable for the maintenance of natural biological control. However, the potential is present and will only be developed by species-specific and localized study.

D.2.2.1.3 Periodic Release of Propagated Natural Enemies

D.2.2.1.3.1 Predators and Parasitoids

At present, there are no predators or parasitoids of African locusts or grasshoppers that are potentially available for use in population management systems.

D.2.2.1.3.2 Pathogens

Work with the Microsporidian, Nosema locustae Canning, has progressed to the point of its being registered in the United States and commercially available for field use. One field test has been conducted in Africa with limited success.

The epidemiology of a fungus, Entomophaga grylli, is being studied in the western United States (Carruthers and Soper, 1987). Several pathotypes (probably different species) of E. grylli have been collected from Asia, Africa, and the United States. Some of these pathotypes are highly virulent, giving high levels of mortality in 7 to 10 days following application. The major obstacles to the commercial development of E. grylli appears to be selection of appropriate pathotype(s) and development of mass propagation methodology. However, it is important to note that Soper and Humber (1982) suggest that E. grylli could be used presently in Africa. Infected adult grasshoppers can be easily collected, ground and prepared in a slurry for application to egg fields and other dense populations of grasshoppers. Such a practice might be implemented by an aggressive extension program to educate the rural populations in the proper methodology.

The viruses listed in Appendix 9. Table 2. are potentially available, but the expected time to commercial implementation probably exceeds 5 years. These viruses appear to have a wide host range, making them potentially usable as

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biological insecticides. The Cedaleus group viruses (OEV) was isolated from the Senegalese Grasshopper and other African grasshoppers.

D.2.2.1.3.2.1 Nosema locustae: Origin, Host Relationship, and Effect on Hosts

The host list for Nosema is extensive and probably not exhaustive but it has not been recovered from natural field populations of locusts or grasshoppers in Africa (Henry, et al. 1985a, b; Prinsloo, 1960) or reported in the African or Asian literature.

Nosema has been shown to reduce feeding of adult grasshoppers by 40% and reduce fecundity by 20 to 85%, depending upon the study and host species. Canning (1962b) showed that flight capability of infected African Migratory Locusts declined greatly from 14 to 41 days of age. The initial flight speed, cruising speed and duration of flight were reduced by about 25 to 50%.

Kinds of Mortality: There are two distinct kinds of mortality in grasshoppers infected by Nosema, and these are important to the understanding of its utility. There is major mortality occurring shortly after the initial infection, if hosts are infected as nymphs. Additional mortality occurs during the life of the adult grasshopper in the form of a steady time-dependent decline in survival of about 5% per day.

Transmission of Nosema locustae: The primary method of transmission of Nosema is by oral ingestion, primarily due to cannibalism of infected, dead or dying grasshoppers/locusts. Infective spores have been found in the frass of grasshoppers and it is assumed that the insect may also contact the spores by feeding on substances contaminated with the infected frass. There is no direct evidence that the parasitic protozoan is transmitted transovarially, although Henry and Oma (1982) conclude that the appearance of Nosema early in the season is due to transovarial transmission.

African Field Tests: A field trial of Nosema locustae has been conducted on Santiago Island in Cape Verde and near Kaedi in Mauritania against some of "the more sedentary grasshoppers". There was no attempt to determine population suppression resulting from the applications.

There was an additional study to determine the range of infectivity of the Nosema among other grasshoppers collected from the treatment area and fed the suspensions of the spores of Nosema.

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The data show 5.7% to 12.1% and 12.4% to 15.5% infection at 21 and 42 days post-application, respectively, in Cape Verde. In Mauritania, infection levels were 10% to 26% at 28 days post-application. Again, no data were provided to evaluate population suppression.

Of the grasshopper and locust species of concern, only the Senegalese Grasshopper was reported to be infected naturally from the field test area. However, seven other species of grasshoppers important in the test area were found to be infected. Of the species tested for susceptibility in the laboratory, three are subjects of this draft, and they are the Variegated Grasshopper, the Senegalese Grasshopper, and the Sudan Plague Locust.

D.2.2.1.3.2.2 Integration of Insecticides with Nosema locustae

Mussgnug and Henry (1979) found in laboratory experiments that malathion and Nosema could be used in combination. The combination provided additive, but not synergistic affects on mortality. They found that the LD50 for Nosema was 1.5 X 10 spores/grasshopper.

Subsequent tests have attempted to utilize Nosema in combination with carbaryl applied to wheat bran bait.

There does not appear to be any field data which indicate any significant benefit gained from adding Nosema to carbaryl on wheat bran baits. The majority of the publications show the effect on level of infection, but avoid or openly deny any implications with regard to population suppression. While the level of infection and the positive connection of the spore of Nosema as the cause of mortality is critical to the evaluation of the organism as a biocontrol agent, it is critical that some data be available which demonstrates efficacy in regard to population suppression. Problems associated with previous field tests (Onsager, 1987) need to be identified and avoided in future large scale field trials.

D.2.2.1.3.2.3 Timing of Applications

Research data show that the timing of applications of spores of Nosema locustae is critical to success. Henry (1971b), Henry, et al. (1973), and Henry and Oma (1974b) suggest that it is important to apply Nosema when most of the population is to the 3rd instar nymphs, so as to optimize mortality and infection level. The timing is well described by population models based on day-degree accumulations for North American grasshoppers, but such data are not available for African populations.

D.2.2.1.3.2.4 Prospects for Efficacious Use in Africa

The prospects for the efficacious use of Nosema locustae against African migratory locusts and grasshoppers remain in question. There have been no experiments or demonstrations which would support the conclusion that Nosema locustae can be used effectively to control African locusts and grasshoppers. Conversely, there also are no experiments or demonstrations which would suggest that this protozoan could not be utilized in an efficacious manner; there simply are no control data available. Data show that migratory locusts, namely the African Migratory Locust and the Desert Locust, support infection in laboratory colonies. Likewise, the Variegated and Senegal Grasshoppers and the Sudan Plague Locust are infected if fed suspensions of the N. locustae spores in the laboratory. However, successful infection does not allow one to conclude that there will be successful control.

D.2.2.2 Host plant resistance

Certain strains of crop plants are less preferred than others by grasshoppers and locusts, and enough genetic diversity and the requisite screening methods exist to select lines that are avoided when there is a choice of food (Hewitt and Blickenstaff, 1974; Hewitt and Berdahl, 1984). However, food preferences break down depending on the availability and succulence of vegetation.

Resistance through nonpreference would be most useful where noncrop plant cover offers a relatively attractive food source during the entire cropping season. In rainfed arid environments, planting nonpreferred crop varieties might favor survival of crop seedlings when early-season grasshopper numbers are high and surrounding vegetation provides an alternate food source. Irrigated desert crops and those still in the field when natural vegetation is dessicated or when hungry swarms descend from more arid areas will inevitably be attacked.

Traditional crop varieties often already possess antifeedant characteristics. Sorghum varieties show varying degrees of antifeedant defense against the African Migratory Locust and other pests at the seedling stage through the release of cyanide and phenolic acids by bitten leaves, and through repellent leaf wax components.

D.2.2.3 Antifeedants

Many natural plant substacles will protect crops from locust and grasshopper attack when extracted and applied to the foliage. Notable among these is azadirachtin, found in seeds and

other parts of neem, Azadirachta indica. Neem is an Asian tree now widely planted throughout the arid and semiarid tropics, including Sahelian reforestation tracts and city streets. It is reportedly left untouched by swarms of Desert Locust. Neem extracts are a proven antifeedant for the Variegated Grasshopper and the African Migratory Locust. In India, a spray of 0.1% neem kernel extract in water as well as ground neem seed mixed with dry soil and applied as a 1% dust both protected crops from Desert Locust attack. In Togo, researchers found that 250g crushed seed in 10:1 water will repel grasshoppers effectively when applied to crops every 3 weeks, or every 4-5 days in a severe infestation. The feasibility of neem insecticide manufacturing as a Sahel village industry is being investigated under an AID contract. Preliminary results show that water extracts prepared with simple local tools have a significant antifeedant effect on the grasshopper Kraussasria angulifera attacking sorghum seedlings (Radcliffe et al, 1987).

Neem and other antifeedants may work best when alternative food sources are available. Persistence of the antifeedant effect and the frequency of applications necessary will influence the practicality and economy of this method.

Neem may have adverse environmental effects:

- Not much is known about effects on nontarget species. It can exert antifeedant, growth regulatory, repellent, hormonal disruption or pesticidal action on inset larvae and adults, including beneficials.
- It has proven non-toxic to humans and other mammals thus far, but could be implicated in the occurrence of Reye's Syndrome.
- Neem seeds carry the fungus Aspergillus flavus, which in certain conditions produces carcinogenic aflatoxins, and is a particular concern in waste piles at preparation sites.
- Neem extracts can upset the ecological balance of organisms in rice paddies.

The potential advantages of azadirachtin or similar natural antifeedants when compared to broad-spectrum, synthetic pesticides include greater specificity, relative safety for consumers and applicators, low cost and the provision of work for villagers in areas of high unemployment.

D.2.2.4 Laser technology

"Sky Sweep," a recent Lockheed proposal, suggests a novel approach to locust swarm control. It outlines a three-phase feasibility/demonstration/production program for aircraft-based lasers that would circle a swarm, permanently grounding locusts by damaging their cuticle, internal organs, or

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sensory organs necessary for flight. If care were taken to insure that the laser beams do not hit nontarget species or objects, negative health and environmental impacts would be nil (J. Coble, personal communication, 1987).

D.3 Current Chemical Control Practices

D.3.1 Pesticide Applications

Properly used, chemical pesticides are essential elements in most pest management programs. With the use of approved chemical compounds, minimum dosage and proper application to targeted areas, pesticides should be viewed as a short-term response to the build up of a particular pest species to threshold levels which have been found to be economically damaging. Ground and aerial application techniques are especially useful for reasserting control after a pest outbreak has occurred, because they can be applied relatively quickly and produce rapid results.

Chemical and biological pesticides can be dispersed with a full range of equipment types. These could include the most primitive bag dusters, to hand crank dusters and sprayers, backpack sprayers and mist blowers; truck and tractor mounted sprayers, dusters, foggers; hand held spinning disc concentrate sprayers and up to sophisticated airplanes and helicopters of various sizes.

Vast locust swarms during outbreak conditions covering hundreds of square miles and their continuous movement creates a situation beyond the control of the best organized ground treatment programs. At this time only aerial application can check grasshopper/locust invasions.

D.3.1.1 Aerial Applications

There have been many noteworthy sizeable aerial control projects over the years, including the Onchocerciasis or river blindness program in West Africa with from 18,000 to 50,000 km of rivers being treated regularly by aircraft.

Early U.S. attempts at grasshopper control with poisoned bait were not too successful. However, from 1951 to 1963 with new insecticides and aerial application, in excess of six million hectares were treated. It has been estimated that if all grasshopper damage to rangeland in the eight northern Great Plains states was eliminated an additional 1,076,000 animal units could graze on the forage saved (F. Cowan, 1969).

In the 1950's ultra-low-volume application developed in

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England using a spinning cage called the Micronair. When compared with standard broom equipment in ultra-low-volume applications, the Micronair, with somewhat more uniform droplet size, gave no significant difference in the mortality rate (F.T. Cowan, 1969).

Ultra-low-volume sprays with a volume median diameter in the range of 60 to 150 microns can be used for contact and residual treatments against pests and diseases. They will penetrate foliage and are effective on flying insects. Preference should be given to non-volatile materials and flying at lower attitudes so that the droplets do not remain airborne long - creating excessive drift. However, this drift or "extended swath" can be used to advantage on locust spraying where wide swaths can cover broad areas and fill in flight paths that are not exact due to lack of guidance systems. An increase in aircraft efficiency through the increase in the hectare coverage that can be carried in the spray tank is probably the most important feature of ULV applications. Also, use of concentrate materials directly eliminates the need for mixing formulation in the field plus transport of dilution material such as water or oil.

It would be ideal if systems were available which would distribute particles or spray droplets all of a uniform size. Instead, a spectrum of particle sizes is produced by all actual aerial application equipment as well as ground equipment. As narrow a spectrum as is practical is generally desirable. The production of a number of large droplets in a spray in which smaller droplets are desired for good distribution is very wasteful of the chemical.

In selecting aircraft, flexibility is required in accordance with their spray performance. A combination of aircraft types may be required. Small airplanes would average a 2000 pound load. The medium size airplane would average near 3000 pound loads. Turbine modified aircraft would reach 4000 pound loads. Obviously with more load, the pilot can carry more fuel thereby being able to make longer ferry flights to spray sites.

There are some light twin engine spray aircraft also available. These larger ships have good dual capability of carrying people and supplies as well. There is good speed, range, and twin engine safety. Then, there are the larger aircraft up to the four engine transports - developed for spraying. They may be used to advantage in operations where the distances to be covered and strategic considerations clearly require aircraft with such long range capability and where the extent of the grasshopper infestation justifies their use.

Aerial Application Equipment (C. Hardy, 1987) lists all aircraft and their specifications, fixed-wing and rotary wing, along with dispersal equipment and supporting equipment.

As with the fixed wing aircraft, there are a variety of helicopter sizes and capabilities. The larger ones obviously are more expensive but accomplish more work for the cost. Thelargest number of helicopters in agricultural use are the smaller reciprocating engine models. For ULV spraying a number of these could accomplish a considerable volume of work. The large helicopters, considering on site loading, in ULV applications would compete quite favorably and economically with the larger airplanes.

An important factor when contracting aircraft for large variable size spray programs in Africa is that consideration be given to allowing a mix of categories. Every job will have a mix of requirements. The long ferry portion would need larger aircraft whereas smaller blocks closer to airstrips could be more economically handled by smaller aircraft. Helicopters have the capability of handling many areas faster and with short turn ability; areas with no airstrip capability, sensitive areas, and smaller cultivated fields. Helicopters for survey work in inaccessible and remote areas is a necessity.

Contracts should not specify only one type of aircraft. Competitively this will limit bidding to only a small number of operators who may have that specifc type of machine. Alternatively, an operator with a mix of smaller or medium sized aircraft could perhaps do the job more econorically.

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Figure D.4
Relationship between droplet size, number of droplets/cm ^{2} and drift distance in a wind of 5 kph when applying a liter/ha.

Droplet size (um)	Type of droplet	Fall time from 3 m (still air)	Number of droplets/cm when applying	Drift distance (wind speed 5 kph)
5	fog	66.0 min.	152,789	5.5 km
10		16.9 min.	19,099	1.4 km
20		4.2 min.	2,387	350.0 m
50		40.5 sec.	153	56.3 m
100	mist	10.9 sec.	19.1	15.1 m
200		4.2 sec.	2.4	5.8 m
500	lt. rain	1.7 sec.	0.298	2.3 m
1000	mod. rain	1.0 sec.	0.019	1.4 m

D.3.1.2 Ground Application

H. Lloyd (1959) in comparing aircraft versus ground equipment for controlling adult locusts made the following observations:

It was shown that insecticide dosages varied greatly in routine ground spraying, and that wasteful over-dosing occurred on a large scale. This arose partly because spraying operators did not check the characteristics of the machines or poison formulations that they used. In air-to-ground spraying work, aircraft output-rates were checked frequently, and ground parties were advised constantly of the repetition intervals they had to use to apply a given dosage. The work was more orderly and required a better division of labor among more highly skilled people and, consequently, aerial spraying was able to proceed more efficiently. Checks on dosages applied by aircraft indicated that they were very near the expected values. For ground spraying, it was difficult to formulate exact procedures for using machines under a wide variety of difficult circumstances and inefficiency was more likely to arise. Apart from this, the results of ground control were rarely checked because the operators had too much work to do. The greater speed and simplicity of aerial spraying allowed ground parties more time to make checks; mistakes or failure were discovered quickly so that the work could be repeated or improved.

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Properly calibrated and used, ground equipment can give as good control of grasshoppers and locusts as aerial equipment. It is not a matter of one replacing the other. The greater the arsenal, the better the chance for effective pest reductions.

Ground Equipment to be efficient for large area work, require ULV capability. In 1958 the "Sayer Exhaust Sprayer" was developed for use in Desert Locust control in Ethiopia. This device, still widely used in Africa, is attached to the exhaust of a motor vehicle similar to a fog generator and was the first successful machine to apply less than 1 pint per acre.

There are ground sprayers which also use the ULV principle and gain the same advantages as listed above. These include the hand carried battery powered spinning disc sprayer; the ULV backpack engine powered sprayer; and truck mounted mist blowers and exhaust sprayers.

There is no specific "universally acceptable" sprayer; The choice of the type of application equipment that will best suit the control situation depends on many factors:

- Size of area to be treated
- Characteristics of the area
- Frequency of application
- Speed required to treat the area
- Pesticide formulation to be used, including hazards
- Ease of use
- Initial Cost
- Operating Cost
- Durability
- Availability of maintenance & parts
- Training needed
- Exposure of applicators (Overholt, 1984)

Ease of use of a type of equipment is one of the most important factors from both physical and mental aspects.

D.3.1.3 Twenty Year Analysis of Pesticide Treatments in Africa

Historically there appears to have been treatment activities every year in some area of Africa (Figure D.5).

D.3.1.4 Assessment of the 1986-1987 Control Campaigns

In conformity with the strategy planned by FAO in late 1985, the 1986 campaign was executed in two phases. The first (May to August) was aimed at the application of insecticide dust and sprays by farmers and plant protection services. The second (September to October) was mainly based on larger-scale aerial operations.

Figure D.5

COUNTRY	YEAR 63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	No. of years country control	
Somalia				x	x				x	x			x		x						7	
Djibouti					x					x					x				x		4	
Ethiopia	x		x	x	x	x	x		x	x	x	x		x	x	x					13	Red Sea Coat difficult of access Tokar delta important
Sudan		x		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x		17	
Saudi Arabia		x	x		x	x	x		x	x	x	x	x	x	x	x	x	x	x		16	
Yemen AR			x		x	x	x		x	x	x	x	x	x	x				x		13	
PDR Yemen					x	x	x		x	x	x	x	x	x	x				x		11	
Egypt					x	x	x	x			x						x				6	
Oman													x								1	
U.A.E				x									x	x							3	
Kuwait													x								1	
Jordan					x																1	
Pakistan	x	x	x	x	x	x	x	x		x	x	x	x	x	x		x		x		11	
India		x	x		x	x	x	x			x	x	x	x	x				x		12	
Iran		x			x					x	x	x	x	x			x		x		9	
Afghanistan												x									2	
Nigeria					x																1	
Niger				x	x	x	x					x	x	x	x		x	x			11	
Mali				x	x	x	x	x				x		x	x		x	x			11	
Chad				x	x																12	
Mauritania			x	x		x	x	x				x	x					x			8	
Western Sahara						x		x													2	
Morocco						x	x		x			x	x	x							6	
Algeria				x	x	x	x						x	x			x	x			8	
Libya		x		x					x	x	x	x	x	x	x	x		x	x		9	
N. of countries doing control in any year	2	5	6	8	14	18	13	8	7	9	12	14	12	16	8	11	3	8	7	8		

the incidence of control operations in countries during the years 1963 to 1982

Egg pod surveys started very late in all countries. Farmer training began by mid-year in some countries and not at all in others. Pesticides were distributed to farmers prior to the rainy season, but in only a few countries was this done early enough and in large enough quantities to be of substantial value. repairs to equipment and vehicles were often done late.

Preparations for phase II were more difficult to organize, due to the extent of the infestations, the preparedness of staff for aerial operations, the inaccessibility of roads after rains, donors' diverging interventions, a lack of transport and communications, and the late ordering and arrival of equipment and pesticides.

1987 aerial operations were not always justified, necessary or economical. Over-dosage of pesticides was noticed in many ground and aerial operations. On the positive side, crop loss was generally small. With a few exceptions, air shipment of pesticides resulted in timely intervention. Negative factors were mainly; the insufficient follow-up to the infestations, the delay between infestation and intervention, the lack of organized radio communication, road communication and technicians experienced in logistics.

Separate areas to be treated within one country were sometimes subdivided and parceled out to various donors. This may have had administrative advantages, but aerial spraying on a more rational basis would have been more efficient, would have needed fewer ground support teams and would have concentrated efforts when and where most needed.

Helicopter and light aircraft proved to be very useful for survey and liaison. Aerial operations often suffered from poor ground support and poor living conditions for pilots. The efficiency and output of small aircraft were handicapped by the lack of sufficient landing strips, which sometimes were up to 100 kms away from each other.

D.3.1.5 Volume of work accomplished

Having listed the above constraints, it is quite noteworthy that the volume of ground and air treatment reached record levels never before recorded in Africa grasshopper control history. In the Sahelian countries alone, ground treatment reached 931,231 hectares and aerial treatment reached 3,722,122 hectares - or a total of 4,653,353 hectares.

Figure D.6 lists countries and hectares treated in each by ground and air in 1986 and 1987.

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Figure D.6

Total area controlled in the Sahelian countries in 1986.

	1986 Ground (ha)	1987	1986 Aerial (ha)	1987	1986 Total (ha)	1987
Mauritania	100,000	22,365	193,000	225,200	293,000	247,565
Senegal	300,000	36,556	1,159,800	134,872	1,459,800	171,428
Gambia	11,500	12,104	247,710	41,940	259,210	55,044
Mali	68,000	2,329	484,000	166,866	552,000	169,195
Burkina Faso	20,893		211,140		232,033	9,062
Chad	25,222	42,428	143,700	212,555	186,922	254,983
Niger	151,414	75,420	270,505	230,834	421,919	306,254
Cameroon		54,000				54,000
Guinea Bissau		9,000				9,000
Nigeri					60,000	60,000
	677,029	254,202	2,709,855	1,012,267	3,403,884	1,322,531

The 1987 infestations were in general of less significance than in 1986 and their intensity varied considerably from one place to another. By comparing the 1.3 million hectares, sprayed in 1987 with the 3.4 million hectares of 1986, it reveals the more limited scale of the 1987 control campaign.

The FAO 1987 Evaluation indicates that the experience gained during 1986 has been of considerable help in improving the preparation and effectiveness of control operations during the 1987 emergency campaign. In particular, farmers had in general been made better aware of the problems to be solved and instructed on how to carry out the pest control operations.

All countries in 1987 reported that the control operation, both on the ground and by air, had generally led to satisfactory results. Grasshopper mortalities reported varied from 70 to 90%.

D.3.1.6 Logistical guidelines for mobilizing manpower and equipment

A principal step in the organization process to mount an effective treatment program is the mobilization of the required logistics. Facilities and operational support items which are readily available in countries like the US are just not available in Africa. Therefore, considerable advance planning is required.

Even the best logistics can fall short in situations as exist in Ethiopia where lack of roads and other disrupting conditions create a serious transportation problem. In 1987 the Canadians supplied two large helicopters for the purpose of airlifting pesticides and supplies to inaccessible areas. The International Red Cross supplied planes for the same purposes as well as for spraying. The Desert Locust Control Organization for East Africa supplied aircraft for spraying and surveying in northern areas. Poland supplied a relief helicopter squadron. Yet, in spite of detailed planning and support, escapes from control occurred. Drought conditions may have been the major contribution in maintaining the population within reasonable bounds.

D.3.1.7 Aircraft operations guidelines

Each aspect of an aerial spraying operation must be understood and the operation controlled so as to secure maximum productivity at minimum cost. Organization requires the classification of the various elements of activity involved into groups of functions. Optimization of these variables is a matter of planning, training of staff, and of close supervision of the execution of all stages of the control action plan. It must be

accepted that in the end, any program is dependent on people. The pilots are the key personnel in an aerial spraying operation without whom the operators' objectives cannot be fulfilled. Other personnel, however essential, are there to assist the pilot and provide the facilities he requires.

All the prior preparations, plans of action, logistical support, pesticide placement, manpower and equipment and training that go into the strategies of grasshopper/locust control are a build-up for the moment when the aircraft or the ground sprayer actually starts spraying.

Pilots have to be top professionals capable of expert function in the harsh environment of Africa. To this end any assistance from research for more effective pesticides, techniques and improved equipment is very important. Details such as swath width, height of flight, marking or guidance of flight paths, adequate communications, spray droplet assessment and proper calibration are but a few of the items that need to be studied to give the pilot the best information that technology can provide.

One operational detail which frequently came up for discussion in the field was that of swath width. There are some variations in aerial spraying techniques as practised by agricultural aviation operators from different countries. No fixed guidelines exist in reference to the best method to spray using an ULV dosage. The effective swath width should not be confused with the total swath width. The total swath is the width from one end of the chemical deposit on the ground to the other. However, swaths must be overlapped to obtain uniform and effective distribution of the pesticide. The effective swath width is the width from the start of the last overlapped swath to the start of the next one.

In the United States, the general procedure is to use a narrower swath for light aircraft such as 35 to 40 meters for ULV work. This allows for a build up of deposit on sequential passes and more accurately covers the area in case the pilot does deviate from the swath line. Without flagging, or some other system of guidance it is difficult for pilots to apply an accurate flight line without some deviation.

The other philosophy of ULV spraying is to use the drift effect. This takes advantage of down wind swath displacement. With a cross wind, the small drops will drift some distance and sequential passes will drift the same amount. Calibration will need to allow for a higher output of pesticide to cover the wider swath. Up to 100 meters is sometimes used. Variation in wind movement could make this a less precise technique. However, under the average conditions and the years that this technique

has been used in Africa, there appears to be adequate control achieved according to most reports.

The Loran "C" network does not cover the Sahel of Africa. The Omega Navigation System is too bulky for small aircraft but was used to advantage with DC7 aircraft in navigating long distances to spray block sites. Poor maps and lack of landmarks caused pilots of small aircraft problems in flying from place to place and in locating their spray blocks and their starting points.

A possible solution to these problems is utilizing VHF direction finders. This is a homing device that is wired into the aircraft VHF radio, enabling the pilot to fly directly to the source of a VHF transmission. The transmitters can be the portable VHF radios used to communicate with the aircraft or an emergency locator transmitter set up to transmit on a frequency other than the 121.5 emergency frequency.

Aircraft working in Africa should be required to have an Emergency Locater Transmitter (ELT) installed. If an aircraft goes down in Africa in the summer, it will need to be found quickly.

There may also be the possibility of adapting the standard HSI (Horizontal Situation Indicator) instrument which ties into a gyro compass to indicate 180 ^{o} back and forth passes once the first run is established.

The use of spotter aircraft, which could be a locally available light two seater airplane is another viable solution. A low cost smoke puffer could be installed on the spotter planes which would give long distance visibility plus show the wind drift.

A functional system in Africa has been the use of several jeeps in line at certain distances apart. The drivers have used mirrors successfully to flash at the pilot. If it is an overcast day, a strong spotlight hooked to the cigarette lighter can be seen some distance. For spacing the swath there are counters available which connect to the wheel or axle of the vehicle. There also is an "automatic flagger", a piece of equipment attached to the wing root while the pilot operates a solenoid valve to pop out an accordion-folded strip of paper weighted with a cardboard support piece. This may be visible for some distance in the desert.

Accurate calibration of the aircraft is vital for effective spraying. Maintaining an accurate calibration during operations would be greatly improved if there is installed on the aircraft a monitoring system. This transducer engineered unit

reads liters per hectare, liter per pass, number of passes, time per pass, and total spraying time.

Although all operators may not have this equipment, the minimum requirement is a timer which times the actual spraying time. The pilot can interpolate output of liters per minute and check that the flow rate is the same. This also depends upon use of a meter at the loading site or other means so the pilot knows the exact number of gallons or liters delivered into each aircraft load.

There are two compelling reasons for proper application of pesticide. First, the material is expensive and improper use is costly; it may either waste material as in the case of overapplication, or fail to control the pest problem due to poor timing, maldistribution, or inadequate dosage. Secondly, improper or careless use of the material can cause human exposure, destruction or injury to beneficial or economically important organisms or unwanted environmental contamination (Matthews, 1979).

Handling and application of pesticides in other than closed systems almost inevitably results in exposure of the worker. Recent studies have shown that exposure is greatest for those applying chemicals with knapsack sprayers as compared to ground machine application and aerial application. The level of exposure can be minimized, however, through choice of proper formulations of chemical, correct use of the equipment and the use of protective clothing (Freed, 1979).

Deutsch (1987) states, "the current practice of using dust bags certainly impresses us (as) being a very high-risk approach. Maybe there are no (cost effective) alternatives (currently) available. In that case, the AID program could make a major contribution by developing a safer procedure."

D.3.2. Timing of Treatment

D.3.2.1 Developmental Stage of Insect

To terminate a locust or grasshopper upsurge it is necessary to eliminate or to reduce to a low level the upsurge population. The best strategy is not simply a matter of using an effective method of control against infestations in existence at the time; it is a question of deciding at which location and at which stage of an upsurge effective control can be mounted most economically (Symmons, 1977) with the least possible environmental impact. No one single approach or timing can thus be considered a "cure all" for every occasion. A broad range of alternative methods is often required, based to a large extent on the biology and behavior or the target pest(s) and the locale in

which they may be found. For instance,

a. Locusts and grasshoppers are subject to the highest natural mortality in the first three instars, up to 90% or more in many instances. Control should thus be withheld until at least the third instar, even though this may substantially reduce the time available for treatment prior to egg laying.
b. When a locust population becomes gregarious the hoppers band together while the area infested and needing treatment decreases dramatically in spite of the fact that the total number of locusts per given area will increase.
c. The area occupied by gregarious swarming locusts when settled is from 3 to 10 times less than the area occupied when they are flying.

D.3.2.2 Population Growth and Gregarization

Mathys (1986) estimated that in the Mourdiah area of Mali, where grasshopper densities in 1985 were 40 to 60 per square meter, the population would increase by 4 to 7 times when hatch occurred in the spring of 1987 (287 per square meter). His calculations were based on an average of 23 egg pods of 25 eggs each and 50% mortality of the eggs by predation and parasitization.

Egg surveys conducted in Mali in the spring of 1987 indicated a loss by predation and parasitization of 45% of diapausing eggs of the Senegalese Grasshopper. Assuming a 1:1 male-female ratio and a 90% mortality in the early instars (not considered by Mathys) the F1 1987 adult populations would be about one-fourth larger than the 1986 parent population. Eggs laid by the F1 and F2 generation are not normally subject to diapause. Predation and parasitization are reduced due to the short time frame between laying and hatch. So assuming a continued 90% mortality in the early instars, the F3 generation could be about 12 times that of the 1986 parent population.

Hemming (1974) calculated that it was theoretically possible for Desert Locusts to multiply 100 times in a single generation. However, such multiplication rates are never even approached since enormous mortality due to natural causes always occurs; but favorable breeding conditions coupled with only small reduction in natural mortality can quickly build a recession population to plague status.

D.3.2.3 Phenological Stage of Host Plants

The treatment of the early generations of grasshoppers on newly planted crops should be done by the farmers. They

should be able to detect these localized populations. The farming community should be trained in the management of grasshopper populations. The Crop Protection Service during the entire cropping season must have a sufficient number of trained teams in the field of grasshopper survey and intervention. These treatment decisions should be based on thresholds that have been determined by experts prior to the season.

One target insect, the Senegalese grasshopper is migratory and reproduces in range grasses, its favored habitat. As the range grasses dry and become less attractive as a food source, these insects move into food crops to feed. One of the primary staple food crops for west Africa is millet. Grasshoppers moving from grasslands attack millet when it is in the flowering stage, totally destroying the food production of each plant.

At the meeting on the assessment of the 1986 Sahel grasshopper control campaign held in Rome, Italy, December 3-5, 1986, the FAO proposed a two phased program for 1987, based on the two most vulnerable phenological stages of millet, the crop most subject to economic damage, the first at the seedling stage and the second at the milky-grain stage.

Phase I would largely consist of farmer applications of pesticides to protect their newly emerged seedlings.

The initial threat to the seedlings eases off later in the season as the millet plants increase in size, at which time they can withstand considerable amounts of leaf damage, and pressure on the crop diminishes as the grasshoppers turn to alternate sources of food with development of the annual vegetation. (Popov, 1984).

Phase II was projected as a much more widespread operation against nymphs and adults of the second, third and possibly fourth generations when the millet heads are in the milky-grain stage of growth. When this coincides with a large part of the adult population they feed preferentially on the millet heads. The severest damage to millet generally occurs during this period.

The committee on strategy appointed at the Rome meeting pointed out that the two phase approach was not good strategy. Without control of economic populations both within and outside cropland in Phase I, a pyramiding population and greatly expanded area of infestation would likely occur by Phase 2 necessitating very widespread control to protect the maturing crops and pasturelands and to reduce the next years potential population. The committee recommended that to the extent possible, maximum effort be placed on early intervention, but recognized that some

late intervention might be necessary due to a lack of adequate manpower, equipment and other resources in many of the Sahel nations. Despite this recommendation many nations continued with the two phase control approach. Nations such as Senegal, which subscribed to the early intervention strategy, were able to forego late season treatment.

D.3.3 Treatment strategies in locust control

Strategies for locust control are aimed at plague prevention. A locust plague is defined as a period when many countries are infested by successive generations of gregarious locusts. Plagues alternate with recessions when there are limited or no gregarious populations. Recessions are punctuated by outbreaks, or local increases in population density accompanied by gregarization which may result in the production of hopper bands and swarms; outbreaks may lead to plague upsurges when populations increase and gregarize on a larger scale and over several generatioons (Waloff, 1966).

The capacity for locusts to migrate is one of their most important characteristics. Swarms usually migrate as discrete bodies leaving remarkably few stragglers behind.

The suppression of a loucst population must involve the manipulation of those limiting factors in the annual and daily cycle of its acivities. The most evident limiting factor of the African Migratory Locust in Mali is the population movement of solitary locusts at the end of the rainy season to the flood plains after the flood waters have receded. This enables the locusts not only to survive, but to breed during the dry season when conditions elsewhere are unfavorable. Therefore, the most efficient means of control is to drastically reduce the carry over of residual dry season populations before the start of the first rains (Alomenu, 1985).

The main difficulties for control of the Desert Locust arise from (1) the great probability that at any one time there will be adults in all phases; (2) the very unstable environment in the recession area; (3) the resultant continual fluctuations in numbers in, and density and phase of, recession populations; (4) the large size of the recession area and the emptiness and geographical remoteness of much of the terrain in which outbreaks and plague upsurges occur (Hemming, Popov, et al, 1979). Thus, to be most effective, strategies must take advantage of situations in which populations are most likely to be concentrated. This holds true not only for the Desert Locust, but for other locusts as well.

Rainey (1963) suggested that since Desert Locust swarms are brought into and remain within areas of low level wind

convergence, they can be trapped in valleys such as the Souss of Morocco because low temperatures over the mountains prevent them from escaping. Therefore, he reasoned that the ideal strategy might be to concentrate resources in a few areas and wait for the swarms to arrive.

Data collected between June and August, 1961, (Joyce, 1979) indicate that in zones of low level wind convergence Desert Locusts from much larger surrounding areas are trapped and accumulate. Such an area was found to develop in Northern Somalia and could drain breeding areas covering some 500,000 sq. kms. in the Somali peninsula and adjacent areas of Ethiopia and Southern Arabia and concentrate them in an area of only 8,000 sq. kms.

During the summer months the Desert Locust breeding area extends in a wide band across the Sahel of Africa from the Atlantic Ocean to the Red Sea. In west Africa in late summer and fall the immature adult locusts leave the summer breeding area and migrate northward to Morocco and Algeria where they become concentrated and trapped by the Atlas Mountains.

In Eastern Africa during the late summer and fall, migration is easterly to the Red Sea Coast. During this migration the swarms must ascend the western slopes of the northern Ethiopian highlands (Elev. 7,000-11,000 ft.). During prolonged periods of cold weather the swarms become immobile or are able to move only short distances during the warmer parts of the day. Sayer and Rainey suggested that most swarms which resulted from breeding in the eastern Africa portion of the summer breeding area would concentrate in a confined area along these slopes and thus make ideal control targets. Any swarms that escaped control by going north around the mountains would again be trapped in the winter breeding area of the western Red Sea Coast.

Swarms entering the winter breeding area on the Tihama of Saudi Arabia on the eastern side of the Red Sea would be trapped by the escarpment (elev. 7,000-8,000 feet) a few miles inland. The progeny of these swarms would be expected to move north in the spring with the northerly progression of the Red Sea convergence. Sayer speculated that when they reached Lith where the escarpment bends to meet the sea the locusts would pile up like automobiles at a traffic light (Figure D.7).

Sayer and Cavin, (1967) proposed an action plan for eastern Africa and Arabia which concentrated efforts in the northern Ethiopian Highlands and the coastal areas on each side of the Red Sea. AID and DLCOEA in eastern Africa and the US Air Force operating from Taif, Saudi Arabia implemented this strategy

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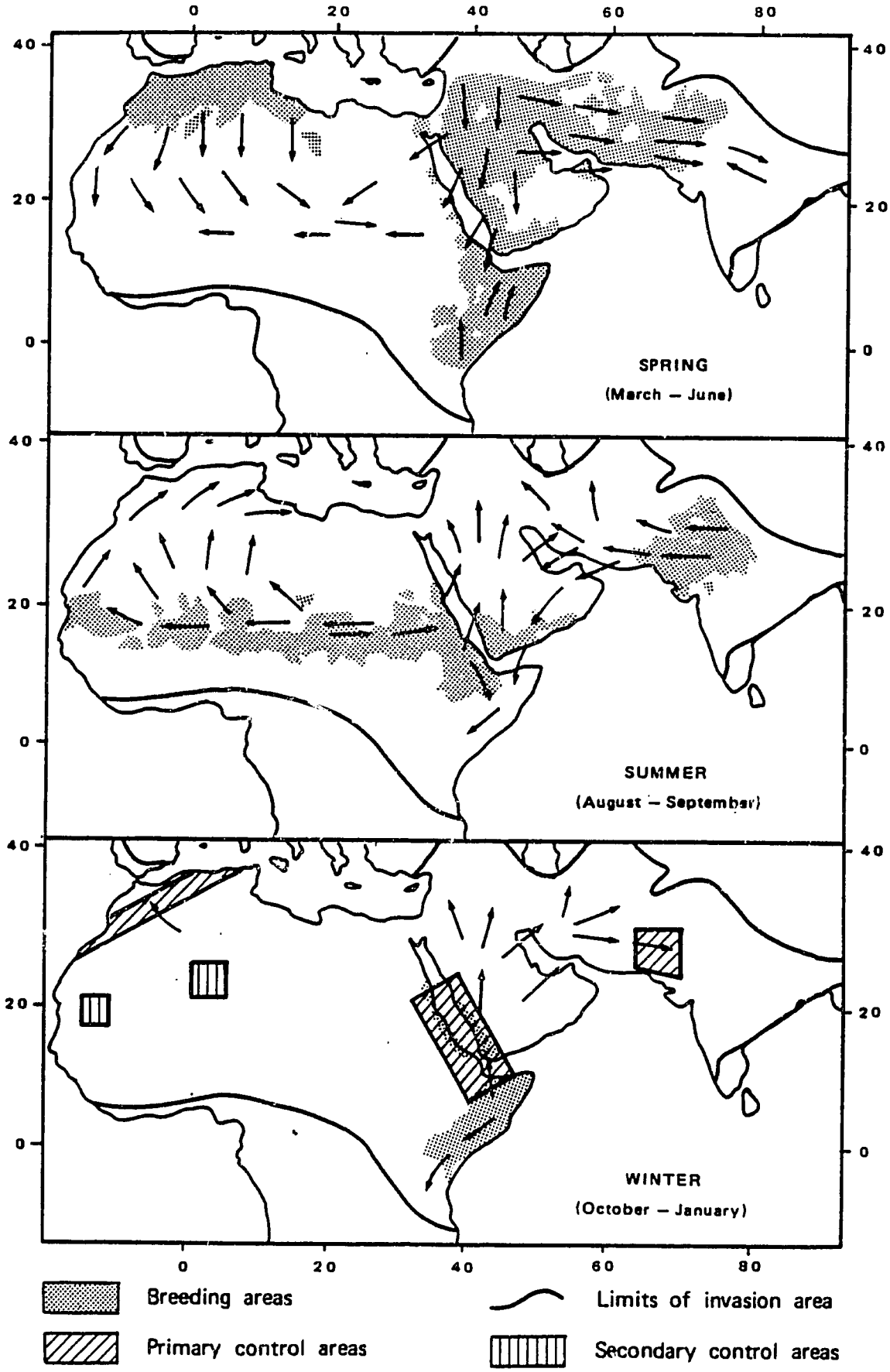

Figure D.7 Desert Locust breeding and control areas. The illustration shows the spring, summer and winter breeding areas of the Desert Locust and the major migration directions of the swarms produced in them, and the locations of the major control areas.

successfully. Eastern Africa and the Arabian Peninsula were soon free of gregarious locust swarms.

Swarms resulting from gregarious breeding in the summer breeding areas of west Africa moved north to the Atlas Mountains of Morocco where they were controlled. Gregarious breeding on a smaller scale also occurred in Pakistan and India. These were controlled at the eastern terminus of their migration route in the Rajistan Desert of India.

For the first time in history Desert Locust plague prevention appears to have been accomplished.

During the mid-1970's a new gregarious upsurge, which threatened to reach plague proportions, developed in eastern Africa. Again, by concentrating efforts in the northern Ethiopian highlands the problem was quickly returned to recession status.

Desert Locust upsurges can initiate from a number of locations, several of which are critical wildlife habitats. Plague prevention or control appears to hinge, however, on concerted action in the winter breeding areas, particularly the area surrounding the Red Sea where as many as six generations can occur yearly.

Hopper bands of the African Migratory Locust occur most frequently in the cool dry season as the floods recede. Hopper bands produced at that time rarely give rise to swarms, but control is most successful against hopper bands, and the use of pesticides is minimized.

Since the middle Niger is an environmentally sensitive area every effort should be made to hold pesticide applications to a minimum. An analysis is required to determine the benefits derived from control of hopper bands at this time versus hoppers of other generation and the damage to the environment that may occur at different periods of the year.

Barrier spraying hopper band is by far the most economical method of halting an upsurge of locusts, since hopper bands are much less mobile than swarms and the infested area is relatively stationary for weeks at a time.

D.3.3.1 Hopper bands

In a year of heavy infestation, the numbers of locust hopper bands in outbreak areas might be on the order of 100,000. It is not feasible to locate and mark each hopper band from the ground. For the control of hopper bands, two systems are utilized.

a. Pesticide applied directly to the individual bands: This technique is applicable only if the bands are readily visible such as in non-vegetated desert areas or when the hopper are roosting or resting at the tops of the vegetation. Only the area occupied by the band needs treatment, allowing for small areas of treatment surrounded by much larger untreated areas. Both dusts and sprays applied by air or ground are applicable.
b. Barrier Treatment utilizing a persistent stomach poison: This technique is undoubtedly the most efficient method of hopper band control. Either sprayed strips of vegetation or bait strips can be utilized. Common bait materials are wheat or rice bran, sometimes mixed with sawdust, rice and peanut hulls. The spacing of barrier strips is determined by the persistency of the pesticide used, distance of anticipated hopper band movement each day based on average hopper instar and whether moulting is or is not occurring. The hoppers do not feed for a day or two before and after moulting.

With discontinuance, in most cases, of the use of the persistent chlorinated hydrocarbon pesticides the effectiveness of barrier spraying may have been reduced. Barrier treatment with bait uses the smallest quantity of pesticide. Costs of mixing, transport and application are greater than with the use of sprays, but by utilizing locally produced agricultural products as the bait, costs become competitive with other methods.

In tests in the US northern great plains carbaryl (Sevin-4-Oil) diluted 4:1 with diesel fuel has provided residuals up to 21 days. This would be adequate for barrier sprays for hopper band control. However, considering the higher temperatures that are present in most areas where barrier sprays are applicable for Desert Locust, Brown Locust and African Migratory Locust hopper band control the residual longevity could be much less and needs evaluation. Several others on the FAO list of suggested insecticides with evidence of extended residual action also require evaluation.

D.3.3.2 Swarms in flight

Flying locust swarms are classified as either stratiform or cumuliform (Waloff and Rainey, 1951). Locust densities in cumuliform swarms may be less than in stratiform swarms, but the densities in different parts of the swarm are subject to rapid fluctuation. The mean ratio of the increase in areas of flying swarms to their respective areas when settled is about 3 times (Gunn and Perry, 1948). Densities of locusts within a swarm vary from .002-14m. The higher densities are in stratiform swarms.

Theoretically, flying swarm spraying appears highly efficient as based on calculations by MacCuaig and Yeates, 1972. In practice, over-dosing often occurs due to the continuous fluctuation in swarm size and density, and little or no control can be maintained as to where the pesticide not picked up by the swarm will eventually come to earth.

Flying swarm spraying is particularly dangerous. The pilots' vision is blocked by locusts smashing against the aircraft canopy. Aircraft oil coolers and air intakes can be plugged with locusts and cause excessive engine heating. DLCOEA, has modified its aircraft to compensate for some of these deficiencies, but most locust control organizations have abandoned flying swarm spraying.

For flying swarm control contact insecticides which have relatively quick knock-down capabilities and only limited residual action should be used. ULV formulations with low evaporation rates are particularly well suited for flying swarm control as the small droplets must be suspended in the air for long periods of time. Highly volatile and long residual insecticides are inappropriate, as are emulsifiable concentrate and wettable powders as the water evaporates too quickly.

The advantage of flying swarm spraying is that treatment can often continue throughout the day. With large swarms it is not always possible to kill them outright, but treatment may enable the breakup into several smaller but more manageable swarms. Breakup can also do just the opposite. Numerous small swarms are harder to keep track of than a single large swarm, particularly in mountainous terrain.

Detection of flying locust swarms is principally by visual observation by ground survey teams which then guide the spray aircraft to the target. Observation flights by aircraft flying the leading edge of principal frontal systems during the warmer daylight hours has also proven to be a useful detection technique, as locusts move to areas of low level wind convergence often the result of frontal system activity.

D.3.3.3 Settled swarms

Locust densities in settled (roosting) swarms are much higher than those in flying swarms. Swarms settled on the ground have densities in the range of 160 to 370 meters. On bushes, densities reach 1,000m and on tree trunks densities are up to 1,500m (Gunn and Perry, 1948). The insecticide dose received by a settled swarm will vary with the amount of drift and the amount of shielding of individual locusts by other locusts and the vegetation. Shielding often necessitates repeat application on settled swarms, but their high concentration, within very limited

areas favors settled swarm control.

In warm climates insecticides used for flying swarms are applicable to settled swarm control. Under extreme heat conditions, swarms usually do not settle before dark and can therefore only be treated in the early morning hours before flight begins. On the other hand, in colder climates, particularly the higher mountainous areas, temperatures restrict locust movement to only short periods during the day, or not at all.

Feeding by settled swarms in warm areas is mostly at night so a stomach poison has little or no applicability since swarms will fly from early morning until after dark. In colder environments, however, feeding begins when temperatures rise to the point where activity occurs, which is usually mid-day to late afternoon, thus some residual activity is desirable.

D.3.4 Treatment strategies in grasshopper control

Unlike locusts, grasshoppers do not have a recessional state, with localized areas known to have produced outbreaks and identifiable swarms leaving those outbreak areas.

Popov (1984) lists grasshoppers as a chronic pest problem throughout the Sahel. All crops may be attacked, although their vulnerability differs. Some areas have a higher frequency and level of infestation than others. The size of grasshopper populations is subject to large variations principally in response to weather conditions and spatio-temporal variation in rainfall, and their attacks on crops may vary from negligible to total devastations. But some damage occurs in practically every year and on the whole grasshoppers have a large share in the pre-harvest losses estimated at some 30% through the Sahel.

In Africa the principal difficulty of grasshopper control is the sheer size of the problem. The principal pest species the Senegalese grasshopper alone affects all the potential millet growing areas, associated fallowlands, wastelands and adjacent pastures and beyond them into the more arid zone to the north. The affected areas comprise about 70% of the total terrain in the Sahelian and Sudanian zones situated between the 200 and 10000 mm isohyets. The other grasshopper species, some of which overlap with the Senegalese grasshopper, contribute to the problem, particularly in the drier and wetter ecosystems including the irrigated crops in the major river basins.

A successful control strategy depends upon efficient survey to locate and delimit potentially dangerous populations.

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Given the mobility of the Senegalese grasshopper and the often sporadic development of economic populations, the survey problems are considerable.

With the Senegalese grasshopper, overlapping generations will likely occur. As adults of the first generation in the south move north with the northerly progression of the Inter-tropical Convergence zone, they may lay eggs in areas where first generation eggs have not yet hatched or have just begun to hatch. Treatment without taking this into consideration may result in the necessity for retreatment as occurred in Senegal in 1986. Similar situations will occur when a number of species occupy the same area. The biology of each must be considered so that to the extent possible one treatment will suffice for all.

D.3.4.1 Early intervention

Effective early season intervention relies on an efficient adult and oviposition site survey at the end of the prior season, since the best time for conducting control operations against the Senegalese grasshopper is at the beginning of the rainy season with nymphs of the first generation as the main target. Population densities and areas of infestation are generally the most restricted at this time. The rationale for control at this time is as follows:

a. The majority of oviposition sites are associated with shifting millet cultivations and are located either inside the fields or in fallows and pastures in their proximity.
b. The emergence of the hopper coincides with the particularly vulnerable seedling stage of millet.
c. The majority of first generation hatching, 70%, is in the southern part of the distribution belt, 750 to 1000 mm isohyets.
d. Early control will generally effectively contribute to reducing later season populations and crop damage.
e. Logistics of control operations are generally much easier during the dry than the wet season.
f. Control is not hampered by the heavy and frequent later season rains and denser vegetation (Popov, 1984 and GERDAT, 1982).

The scale of infestation is influenced by egg survival, more than half of which could be destroyed by natural enemies and the effect of rainfall. A majority of eggs will hatch following rains in excess of 25-30 mm. Rains of this magnitude also encourage farmers to plant their millet. This can result in early and disastrous attack on the vulnerable seedlings.

To assure an efficient and effective operation, control measures must be taken before migration occurs. This

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necessitates control while the grasshoppers are still in the nymphal stage. Hatching occurs within about 15 days of the start of summer rains. Damage to the crops is usually most serious in the seedling stage, often necessitating multiple resowing.

The general principles of control methods and strategies for the Senegalese grasshoppers are similar to other species. As a rule, each major species or complex of species should be considered in its own right in planning control operations and selecting the method most suitable to particular circumstances (Popov, 1979).

Cavin (1987b) lists a three pronged control approach against the initial generation.

- o Treatment by farmers to their own infested crops using hand applied dusts, liquid spray, and baiting. Multiple applications may be required as the season progressses.
- o Baits sprays or dusts to be applied by Crop Protection Services power blowers to field boundaries and accessible forest and grassland.
- o Aircraft spraying to be used in inaccessible areas including grasslands and forest lands. In case of emergency, this could be targeted to assist on cropland as well.

For the new generation nymphs of the Senegalese grasshopper that develop at the northern terminus of migration, the use of aircraft control may be the only choice. The area of infestation is vast with few roads, and those roads that exist often become impassable with rains. The window of opportunity is small. Personnel, equipment, and insecticides must be in place well in advance of control initiation. With even minimal delay, the opportunity for control may be lost until the coming year.

D.3.4.2 Non-cultivated areas

The Sahelian farmer has neither the facilities nor the time or interest to intervene beyond the immediate surrounding of his crop. This means that monitoring and control of the vast uncultivated areas will have to be done by other means. Little reliance can be placed on herdsmen who have no interest in control measures so it is up to plant protection and extension services to cover this activity. This task is normally entrusted to mobile ground survey and control teams with experienced supervisors and communication equipment. Some control materials may be carried during surveys or brought from the operations base as and when the need arises. Under heavy infestation there will be a shortage of ground teams and trained personnel. Large parts of an area may remain unsurveyed and many important infestations

remain undetected (FAO, 1986j).

As a consequence, the helicopter has proved to be a very efficient and versatile tool. When accompanied by an observer with a good knowledge of the area and of grasshopper ecology, they could adequately evaluate the situation and detect the main targets of infestations over an area of one million hectares in about ten flying hours.

Short residual insecticides such as malathion and fenitrothion ULV formulations have provided good control results in most instances where non-cultivated areas required treatment. Most Sahelian nations' Crop Protection Services have a limited amount of mechanized or exhaust nozzle ULV application equipment mounted on motor transport. Few, however, have access to aircraft, essential for insecticide application to remote or large, generally infested areas containing economic populations.

D.3.4.3 Cultivated areas

Few grasshoppers use the intensely cultivated fields as natural habitats, but many breed in fallow fields, and land abandoned after cultivation. Cultivated areas are invaded when other food sources dry up or disappear. Clean fields appear to be less attractive to grasshoppers than weedy ones. One large field is less vulnerable than several small scattered ones.

The treatment of the early generations of grasshoppers on newly planted crops should be done by the farmers. They should be able to detect these localized populations. The farming community should be trained in the management of grasshopper populations. The Crop Protection Service during the entire cropping season must have a sufficient number of trained teams in the field for grasshopper survey and intervention is necessary. These treatment decisions should be based on threshold levels.

In normal years farmers are able to protect their crops themselves by applying poison baits to their field margins, the removal of vegetation in their field margins and spraying or dusting their fields by hand. Some farmers have had good results with ground neem seeds used as a grasshopper repellant.

During the initial stages of a grasshopper upsurge, mechanized ground applicating equipment applying ULV insecticide formulations may be required, applied by trained crop protection service employees or specially trained farmers.

In outbreak situations such as has occurred during 1986-87, the farmer and most African and Middle East nations crop protection services are ill equipped to handle the situation and

outside assistance has been necessary. Swarming grasshoppers move into fields overnight in large numbers and severe damage occurs prior to control efforts being mounted. Young nymphs are highly mobile. They can traverse large expanses of bare ground, or ground devoid of suitable food-plants, covering distances in excess of 100 meters from their hatching sites, within the first 48-72 hours of their life. Given the relatively open nature of the terrain at the end of the dry season and the vulnerability of young nymphs, control conditions are at their best. (Popov, 1979) Thus, in outbreak conditions the only solution is the treatment of grassland breeding areas which are often well removed from cropland areas. Cooperation between nations is often necessary since grasshoppers such as the Senegalese grasshopper may cross two or more nations boundaries in their downwind migrations following the movement of the ITCZ.

Baits could be an important and selective way of applying insecticides for grasshoppers and locusts. In tests by Henry and Onsager (1982) in the U.S., mortality was measured to be 65.7% using 1.96% carbaryl on 1.68 kg. wheat bran bait/ha. They concluded that at the test rates a grasshopper must consume 7 treated flakes to cause death. So the density of grasshoppers/locusts per meter will determine the rate of bait application. As some species do not feed on bran it is necessary to evaluate effects on a species by species basis.

Popov (1979) states that poisoned bait tends to be regarded as old-fashioned. Yet in some situations, it can be more effective than other methods.

D.4 Review of Insecticides Currently Used or Under Consideration

D.4.1 Insecticide registration status

The current registration status of the 13 insecticides reviewed in the EA is summarized in Figure D.8 (USEPA Registration Status) and Figure D.9 (Registration Status in Selected Developed Countries).

D.4.2 Effectiveness of insecticides for the control of locusts and grasshoppers

Effectiveness is only one criterion for deciding which insecticides and formulations to use in a locust and grasshopper control program. Other things to be considered are environmental impacts, costs, storage characteristics, target species and stage(s), land use and habitat type, application strategy and patterns, and logistics. Detailed information on properties of the thirteen insecticides is given in Appendix 10.

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All of these chemicals are quite toxic to grasshoppers and locusts, but at different dosages and with different formulations, application characteristics, action times, and residual effects. Hence, the use patterns of those employed widely in locust/grasshopper control differ. Launois, et al propose that the use of dusts be discontinued because in general they are more expensive, less effective and more polluting than ULV liquids.

The LD50 of an insecticide (the dosage at which 50% of the target insects will be killed) varies between target species and also with the insects' life stage, younger stages usually being more vulnerable. No insecticide with an LD50 higher than about 400 micrograms per gram has found large scale acceptance.

The effective dose changes according to the amount of vegetation and the speed of action necessary. If rapid, complete knockdown is desired, a relatively high dose must be applied. Except for the most ephemeral chemicals, a lower dose acting over a longer period will achieve the same final mortality. At high temperatures insecticides act faster.

Figure D.8

Registration Status of Locust/Grasshopper Insecticide in USA

Insecticide	Registered by EPA	Registered by EPA for Grasshopper/Locust	Special Review Status and Trigger
Main			
1. Malathion	Yes	Yes	
2. Carbaryl	Yes	Yes	
3. Fenitrothion	Yes	No	
4. Propoxur	Yes	No	
5. Diazinon	Yes	Yes	
6. Lindane	Yes	Yes	Avian effects (golf course use)
7. Dieldrin	No	No	PD4 (review complete); onoho cancelled
8. Acephate	Yes	Yes	
Others			
1. Bendiocarb (Filan)	Yes	No	
2. Chlorpyrifos (Dursban)	Yes	Yes	
3. Cyhalothrin (Karate)	No (pending)	No	
4. Tralomethrin (Scout)	Yes	Yes, in combo with zylene	
5. Cypermethrin	Yes	No	
6. Carbosulfan	Yes	No	

Figure D.9

International Registration Status of Locus/Grasshopper Insecticides in Selected Developed Countries

Insecticide	Canada[1]	France[2]	UK[2]	West Germany[2]
Main				
1. Malathion	Yes	Yes	Yes	Yes
2. Carbaryl	Yes	Yes	Yes	N/A
3. Fenitrothion	Yes	Yes	Yes	N/A
4. Propoxur	Yes	N/A	Yes	N/A
5. Diazinon	Yes	Yes	Yes	Yes
6. Lindane	Yes	Yes	Yes	Yes
7. Dieldrin	No	No	No	No
8. Acephate	No	Yes	N/A	Yes
Others				
1. Bendiocarb (Ficam)	Yes	Yes	Yes	Yes
2. Chlorpyrifos (Dursban)	Yes	Yes	Yes	Yes
3. Cyhalothrin	No (pending)	N/A	N/A	N/A
4. Tralomethrin (Scout)	No	N/A	N/A	N/A
5. Cypermethrin	Yes	Yes	Yes	Yes
6. Carbosulfan	No	Yes	Yes	N/A

N/A = not available

1. Dr. Peter Bennett, Chemical Evaluation Division, Bureau of Chemical Safety, Food Directorate, Ottawa, Ontario, Canada, KIA OL2, January 1988.
2. European Directory of Agrochemical Products, Part 3, Insecticides and Acaricides, Royal Society of Chemistry, The University, Nottingham, England, NG7 2RD, 1984.

Insecticide formulations must be capable of distribution by well-tried methods, non-corrosive and non-phytotoxic, and storable for at least 18 months (preferably up to five years). The major categories of formulation are spray ultra-low volume (ULV), emulsifiable concentrate (EC), and wettable powder (WP), bait (insecticide spray or dust mixed with an inert edible carrier such as wheat bran or rice or millet hulls), and dust.

The persistence of insecticides and chosen formulations is important in locust and grasshopper control. Relatively ephemeral, fast-acting contact poisons are effective for spraying swarms of adult locusts, but in other situations residual toxicity is a valuable characteristic. Preferred formulations have low volatility, are mixable with diesel oil or other nonvolatile oils for better adherence and penetration, and are temperature stable, i.e., they stand up well to sun and rain. Cumulative stomach poisons that are not easily excreted or detoxified are efficient because insects that first receive a sublethal dose, or which were missed, can ingest lethal amounts as they move about after the application. Insecticides that depend almost entirely on initial contact and feeding on the first day leave little margin for error in application and usually require a higher dosage rate and complete coverage to insure control. This is particularly important for aircraft application, since cost is minimized by low-volume spraying and coverage is sometimes not the best. USDA is researchingin-flight insecticide encapsulation, which increases the residual action and rain resistance of anti-grasshopper chemicals while reducing the dosage necessary.

Popov, et al (1987) in field tests in Mali showed that micro-encapsulated fenitrothion, chlorpyrifos and dieldrin gave good control after 48 hours, and recommended that they be evaluated for persistence.

D.4.3 Current pesticide management practices

D.4.3.1 Prepositioning of insecticides

It is desirable in a pest control program employing chemicals to have those chemicals accessible in a site relatively near the site of operation. This may be particularly true of the Locust/Grasshopper Program, where the distance between sites of operation and the extent of area to be treated could make it much more convenient for the chemicals to be prepositioned in an appropriate storage facility that would give the operators accessibility on relatively short notice.

Prepositioning entails prior decisions as to what chemicals will be needed and used, the probable quantity required, the formulation compatible with method of application and some system of accounting for the chemical and replenishing the supply as needed. There would have to be a central facility

to maintain a large enough supply of the various chemicals, and an appropriate transport and distribution system. Inventory control, not only in the main facility but also in the subsidiary facilities, would also be necessary to insure against possible shortages or oversupply.

D.4.3.2 Storage facilities

Inadequate numbers of storage facilities for locust control chemicals have been identified as an acute problem (FAO, 1986j; WEC, 1987; Jensen, 1987a). Many pesticides are stored in unfenced areas out in the open, often adjacent to populated areas. Outside Khartoum, Sudan, a mound of approximately 2,000 5-liter cans of dimethoate have been stored out in the hot, dusty atmosphere so long that the cans have corroded and become part of the landscape (Jensen, 1987b).

Where there are stores, the stores are often poorly ventilated and in need of repair. In Sudan, for example, all of the provincial stores visited (7 out of 17) by an FAO team of experts needed a complete overhaul (FAO, 1986j). The main defects were too few fixed structures, no water, no electricity, and a lack of management skills.

DLCOEA, has pesticide stores in Ethiopia and Somalia which could be used as models in the region. However, their stores in Sudan and Kenya are less than exemplary (WEC, 1987).

Leaks and spills are typical sources of contamination in most pesticide stores, especially in stores with old stocks. DLCOEA has reported leaking, crystallization and rusting of drums, despite a continuous process of inspection and decanting old stocks (DLCOEA, 1986b).

If not contained in a timely fashion, leaks and spills can lead to major sources of contamination. An extreme example of this can be found at the Desert Locust Control Center stores outside Gomeisha, North Yemen, where 26 metric tons of old dimethoate, heptachlor and fenitrothion have leaked to form a lake of toxic chemicals (Jensen, 1987a). These chemicals, which were donations, were inadequately packaged for storage and use in the tropics.

The storage of the pesticides, whether at the central facility or at subsidiary storage sites, necessitates having proper facilities in which to store the chemicals. Among the features of a proper storage facility are:

- Sufficiently removed from human habitation or areas of activity as to be somewhat isolated.
- A storage building should be removed some distance from other buildings in the event of spills or fire

so that persons in other buildings or the building itself are not jeopardized.

- Located on such a site that in the event of spills or fires, there would not be the likelihood of water supply contamination.
- Have an adequate water supply for cleaning up spills or fighting fires.
- Having a concrete floor with a good finish and a slope to a drain which would carry off spill to a decontamination tank or pond.
- Adequate ventilation such that any vapors will escape.
- Maintain a running inventory of contents of the storage building such that anyone having to deal with a spill or other emergency would have some knowledge of what is in the building and the proper precautions to take in combatting that emergency.
- Have adequate supplies for dealing with spills or leaks, which would include absorbent materials, such as sawdust, soil, or clay to absorb liquid spills; an alkaline material such as lime or soda lime for neutralizing such chemicals as the organosphosphates and carbamates.
- Protective clothing such as rubber boots, rubber gloves, and respirators for workers who may have to deal with spills, .
- First aid supplies which would include water for washing off any splash or contamination of a human, and a universal antidote if the chemical is swallowed.
- A decontamination tank, or pond, to which spills of liquids and others may be washed for decontamination. If a pit is used, the pit should be lined with plastic or concrete to avoid the chemical soaking into the soil.
- Containers in which absorbent material used in soaking up the spills or leaks can be put for disposal.
- Provide at least one person at the storage facility emergency first aid training in the event of an exposure.

People with access to the storage facility should have a basic knowledge of the chemicals that are stored there, some of the hazards to the humans that the chemical may present in spills or splashes, and training in procedures for dealing with such emergencies.

D.4.3.3 Pesticide store management

Except for DLCOEA, the management of existing locust chemical stores is considered a problem in most countries (McWain, 1987; FAO, 1986j; WEC, 1987; Jensen, 1987a). In most instances, especially in the more remote areas, there is no management system at all, resulting in the chaotic storage of fresh and redundant pesticides with drums of fuel and application equipment. Rarely is there a current inventory, a first-in, first-out use of chemicals, or an established procedure for cleaning up spills and for decanting leaking drums.

D.4.3.4 Formulation stability

Thirty years ago, the more persistent, broad-spectrum insecticides such as aldrin, BHC and dieldrin were used to control locusts. Now, less persistent, more environmentally safe insecticides such as malathion, carbaryl, fenitrothion and propoxur that can be used at lower dose rates because dusts, baits and liquid sprays are preferred.

This shift in preference has caused some pesticide storage problems. The main one is that the newer generation of insecticides is less persistent, so that the storage shelf life is considerably less. Most manufacturers guarantee their products for two years under tropical storage conditions only if the products are stored unopened in their original containers out of direct sunlight.

Studies by Shell Chemical Company in Sudan have been conducted to determine the internal temperatures of pesticides in drums left in direct sunlight. With red or black painted drums and an ambient temperature of 30-35° C, the internal temperature of the pesticide inside the drum was 55-60° C. In drums painted white at an ambient temperature of 30-35° C, the internal temperature was only 35-40° C. The explanation for the differences is that the red or black drums absorbed the heat from sunlight, and the white drums reflected the sunlight.

Pesticides are often stored outdoors, where daytime temperatures in some Sahel countries can exceed 40° C, with full exposure to the weather. In Dakar, for example, large numbers of bags of propoxur dust and liquid insecticides were stored outside on the ground even though a suitable covered storage area was available nearby (FAO, 1986j). Pesticides are also commonly stored in poorly ventilated stores. With poor storage conditions, the stability of the formulation could be adversely affected, making it less effective for locust control. In Mali, there was serious question as to the efficacy of the 2% propoxur dust that was being used late in the 1986 campaign (FAO, 1986j).

It is strongly recommended that locust insecticides stored and used under tropical conditions be specifically formulated and packaged for these conditions. This may include additional stabilizers and higher boiling solvents for liquids. Since the formulation of pesticides involves complicated technical processes, locust chemicals should only be purchased from reputable sources such as an internationally recognized laboratory. Each shipment should contain an analysis of formulation properties especially for active ingredient and suspensibility using standardized accelerated storage tests.

D.4.3.5 Health monitoring of personnel

The basis of concern for escape of chemicals whether it be in the work environment or the more general, ambient environment, is the exposure of man and other organisms and the potential effects of this exposure. Exposure is not alwaysinnocuous, particularly at the relatively higher levels of exposure encountered in occupational settings or with prolonged (chronic) exposure from general environmental contamination.

D.4.3.5.1 Exposure

There are three usual routes of insecticide exposure experienced by humans: respiratory exposure, dermal exposure, and ingestion (Freed, et al, 1980). Occupational settings may result in high respiratory exposures from volatile or dusty substances, in dermal exposures from spillage or direct contact with a chemical, or in ingestion of contaminated food or water. Of course, there are instances where any combination of the three exposure routes may be experienced. For example, an individual mixing a chemical for use may be exposed by both respiratory and dermal routes.

An essential component of any monitoring program is an inventory of either the sources or the agent of pollution. These data may be useful in establishing parameters for further research or in developing new measurement techniques.

D.4.3.5.2 Monitoring options

Knowledge of changes in environmental quality gained through monitoring provides a basis for assessing and anticipating probable effects. The most feasible course is to monitor the environment; but, on occasion the biota may be used for monitoring purposes.

In monitoring the transport, storage, use, and disposal of pesticides or the containers, primary attention would probably be focused on human exposures or environmental contamination, that would occur during the mixing and application

of the chemical. Spills and leakage in transport and storage would also be of concern.

D.4.3.5.3 Monitoring of humans

Individuals most likely to receive an exposure to the chemical are those handling, mixing and loading, or applying the chemical. These are the individuals that not only would most likely be exposed but also would be most likely to receive the greatest exposure. The bystander, observing the application at a distance may receive drift exposure of spray or dust, but would experience substantially less exposure than a worker unless directly in the path of the application. The general public would most likely receive it through water or food that had been contaminated either through spills or drift, and over-spraying of the water supply or food crops (Swan, 1985).

The handler, i.e., mixer, loader and applicator is the one most likely to receive the heaviest exposure and, hence, is the one for which the monitoring, both in terms of exposure and health effects, may be the most critical. It is probably that because of the sporadic and infrequent application of the chemical for control of locust and grasshoppers in a given area that the exposure of the public would be quite small (Honeycutt, et al, 1985).

In the case of workers, monitoring is no substitute for adequate protection. This would include both protective clothing and devices and adequate training in safe handling and use of the pesticide involved. Measurement of the extent of chemical exposure by laboratory analyses, or health monitoring, ascertains after the fact that such exposure has occurred. If there is an effect, the exposure has been too great. Even though the worker may be removed from the exposure and recovers fully, prevention of that exposure would be the most prudent course of action.

For the public, assessment of exposure is probably most conveniently done by determination of residues in environmental samples such as water, air, and food supplies including fat and milk of livestock. To be sure, a nearby population should be observed for overt manifestations of effect, but in well performed spray operations the exposure should not result in such manifestations.

Assessment of human exposure to pesticides or other chemicals may be quantitative by either direct measurement methods or the more indirect methods that rely on evaluating the activity of a particular enzyme, e.g. cholinesterase, or analyses of tissues for the presence of the chemical, a metabolite, for observation of particular manifestations.

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Among the first direct methods of measuring exposure to pesticides is the use of alpha cellulose patches attached to clothing or taped to the skin. Shirts have also been used to measure exposure and, of course, even the clothing itself may be analyzed to determine exposure. However, where T-shirts or other items of clothing may be used as the "trap" for the chemical, care must be taken in the analyses to avoid problems with possible contaminants that are extracted from the clothing. Another technique utilized in direct measurement of exposure is that of skin washes with an appropriate solvent. This has been used particularly in the case of hands and forearms, where a bag rinse technique has been used (Honeycutt, 1985).

For respiratory exposure, respirators with special filter pads and various types of air samplers have been used. The air samplers maybe a battery operated dynamic sampler with appropriate absorbent for the chemical, or a passive sampler that depends on diffusion. These direct methods have been used to measure the exposure of workers to a wide variety of pesticides.

D.4.3.5.4 Environmental monitoring

Chemicals in the environment may produce adverse effects on biota, water quality, soil, productivity, or air quality. For these reasons, it is often desirable to monitor during the application or release of chemicals to assure that such adverse affects are not being produced, or if they are, that appropriate legislative actions can be taken. In the application of pesticides, monitoring can be very helpful in modifying the application techniques or changing chemicals to avoid adverse effects.

Among the adverse effects that can be produced by the chemicals are direct effects on nontarget species such as the killing of bees or birds and poisoning of fish and other organisms by direct contact with the spray. The more persistent chemicals may produce a subtle effect at lower concentrations, such as reducing reproductive capacity, e.g. thinning of bird egg shells through bioaccumulation. Another possible contributory factor is soil residues being picked up by subsequent crops, or drift of the chemical creating residues on current crops.

The organophosphate, carbamate and synthetic pyrethroid chemicals, proposed for use in locust and grasshopper control are, for the most part, materials of short persistence in the environment. However, they have a direct impact on non-target species, thus warranting a monitoring effort. However, persistence for a matter of days may be desired to provide an opportunity for exposure and, hence, kill grasshoppers and locusts that come into the treated area. Again, monitoring under the particular conditions of use permits an assessment of the

persistence and effects of a biologically effective concentration of the pesticide.

One may take samples of water, soil, some of the available biota, and on occasion, air, for determining the distribution and fate of the residues. When using organophosphates, carbamates, or synthetic pyrethroids with a somewhat short persistence, it is particularly valuable to sample water to assure that fish and other aquatic organisms are not adversely affected; count and observe birds to determine acute poisoning effects; sample plants in the treated area (or just adjacent) to determine residue levels and insure against excessive drift, and to sample biota to see the level of their exposure and whether there is harmful insecticide.

Some of the persistent chemicals, such as the chlorinated hydrocarbons, such as the lindane and dieldrin that has been used extensively in the past, may accumulate as soil residues because of their persistence. Additionally, one would want to take samples of water, plants, and resident animal organisms, to determine the level of exposure occurring during and after the application. For following the residue levels in the environment for a longer period of time, one may want to look for an accumulator species such as earthworms or fish and relate either the effect on these species or the residue level found by chemical analyses to the residue in the environment.

D.4.3.5.5 Types of monitoring protocol

Just as with humans, there are two types of environmental monitoring procedures. There is the direct monitoring by chemical analyses of environmental samples or biota, and biological monitoring where the organisms are observed for longer-term effects on individuals of the species or a population. Biological monitoring calls for experience, a good background knowledge of the biology on the system and the organisms, and keen observation. There must be an inventory of key species present, knowledge of the susceptibility of key species to the chemical in question, and then a pattern of observation that insures a representative and adequate sample of the area and the species used as a basis for the monitoring.

Wildlife counts and observations must be carefully planned. Factors that will affect exposure include degree of insectivory and resident territorial versus nonterritorial or migrant occurance patterns. Searches for dead wildlife must be painstaking, since dying animals tend to head for dense or thick cover. Changes in behavior caused by a sublethal insecticide dose may lower breeding success or make poisoned animals more vulnerable to predators (McEwen and Brown, 1966; McEwen, 1982; DeWeese, et al., 1986).

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It is important to have a baseline knowledge of the performance of the species being observed in order to distinguish between other causes of stress and the effect of the chemical. As morbidity or mortality is observed, it would be important to be able to evaluate the direct effects on the organism, the more indirect effects produced by modification of that organism's food supply and, if possible, the impact on reproductive potential, behavior, survival, or related effects.

D.4.3.5.6 Sampling for laboratory analyses

Before undertaking a sampling program, careful study should be given to what types of materials may be available, what questions are to be answered by the sampling and analyses, and the pattern of sampling necessary for an adequate representation of the environmental compartment or biota that is to be used in the study. Another consideration is the number of samples to be taken. One needs to have a sufficient number of samples to have statistical validity but not so many samples that it is beyond the resources to do the analyses. It may be desirable to take a few additional samples to be held in reserve in case a sample is lost or it becomes necessary to recheck a particular sample.

Sufficiently large samples should be taken to provide adequate material for any analysis or examination that may be desired. In planning the sampling program, one must know what is available so that the sampling does not deplete the source. If the samples must be shipped for any distance, it is recommended that they be put into a package with dry ice to preserve them until they reach the laboratory.

D.4.3.6 Emergency preparation

In a control program as large and complex as the locust/grasshopper control program in Africa, a number of different types of emergencies have a high probability of arising. Of immediate concern are those emergencies that would occur in the transport, storage, use and disposal of the chemicals. These include leakage of the containers, accidents resulting in spills, and human exposure from spills/splashes or drift of chemical, with attendant contamination of humans, the water supply or food crops and/or hazard to beneficial nontarget organisms.

It is important, to be prepared to meet the various types of emergencies that may arise. Transport, handling and storage facilities should be reviewed for suitability and safety. Workers need to be trained to contain and clean up any insecticide spills, whether by leakage or accident. Adequate

equipment and supplies should be readily available to them for this purpose. Provision should be made for fighting fires, either by workers trained to do this or by alerting emergency services. It is essential to provide adequate first aid on the scene and subsequent medical attention for those who may have received exposure to the chemical, particularly, the concentrates that would pose the greatest health risk.

Emergency planning must include provision or first aid and medical treatment, particularly to those who may be exposed to the concentrate through spills, splashes, leaks or otherwise contaminated by handling and use of the chemical. Exposure to the chemical may occur in transport through leaking containers or an accident and having to clean up the material, or it may come betwen the mixing and loading operation, application, or in the case of application with backpack sprayers, splashes from these pieces of spray equipment. Unfortunately, there are also instances of ingestion of the chemical through careless handling and/or repackaging.

One or more individuals should receive basic training in first-aid procedures. Very often an accident will occur far removed from accessible medical facilities and immediate first-aid could be the difference between an adverse effect and a very mild or no effect.

D.4.3.7 Transport of pesticides

There is always the potential hazard in the transport of pesticides and, of course, also in storage since at this stage the chemical is likely to be in a highly concentrated form, either as a technical product or dissolved in solvents. In this concentrated form, they afford a higher toxicity to humans and, of course, a greater contamination to the environment than in the more dilute forms applied as a spray. Further, some of the pesticides, and formulations of pesticides, are flammable and/or may be converted to toxic gases upon burning.

Pesticides must not be shipped in the same containers or compartments or trucks with cargo such as clothing, food, drugs, toys or household furnishingthat could become a hazard if contaminated. Containers showing any evidence of leakage should not be transported. Pesticide containers should be loaded into the carrier and secured in such a way that they are held in place without the possibility of damage to each other during transit. In loading and unloading of the pesticides, appropriate equipment and tools that wouldn't damage the containers should be used. Specifically, the use of hooks which may puncture or tear pesticide containers should not be employed.

Any facility where quantities of toxic pesticides are being handled should have access to a qualified physician who has been informed beforehand about the nature and toxicity of the chemicals.

D.4.3.8 Disposal of obsolete insecticides

With the preferred use of the new generation of insecticides comes the problem of getting rid of the stocks of obsolete organochlorine insecticides, some of which have been stored since the early 1960's. Many of the chemicals are banned in-country and elsewhere for agricultural use, so they cannot be used as intended. Recent estimates of pesticide wastes for disposal in Sudan, Ethiopia, Kenya, Somalia and North Yemen include BHC, DDT, diazinon, dieldrin, dimethoate, fenitrothion and malathion (Figure D.10).

Figure D.10
Estimated Quantities of Obsolete and Waste Pesticides (in Metric Tons)

Country	Locust	Other	Total
Sudan	280	800	1080[1]
Ethiopia	193	193+	440+1
Kenya	25	23+	48+[1]
Somalia	103	na	103[1]
OCLALAV	35		35[2]
N. Yemen	143	12	155[3]
			1861

[1] WEC, 1987; [2] Cavin, 1987; [3] Jensen, 1987.

No additional recent estimates of obsolete locust insecticides for disposal in other countries are available. In 1982, however, FAO reviewed the existing stocks of locust control chemicals in 41 countries in Africa, the Middle East and South Asia (FAO, 1982e). Although these figures are dated and many of the stocks likely already used, they give an indication of the countries where there may be organochlorine disposal requirements. The organochlorine stocks at that time were as follows: 747 metric tons (MT) of 20% dieldrin, with Saudi Arabia and Pakistan each with 150 MT; 463 MT of 15% BHC liquid, with DLCOEA with 201 MT; 6022 MT of 25% BHC dust, with India having 1360 MT and Tunisia 850 MT; and 3622 MT 1% BHC bait, with Sudan having 2800 MT.

Pesticides disposal involves a degree of risk to people and the environment. A variety of factors need to be considered before the method of disposal is determined. These factors are (Freed, 1987a):

- The type of the chemical.
- Its toxicity and environmental hazard.
- Cost of the disposal method.
- Amount of chemical for disposal.
- Whether it is concentrated or dilute.
- Availability of facilities for disposal.
- Whether the chemical for disposal may degrade into a product of concern to health or the environment.
- Proximity to humans, animals and their activities.
- Expertise available to conduct the disposal operation safely.

Figure D.11 summarizes thirteen different disposal options and gives the feasibility of each alternative, taking into account the special limitations of working in Africa and the Middle East. Figure D.12 then lists the chemicals by common name with the recommended disposal alternatives for each chemical.

D.4.3.9 Decontamination from pesticide leaks or spills

The cleanup of contaminated stores or soil resulting from leaks or spills of pesticides is a common problem in most chemical stores. Information in this section should be of particular relevance to stores which need major cleanup efforts because of leaks or spills like those which occurred at the Desert Locust Control Center store outside Gomesia in North Yemen (Jensen, 1987a).

Extreme care should be taken by all workers during store cleanup, especially when working with concentrated formulations and contaminated drums. Full protective clothing and respirators should be worn by all those working in a contaminated store.

In highly contaminated stores, the first step is to decant (or transfer) the liquids from leaking drums into good

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Figure D.11
Feasibility of Pesticide Disposal Alternatives

Method of Disposal	Physical State of Wastes		
	Semi-Solid	Solid	Liquid
A. Incineration in mobile incinerator			
o on site	Q	U	F
o at remote site	Q	U	F
B. Incineration in cement kiln	F	F	F
C. Incineration on ocean going ship	U	U	Q
D. Other incineration techniques	F	F	F
E. Land burial, lined/unlined pits			
o "as is"	U	Q	U
o reformulated/solid products	Q	F	Q
o repack/appropriate container	U	F	U
F. On-site detoxification	U	U	Q
G. Long-term secured warehousing	U	Q	U
H. Use as intended or spread "as is"	Q	F	F
I. As in H, after reformulation	Q	Q	Q
J. Use portable UV disposal unit	U	U	U
K. Ship to developed country for			
o land burial	U	Q	U
o reprocessing	Q	Q	Q
o incineration	F	F	F
L. Ocean dumping	U	U	U
M. Deep well disposal	U	U	Q

F = Feasible; U = Unacceptable; Q = Questionable

Modified from WEC, 1987.

Figure D.12

Insecticides for Disposal in East Africa
Their Toxicity and Suggested Methods of Disposal[1]

Common Name	Chemical Type[2]	Physical State	Oral LD 50 mg/kg	WHO[3] Hazard Class	Disposal Options[4]
acephate	OP	solid	866	III	A B D F H
aldrin	OC	solid/liq	60	Ib	A B D H
bendiocarb	C	solid/liq	40-156	Ib	A B D F H
BHC	OC	solid/liq	270	II	A B D H
carbaryl	C	solid	850	II	A B D F H
chlorpyrifos	OP	liquid	163	Ib	A B D F H
cypermethrin	PY	solid	4123	HU	[5]
diazinon	OP	liquid	400	II	A B D F H
dichlorvos	OP	liquid	100-300	II	A B D F H
dieldrin	OC	liquid	45-50	Ib	A B D
fenitrothion	OP	liquid	800	II	A B D F H
lambda-cyhalothrin	PY	solid	56	II	A B D F H
lindane	OC	solid	88	II	A B D H
malathion	OP	liquid	2800	III	A B D F H
propoxur	C	solid	90-128	II	A B D F H
tralomethrin	PY	solid	3000	HU	[5]

1. Adapted from World Environment Center, 1987.
2. OC = Organochlorine; C = Carbamate; OP = Organophosphate; PY = Synthetic pyrethroid.
3. World Health Organization classification of pesticides by hazard, based on the oral LD_{50} of technical material for the rat (mg/kg body weight); Ia extremely hazardous, Ib highly hazardous, II moderately hazardous, III slightly hazardous, HU highly unlikely to be hazardous.
4. Disposal options from Table 1 of D.4.3.9.
5. Care must be taken in case of hazard to fish; may be buried with addition of lime.

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drums. All drums and other containers should then be removed from the store.

Next, the spillage on the floor should be absorbed by a suitable dustless solid absorbent, such as sawdust or granular absorptive clay. In countries in Africa and the Middle East which lack secure landfills, the contaminated solid absorbent should be taken to an unpopulated area, burned if possible, and then the ashes layered with oil, organic matter and lime in a pit in a secure area with a low water table in order to minimize the potential for groundwater contamination.

The next step is to decontaminate the floor of the pesticide store. This can be done by the chemical treatment of contaminated soil or concrete with lime or strong base, such as sodium hydroxide.

An option to chemical treatment of contaminated soil is to leave the contaminated site fallow for a period of time (possibly many years) so that microbial and physical degradation processes in the soil might take place.

Another option to chemical treatment is the mechanical removal of contaminated soil to a specially constructed decontamination pit located in an unpopulated area where there is a low water table, to avoid groundwater contamination. The contaminated soil should be layered into the pit with organic matter (e.g., animal manure) and lime to enhance degradation.

The contaminated surface, either before or after any of the above treatments, should be sealed with a layer of reinforced concrete if buildings for human habitation are to be erected. It is important that all utilities such as heating and cooling systems be built on top of the concrete liner so that there is no physical contact between the contaminated soil and the building.

D.4.3.10 Pesticide containers decontamination and their disposal

There have been a number of instances of human poisoning where "empty" pesticide containers were used to store drinking water or food.

Inappropriate container size for the intended end use and containers that are not sufficiently durable for transportation and storage under harsh tropical conditions can cause storage problems. Locust chemicals are usually supplied in 200 liter drums. Some countries have no facilities to safely repackage pesticides into smaller, more easily usable packs if the end user is the small-scale farmer.

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In the late seventies, Kenya and North Yemen received large donations of dimethoate for hopper control (Jensen, 1985; 1987a). Many of the drums were leaking on arrival. Because of this, little of the dimethoate was ever used, and the old stocksare storage and disposal problems today.

The disposal of used containers in developing countries is a special problem, as these containers are valued for other uses by the local population.

Although empty insecticide drums have many alternative uses in LDCs, it is USAID policy that the drums from US government purchases must be decontaminated, punctured, crushed and buried. The following steps should be followed:

1. Control inventory throughout the life of the drum.
2. Cut off top of empty drum, then well drain contents into undamaged drum and accumulate for reuse or eventual disposal. Manufacturers estimate that 1% of drum contents remain in drums drained with the top still on.
3. Assemble drums in an unpopulated area, douse with available fuel, and flame off chemical.
4. Puncture holes in all sides of drums to discourage reuse of any sort.
5. Crush drums.
6. Bury drums.

In some cases, rinsing well-drained drums (with top cut off) with solvents and chemical decontamination using alkali may be more appropriate. However, this procedure creates rinsate, which may be a problem for safe disposal.

Local pesticide formulation plants may have disposal facilities. However, they should be carefully checked as to capability before acceptance.

D.4.4 The basis of selection of insecticides - present and future

The selection of a pesticide for use in locust/grasshopper control programs would be simplified if there were only one chemical that was effective for the control of the pests. In fact, at the present there may be several pesticides that could give equally satisfactory control, but each chemical would likely have both merits and disadvantages when weighed against the various considerations that are relevant to this selection. The considerations that should go into the selection of a chemical include, among other things:

- The effectiveness and appropriateness of the particular chemical on the organism, and compatibility with the situation in which the

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organism is to be controlled.

- The cost of the material on a per use basis.
- The possible hazard to man, non target organisms, and/or the environment.
- The availability of that chemical on the market to be used.
- The fate and behavior of the chemical under conditions of use, that is; whether it is persistent or non-persistent, does it move in the environment to contaminate non target areas, or does it bioaccumulate in non target organisms causing adverse effects.
- Will the chemical as used result in undesirable residues in or on crops, water supplies, or elsewhere.
- Are the formulations which are available suitable for the intended use.
- If this chemical is selected will it have a sufficiently long shelf or storage life in the event that the chemical must be stored for sometime before use.

In price considerations it is important not to overlook the cost of shipping to the point of use, and the size and nature of containers in relation to use. Storage durability of both containers and product is also important.

Where a pest control program is receiving support from AID, particularly for pesticides, the selection of the chemical must be governed by AID regulations, particularly Regulation 16 and its various interpretations and applications.

Preference should be given to the short lived and relatively non persistent materials such as the pyrethroids, organophosphates and carbamates. The selection should favor those chemicals that have EPA registration for use, particularly if registered for the use intended.

As a basis for future selection all of the considerations cited above are relevant and to these might be added more detailed assessments of environmental behavior in relation to human exposure and/or environmental contamination.

Thus, a matrix of weighted factors should be developed for selection of the chemical taking into account all of the above, and additionally:

- The nature of the environment in which the problem occurs, especially in relation to persistence of the chemical under the enviro-climatic conditions and recognizing that the quantitative behavior of a chemical will vary with these conditions.

- The biota that may comprise non target species and whether or not some may be endangered.
- Whether single or multiple applications will be required, the interval of time between applications, and over what period of time may these applications be made.
- Human settlement intensity as regards exposure.
- Protection of water supplies and food production capacity.
- Importance of the problem to human welfare and any attendant risk that it may entail.

D.5 The Extent to Which Present Control Activities are Part of an Integrated Pest Management Program

For both grasshoppers and locusts, there is only one main control alternative, the application of broad-spectrum insecticides, often on a large scale. There is an urgent need to expand the choice of control methods that can be combined in an IPM context to help prevent grasshopper and locust outbreaks and to handle them more efficiently, more cheaply and with fewer undesirable environmental consequences.

Integrated pest management (IPM) means using the best mix of available control methods for achieving the most effective, economical and safe pest management possible. Pesticides have been the dominant control measure for the last forty years, but exclusive dependence on them often does not work well. Problems include resistance to pesticides and pest resurgence or the creation of new pests because pesticides decimate pests' natural enemies or competitors. Because of ever-increasing prices, pesticide-related expenses can be a major and burdensome cost of production for the farmer and for importing governments. Safety for users, consumers and the environment has also been a major problem. For this reason, many IPM programs seek to minimize the amount of pesticides used: Chemicals are used only when necessary, while ensuring that applications are made in an effective and specific manner.

At present, broad-spectrum insecticides are the only powerful control weapon against grasshopper and locust outbreaks. They are effective, and so far no acridid resistance to them has been reported in Africa, the Middle East or Asian locust plague areas. The extent and impact of damage to the natural enemies of these pests, as well as to the environment and nontarget species (including humans) is not well understood. Since dieldrin (a very persistent biocumulative compound with detrimental chronic effects on animals) has been used in locust control programs for decades, and since grasshopper control programs can involve blanket spraying of hundreds of thousands of hectares with broad-spectrum insecticides, the potential negative health and

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environmental effects are fearsome. The economics of locust and grasshopper control in Africa and Asia are important, because governments there are hard-pressed to pay for even the cheapest chemicals and regional and national pest control programs have deteriorated for lack of financial support.

For the present, it is necessary to make the best use of what is available, and IPM means good surveillance for pest infestations combined with minimized, effective, specific application of insecticides that are as safe as possible for human health and the environment. Except for the use of organochlorine insecticides, locust control workers are justifiably proud of their achievements in this area, which are based on years of laboratory and field research. Their combination of systematic surveys and effective use of chemicals has suppressed plagues for over two decades. Special attention was paid to minimum effective dosages, appropriate formulations and spray equipment, and accurate placement of sprays at times when the insects are aggregated and areas infested are still small. It must be noted, however, that actual field practices often fall far short of that high standard.

Perhaps because of the larger and less well-defined geographical areas involved, because the problem has received less longstanding international attention, or because effective national plant protection services are still being developed, grasshopper control is not handled so well. Economic thresholds have been used in some spray programs, but they vary greatly between countries and need to be investigated further. Early-season surveys and mobilized farmers could find and eradicate heavy infestations of the relatively small first generation, thus avoiding the necessity of large scale intervention later in the season. However, this is as yet beyond the capability of many national plant protection organizations. Rather than being prevented, grasshopper outbreaks have reached alarming proportions.

A good integrated pest management program seeks to prevent serious outbreaks and improve the quality of pest control on an ongoing basis by adding new technology and approaches to the overall control strategy as they become available. Locust and grasshopper control in Africa, the Middle East and Asia offers a lot of scope for immediate improvement in the application of existing insecticidal pest control methods. Research on microbial and botanical pesticides, pest population modeling, better forecasting and more efficient and specific ways to apply insecticides offer a better outlook for the future.

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D.6 Training of Personnel Who Handle and Apply Pesticides

During the Spring of 1987 AID conducted Train-The-Trainer courses at the following locations in West Africa: Gambia, Senegal, Chad, and a course on Aircraft Calibration in Niger. The Train-the-Trainer courses, of approximately one week duration, consisted of lectures and group workshop activities on grasshopper and locust biology and identification, control practices, survey methods and pesticide safety. These newly-trained crop protection service employees were then expected to transfer this knowledge to other crop protection service and extension service personnel, who would then transfer it to the village level.

The system seems to have worked quite well. Participants contacted spoke enthusiastically. In a few cases the system apparently did break down through no fault of AID. National governments did not allocate sufficient funds for travel and expenses to cover the needs of the newly-trained trainers.

AID also sponsored participants from the Sahel to a two week training course held by PRIFAS at Montpelier, France. Although the program was well organized and presented, comments received indicate that much of the information was basic and of too low a level for the educational background of most participants.

During the workshop held for USAID participants and consultants in the 1985-87 control programs, the continuing need for training received considerable attention. More than 50 current issues in the locust/grasshopper campaign were identified. Although it was agreed that primary responsibility for training rests with the host government and its appropriate agencies, it was felt that AID has a responsibility and role to play in grasshopper/locust control training, particularly where AID purchased pesticides are involved.

D.6.1 Training - Ground

The shortage of trained manpower has rightly been considered as one of the major impediments in the development effort of many countries. The problem becomes accentuated in highly specialized fields like locust control, since the scope of the locust problem is wide and varied and the trainees for the national anti-locust organizations possess different educational, social and linguistic backgrounds. Thus, training is required at different levels, in different languages and with different program contents. Concentration should be on short-term, practical hands-on courses. Training is essential not only to disseminate the latest research findings but also to refresh the

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knowledge of field staff who have, in many cases, very little access to current literature. It is a continuing requirement. (J. S. Gill, 1977)

Put another way, the 1986 FAO Report states: "Training is considered a basic step in building up national plant protection structures. In most countries and regional organizations experienced locust officers are decreasing in number due to the long recession. The present locust upsurges therefore constitute an excellent opportunity for training a new generation. The committee emphasized the need to include these additional components in the present locust assistance programs - training in aerial spraying techniques, the logistics of large scale operations, radio operations and maintenance."

In preparation for the 1987 Control Campaign every affected country held in training courses for their plant protection personnel and the farmers in the early months of the year. Many of the donor countries and their consultants assisted in the course work and practical exercises.

One can reduce the likelihood of exposure and hence toxic effect of chemicals, but unless such practices are known by the operator he is unlikely to take advantage of them. It is therefore important that in order to protect the operator, every effort be made to educate him.

Such education can come from meetings, individual conversations with appropriate agricultural experts, through special booklets using drawings for illustrations or the use of cheap filmstrips.

W. Overholt (1984) has prepared a Pesticide Users Guide for Extension Workers in West Africa.

In the FAO December, 1987 Evaluation of Campaign, the training programs of each country were described.

Training Techniques for Workers

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a. Training sessions prior to employment.
b. Booklets and instruction kits.
c. Film strips.
d. Slide-cassette for self learning.
e. Special lectures.
f. Demonstrations.

For the farmers (or their wives) who are actually applying the pesticides, as well as the men who are involved with chemical mixing or loading of truck sprayers or aircraft, there is continual contact with the materials used in these operations. There are many manuals on the safe handling of chemicals which deal with dermal and respiratory exposure, the use of protective clothing, safety precautions in mixing and filling tanks and clean up procedures. These could include the previously mentioned Pesticide Users Guide, or An Agromedical Approach to Pesticide Management (Davids, Freed, Whittemore). Also, all the listed operations manuals have sections on safety in handling materials: Pesticide Safety Guidelines for Personnel Protection, J. Singer, USDA, FS, Davis California, 1986; Guidelines for Emergency Measures in Cases of Pesticide Poisoning, GIFAP, Brussels, Belgium; Handbook on Chemical Safety in Aerial Operations, Southwell and Cooper, National Research Council, Ottawa, Canada, 1973.

The field worker, though not handling pesticides, may receive exposure through residues on the plant or through drift during the spray operation. Training for field workers should emphasize the need to delay entry to the field for a safe period, avoidance of drift and removal of residues from the body by washing. Additionally, the worker must be apprised of the contamination of clothing and the need for frequent change and laundering.

D.6.2 Training - Aerial

Proper training of aerial operations personnel is of paramount importance. This must reach not only the pilots, but also the support people who keep the aircraft operating. Many of these people may be locally acquired and not acquainted with procedures so they will need proper checkout and supervision of their activities.

The contractors' personnel should be adequately experienced and trained for their duties. Prior to awarding a contract, someone should visit the contractor's operational facilities to check equipment, maintenance, personnel, past experience and contracts satisfactorily completed.

Another subject of training should be the potential for training in-country pilots from Africa and to include recurrent training for those that are available. Admittedly, the numbers of qualified pilots will not be high and those who have been available may have gone on to other positions. However, there are regional organizations (with local pilots) that have some training capability which should be investigated.

D.6.3 Training Personnel in Storage and Transport Facilities

There is a serious problem with the management of pesticide stores for locust chemicals. First, there is the need to train local personnel how to build stores, as there is an acute shortage of them. Additionally, there is the need for training regarding storage procedures, logistics of distribution, as well as administration and management of stores. It might also be appropriate to have the store personnel trained in bait mixing techniques.

Transport personnel should also be trained in pesticide management. They must never store or transport pesticides in any way that will bring them in contact with foodstuffs or other material intended for human or animal use. Transport personnel should be knowledgeable about pesticides and trained in how to clean up leaks and spills, and procedures to follow in case of an emergency.

D.7 The Costs of Locust and Grasshopper Control

The cost of locust and grasshopper control includes spending by farmers, local authorities, national authorities and the international agencies and donors. There is no available data for the amount of money spent by farmers, local or national authorities. The best recent data for spending by the international community is for the 1986 grasshoppper infestation in Africa and the continuing efforts in 1987.

In the 1986 grasshopper outbreak some 42 donors contributed a total of $49,635,008 to fight the grasshopper outbreak in African countries (Figure D.13). Much of this money was for the cost of aerial spraying, both with small aircraft of the type normally used for such operations, and with four DC-7's.

Section C.4 shows that the production directly saved by grasshopper control in nine of these countries was valued at $46,135,000, while spending in these nine countries was around $40,000,000. This makes the efforts look rather expensive and fairly ineffective. Indeed, this point has been made by a number of observers (1).

Any ex-poste cost-benefit analysis of the situation reinforces this impression. However, a number of points need to be made about such ex-poste analyses. Cost-benefit analysis is a useful decision-making tool ex-ante. If one is considering a future program of locust or grasshopper control one might be justified in using it. But in an emergency, one is faced with a situation that is radically different from one where several months can be taken to analyze options before coming to a

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decision. An emergency, by definition, requires quick decisions and fast actions. Threatened with a grasshopper outbreak in 1986, which, it was thought, could lead to a potential famine, donors made the decision to fight the outbreak. Resources sufficient to do this were made available.

Ex-poste it may seem that the resources expended are not justified by the crop saving. However, it is difficult to conceive of an emergency in which donors would decide that they would commit resources only to the point where the cost of fighting the pests (compared to the value of the crops saved) gave a cost-benefit ratio of 2 (for example), and at the point where the costs started to rise above that level would withdraw all resources. Such is not the nature of the response to any emergency.

The consideration should not be whether an emergency response shows a good cost-benefit ratio ex-poste but whether this approach to locust or grasshopper control, that of treating outbreaks on an emergency basis, is really the most effective approach.

If we look at the per hectare figures for the areas treated in 1986 (Figure D.14) we get a figure for donor inputs that ranges from $6-$19 per hectare (ignoring Ethiopia which is clearly a case of money going to the country but <u>not</u> being used for spraying). On top of the donor inputs are the local inputs for which we do not have a breakdown but which will take the costs up to around $15-$30 per hectare. Current costs per hectare in the US are shown in Figure D.15.

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(1) FEWS Special Report: 1986 Grasshopper and Locust Infestations, March 1987; and, Initial Report on the 1986 Locust and Grasshopper Situation in West Africa, Michel Launois for Club de Sahel.

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Figure D.13

1986 Locust and Grasshopper Campaigns in Africa

Donor	Benin	Burkina Faso	Cameroon	Cape Verde	Chad	Gambia	Ghana	Guinea Bissau	Mali
AfDB									
Algeria									
Badea									
Belgium									
Canada		462,000				105,000			445,000
China						50,000			50,000
Denmark		201,310							85,000
EEC					613,332	205,876		43,066	1,207,735
FAO/TCP	71,000		77,000		215,000	51,000	30,000		250,000
FAO/OSRO					65,000				200,000
Finland									
France		239,000			50,000				522,000
Federal Rep of Germany		486,315			531,707	100,000			390,361
Greece						40,000			
Italy		120,000			200,000	72,000			259,000
Japan		246,000							
Morocco									
Netherlands		210,500		100,000	282,790				685,379
Non-Govt Organizations:									625,000
Bandaid					16,060				
BELACO					3,300				
CARE									
CARITAS									
Cathl Rlf Servs									
Christn Rlf & Dev Assn									
Food for the Hungry					5,470				
FRANCE									
OXFAM					44,960				
World Lutheran Fndtn									
World Vision Intl					5,470				55,000
Unspecified									
Norway									1,332,000
OPEC Fund									
Spain									
Sweden					105,030			130,000	80,000
Switzerland					76,000				
Thailand									
UK: ODA					29,800	260,000			318,883
UNDP		478,500			30,000	20,000			200,000
UNICEF		61,000							
USAID		298,800			988,625	758,070		29,000	1,790,160
WFP		18,000							
WHO					4,480				
Yugoslavia									
TOTAL	71,000	2,821,425	77,000	100,000	3,267,024	1,661,946	30,000	202,066	8,495,518

Source: FAO/Rome, 12/86

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Fig. D.13 (cont.)

Donor	Mauritania	Niger	Nigeria	Senegal	Regional West Africa	TOTAL: West Africa	Botswana
AfDB				165,000		165,000	
Algeria	50,000					50,000	
Badea						0	
Belgium				130,000		130,000	
Canada		250,000		1,700,000		2,962,000	
China						100,000	
Denmark				76,000	93,500	455,810	
EEC	1,600,000	143,149		650,000	82,000	4,545,158	388,478
FAO/TCP	166,000		205,000	156,000	110,000	1,331,000	250,000
FAO/OSRO						265,000	
Finland						0	120,000
France	68,500	50,000		100,000	463,037	1,492,537	
Federal Rep of Germany	162,512	536,585		306,585	461,822	2,975,887	150,000
Greece						40,000	
Italy	40,000	200,000		800,000		1,691,000	
Japan				800,000		1,046,000	
Morocco	20,000					20,000	
Netherlands						1,278,669	
Non-Govt Organizations:						625,000	
Bandaid						16,060	
BELACO						3,300	
CARE						0	
CARITAS						0	
Cathl Rlf Servs	13,000					13,000	
Christn Rlf & Dev Assn						0	
Food for the Hungry						5,470	
FRANCE	13,200					13,200	
OXFAM						44,960	
World Lutheran Fndtn	20,000					20,000	
World Vision Intl						60,470	
Unspecified				270,000		270,000	
Norway						1,332,000	1,795,000
OPEC Fund					300,000	300,000	
Spain						0	
Sweden				96,000		411,030	
Switzerland		27,000				103,000	
Thailand				11,000		11,000	
UK: ODA	7,500	18,000		70,000		704,183	370,000
UNDP				400,000	221,000	1,349,500	442,000
UNICEF		25,000				86,000	
USAID	270,000	66,500		2,512,450		6,713,605	1,183,587
WFP						18,000	
WHO						4,480	
Yugoslavia						0	
TOTAL	2,430,712	1,316,234	205,000	8,243,035	1,731,359	30,652,319	4,699,065

Source: FAO/Rome, 12/86

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Fig. D.13 (cont.)

Donor	DLCOEA	Ethiopia	IRLCO/CSA	Sudan	Tanzania	Zaire
AfDB			750,000			
Algeria						
Badea						
Belgium						
Canada		52,000				
China		200,000			200,000	
Denmark			438,000			
EEC		3,605,000		2,000,000		
FAO/TCP			65,000	231,000		
FAO/OSRO						
Finland				280,000		
France						
Federal Rep of Germany						
Greece				50,000		
Italy			68,000	1,000,000		
Japan				102,000		
Morocco						
Netherlands				1,000,000		
Non-Govt Organizations:						
Bandaid						
BELACO						
CARE						
CARITAS		80,000				
Cathl Rlf Servs						
Christn Rlf & Dev Assn		60,000				
Food for the Hungry						
FRANCE						
OXFAM						
World Lutheran Fndtn						
World Vision Intl						
Unspecified						
Norway						
OPEC Fund						
Spain				62,511		
Sweden				560,560		
Switzerland			300,000			
Thailand						
UK: ODA	410,000	80,000	345,000			
UNDP			25,000			
UNICEF						
USAID		75,000		1,024,948	50,000	16,180
WFP						
WHO						
Yugoslavia				64,000		
TOTAL	410,000	4,152,000	1,991,000	6,375,019	250,000	16,180

Source: FAO/Rome, 12/86

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Fig. D.13 (cont.)

Donor	Zambia	Zimbabwe	Regional: Eastern Central and Southern	TOTAL: Eastern Central and Southern	Regional: All Africa	TOTAL
AfDB				750,000		915,000
Algeria				0		50,000
Badea				0		0
Belgium				0		130,000
Canada				52,000		3,014,000
China				400,000		500,000
Denmark				438,000		893,810
EEC				5,993,478		10,538,636
FAO/TCP	124,000	220,000	115,000	1,005,000		2,336,000
FAO/OSRO				0		265,000
Finland				400,000		400,000
France			300,000	300,000		1,792,537
Federal Rep of Germany				150,000		3,125,887
Greece				50,000		90,000
Italy				1,068,000		2,759,000
Japan				102,000		1,148,000
Morocco				0		20,000
Netherlands				1,000,000		2,278,669
Non-Govt Organizations:				0		625,000
Bandaid				0		16,060
BELACO				0		3,300
CARE				0		0
CARITAS				80,000		80,000
Cathl Rlf Servs				0		13,000
Christn Rlf & Dev Assn				60,000		60,000
Food for the Hungry				0		5,470
FRANCE				0		13,200
OXFAM				0		44,960
World Lutheran Fndtn				0		20,000
World Vision Intl				0		60,470
Unspecified				0		270,000
Norway				1,795,000		3,127,000
OPEC Fund				0		300,000
Spain				62,511		62,511
Sweden	175,000			735,560		1,146,590
Switzerland				300,000		403,000
Thailand				0		11,000
UK: ODA				1,205,000		1,909,183
UNDP	22,500			489,500		1,839,000
UNICEF				0		86,000
USAID	100,000			2,449,715	32,925	9,196,245
WFP				0		18,000
WHO				0		4,480
Yugoslavia				64,000		64,000
TOTAL	421,500	220,000	415,000	18,949,764	32,925	49,635,008

Source: FAO/Rome, 12/86

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FIGURE D.14

Donor Inputs per Hectare 1/

Donor	$/ha
Mauritania	12
Senegal	6
Gambia	7
Mali	14
Burkina Faso	9
Niger	8
Chad	19
Sudan	18
Ethiopia	399
Average	11

Source: FEWS 1987

FIGURE D.15

CURRENT COST OF GRASSHOPPER CONTROL, USA ($/HA)

Chemical	Material	Support	Application	Total
malathion	2.5	0.8	2.6	5.9
carbaryl	4.5	0.7	3.6	8.8
acephate	1.7	0.7	4.6	6.0
carbaryl Bran	0.7	0.7	4.6	6.0
Nosema Bran	3.7	0.7	4.6	9.0

Source: Adapted from APHIS, 1987.

These costs are all inclusive and range from a low of $5.5 to a high of $9, which is much lower than the costs for the 1986 Grasshopper Control program in Africa. In part, this is because the APHIS program is ongoing and does not need to mobilize from scratch as happened with the Africa Grasshopper program; nor does it need to air freight ready formulated chemicals between continents. There would appear to be a potential for reducing the costs per ha treated in Africa with a view to making future programs cost-effective. FAO figures for Senegal (Figure D.16) give a cost for aerial application that are comparable with US costs. But this assumes that chemicals are in place. Much of the 1986 cost was the result of having to air freight formulated chemicals into Africa from the US and/or Senegal.

FIGURE D.16 SENEGAL COST COMPARISON

Type	Pesticide	Application	Transport	Total
Farmers				
Dust	14-18		4	18-22
Bait	4		4	8
CPS				
Dust	14-18		4	18-22
Bait	4	4	4	12
ULV (Ground)				
malathion	2	4	0	6
*carbaryl	4.50	4	0	8.5
fenitrothion	2	3	0	5
Aerial				
malathion	2	3	0	5
*carbaryl	4.5	3.5	0	5
fenitrothion	2	3	0	5

*Longer residual may justify additional cost.

Source: FAO, 1986

There are, in any case, a number of pitfalls in utilizing cost-benefit analysis in evaluating locust control. These include the lack of data. There is no good available data on the damage that locust do to crops (Para. C.3). What is available is anecdotal and subjective. Given no data on what damage locusts actually do, it follows that any estimate of the potential damage that they might do is little more than a guess. Given this situation, the measurement of benefits from locust control is subject to wide margins of error. Measurements other than crop damage as a way of determining benefits can lead to the wrong conclusions. One possible measurement would be acreage sprayed, with the cost per hectare being used to determine the most effective means to combat locusts. Such a measure would often show that aerial spraying was much cheaper than hand spraying. Such a measure could be misleading. Many authorities consider that early treatment of locust outbreaks is the most effective treatment. This frequently involves ground, rather than aerial spraying, and on a per hectare basis can look expensive. However on the basis of preventing a plague it can look very effective indeed.

D.8 Policies Concerning Locust and Grasshopper Control Programs

D.8.1 International donors

The FAO has acted as the lead group for coordination of locust and grasshopper control programs since 1952 (when the Desert Locust Programme was launched). That organization has adopted a three-tier approach to the operation. In the first tier a group in Rome at FAO headquarters coordinates donor aid from the international community and acts as a forum for discussion of comprehensive questions.

The second tier are a group of regional coordinating bodies -- located in West and East Africa. Finally, the FAO has set up regional Donor Coordinating Committees in each country.

Initially, the programme was confined to the Desert Locust but it was later extended to include the Central American Locust, the African Migratory Locust, the Malagasy Migratory Locust, the Red Locust and the Bombay Locust.

International coordination of activities has been largely funded from four Trust Funds.

For dissemination of information, FAO provided financial support to the Desert Locust Information Service of the Anti-Locust Research Centre, London (later the Centre for Overseas Pest Research) during 1958-73. A centralized Desert Locust reporting and forecasting service was re-established in 1978 in Rome during a major upsurge. FAO has also assisted in the dissemination of information in survey and control techniques through exchange visits and training courses, on the results of scientific research through the Desert Locust Field Research Stations Technical Services and in the preparation or publication of manuals, handbooks and glossaries (in Arabic, English and French).

Another major activity has been the provision of training, particularly under the 1960-70 UNPD Desert Locust Project and the 1974-76 UNDP Training Project.

D.8.2 Regional organizations

Grasshoppers are generally considered to be a local farmer's or national government's problem rather than an international problem. Regional organizations have thus been confined to migratory pests that cross national boundaries and therefore require international cooperation for their control.

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The independent Regional organizations, those that are operated, staffed and funded by their member nations are:

Organization	Member Nations
DLCOEA (Desert Locust Control Organization for Eastern Africa)	Djibouti, Ethiopia, Sudan, Somalia, Kenya, Tanzania, Uganda
OCLALAV (Organization Commune de Lutte Antiacridienne et de Lutte Antiaviare)	Chad, Cameroon, Dahomey, Cote d'Ivoire, Mali, Mauritania, Niger, Senegal, Burkina Faso
IRLCO-CSA (International Red Locust Control Organization for Central and Southern Africa)	Kenya, Uganda, Tanzania, Zambia, Malawi, Ruanda, Burundi, Zimbabwe, Angola, Botswana, Swaziland, Lesotho

Other Regional organizations are set up as FAO Commissions. The member nations of the FAO Regional Commissions set the policy and determine the activities of the Commission. FAO has accepted the role of coordinator and provides the secretariat to the Commission. Each member nation of the Commission subscribes to the establishment of a trust fund which is administered by FAO and which is used for promoting and supporting control, research and survey activities within the respective nations.

DLCOEA is considered to be the strongest of the Regional Organizations. It has maintained its member nation support through a policy of assisting on principal pest control problems of the member nations whenever locusts are in recession. Examples of other pest control programs in which it participates include banana diseases in Somalia, armyworm control, grain eating bird control, grasshopper control, water hyacinth control, and other locust control.

DLCOEA also contracts out to other nations as requested and upon authorization from their council of ministers. Contractual activities have been limited to locust control.

DCLOEA has functioned well over the years although there are locust recession periods when activity is low. A large fleet of aircraft has been acquired with a very low annual utilization. The same is true of ground transport.

The assessment indicates that the weakest part of the DLCOEA operations appears to be control over the flying side which is the key to the success of present operations and vital

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to future expansion. Flying over the vast area under the control of the DLCOEA with few or no navigational aids requires a high degree of skill as does the spraying itself. Operations in mountainous and isolated areas, often in bad weather, requires a special knowledge of flying that can only come with experience and specialized training. Some of the pilots have an excellent background in flying and many years of service which has given them a thorough understanding of locust control and operations. Others have less experience.

There is a need for an expatriate agriculture pilot instructor to assume the duties of chief pilot for a period of time. This could help establish the necessary discipline and safety procedures.

E. The Environment

E.1 Description of the Locust/Grasshopper Control Areas

Introduction

The combined recession and invasion areas of the nine species of locusts and grasshoppers described in the project cover virtually all of Africa. Africa experiences northern hemisphere equatorial and southern hemispheric climate regions. These climatic regions, combined with the varied topography of Africa, have produced environments ranging from deserts to humid tropical rainforests to frost and snow affected highlands. Consequently, Africa's land resources vary widely, even within countries, and generalizations about the continent as a whole are not very meaningful (FAO, 1986). For the purpose of this report, the environmental description of Africa will be based on the FAO's subdivision of Africa into six major regions, with reference made to climatic and vegetation zones and soils classification provided by UNESCO'S publication on the vegetation of Africa and Soils of the World. Other references are used to provide supplementary or more detailed information.

The six major regions (Figure E.1) are:

1. Mediterranean and arid North Africa
2. Sudano-Sahelian Africa
3. Humid and sub-humid West Africa
4. Humid Central Africa
5. Sub-humid and mountain East Africa
6. Sub-humid and semi-arid Southern Africa

This subdivision of the continent provides a rational perspective of the wide variety of Africa's resources since each region has broadly distinctive environmental features.

E.1.1 Physical features

Locust and grasshopper movements are affected by several important geographical features of Africa. In the northwest the

Atlas Mountains of Morocco and the Piedmont Atlas of Algeria act as barriers to the northwest spread of the desert locust. If cool weather prevails they will remain to the south of the mountains or move eastward along the southern slopes of the mountains to southern Tunisia. In the northeast, the mountains of the northern section of Somalia forces locusts to the west to the border of the west to the border of Ethiopia, and to the south to the Ogaden desert and on to Kenya. Alternately, they may move east to the horn of Africa (east point of Somalia) and to southern Somalia and Kenya.

The northern highlands of Ethiopia (Tigra and Eritrea) slow the movements of locusts to the breeding areas of the Red Sea coast.

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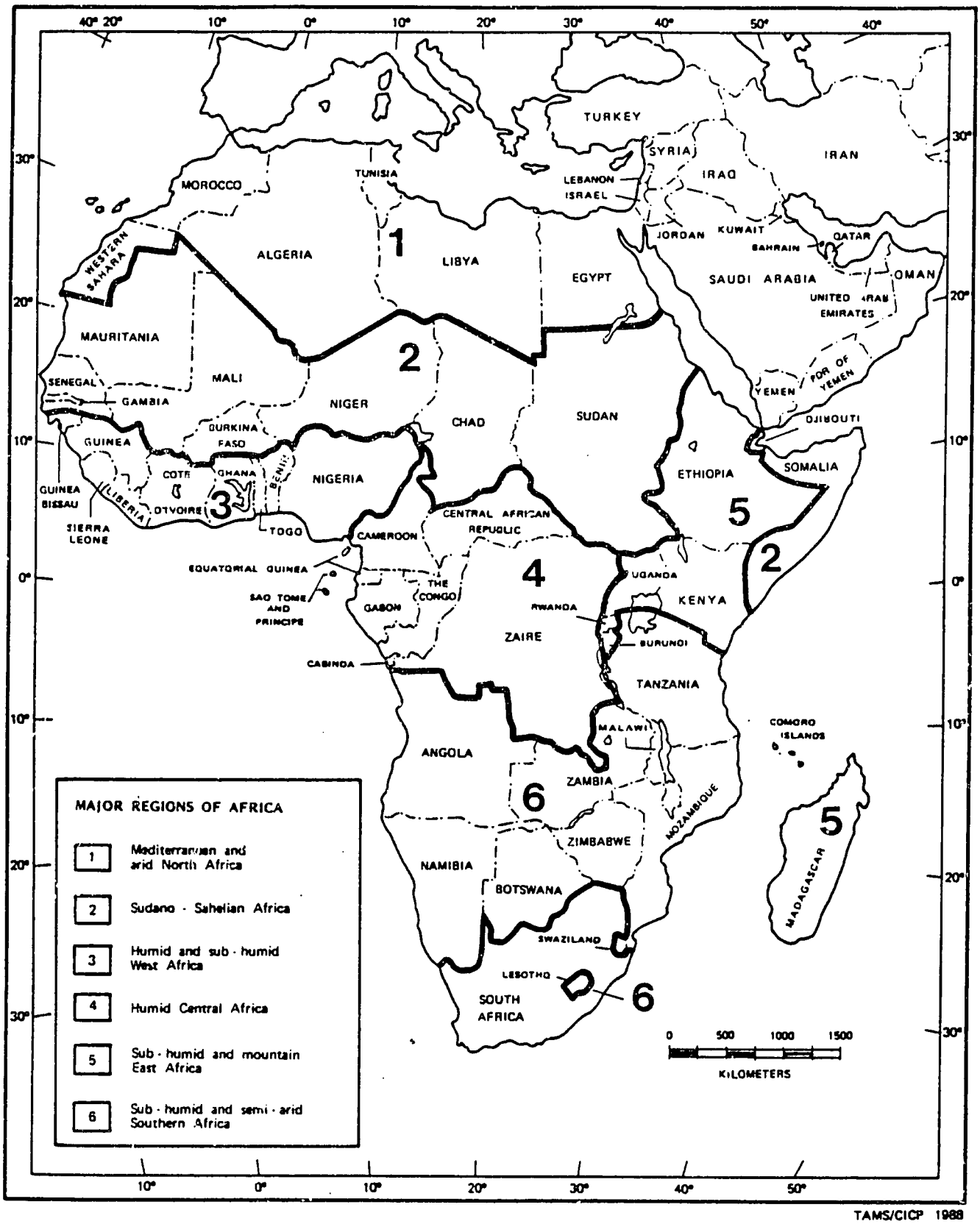

Figure E.1. Major Regions of Africa. Source: FAO, 1986b and 1982c.

The Saudi Arabian escarpment bordering Tihama and Hejaz prevents locust movement to the interior of Saudi Arabia during the winter months. The same is also true for the mountains of Yemen and Hadramaunt. The northern mountains of Iran prevent movement of locusts to the Caspian region of northern Iran and southern Russia during the winter months.

Surprisingly the Sahara, Arabian, and Pakistan and Rogistan deserts of India appear to be no impediment to locust movement.

Some researchers also argue that locusts can only cross to Yemen and the east when the inter-tropical convergence is present and wind direction, associated with them allow locusts to cross the Red Sea to Yemen (personal communication with Cavin, Sayer and Rainey, 1968).

E.1.2 Climate

The major regions are further described according to six climatic zones based on the two climatic factors most affecting production potential, namely temperature and moisture. The zones have been delineated on the basis of "length of growing periods" defined in terms of the number of days when both moisture conditions and temperature permit rainfed crop production (Figures E.2 and E.3).

Rainfall patterns determine hatching,location of breeding and aggregation of locusts and grasshoppers (Appendix 7). In the Sahel, rains normally begin in May and extend to November, with first rains occuring in the south and then progressing north. The most northernly regions have sparse rainfall, often under 50 mm (Figure E.3). Rainfalls of 50-200 mm, occur in sub-Sahara zones (Figure E.3), the Middle East, Morocco and south Asia provide breeding zones for the desert locust. Other species (particularly O. senegalensis) need rainfalls of 200-1000 mm, which occur in West Africa (Gambia to southern Mauritania). Short rains (an extra seasonal rain period in March) and storms (particularly cyclones) off the Indian Ocean are part of more complex weather patterns in East Africa. In this area breeding patterns are more complicated because of more complex moisture zones. Finally, some species of grasshoppers such as the variegated grasshopper prefer to breed in dryer periods of the year.

Weather (fronts forming behind the intertropical convergence) precipitate rainfall in mountainous regions. These habitallly wet areas -- breeding areas for locusts and important habitats for many species -- are found particularly in the Tibesti, Air, Adrar, the Des Aforas mountains and the Ahagyar mountains of Algeria.

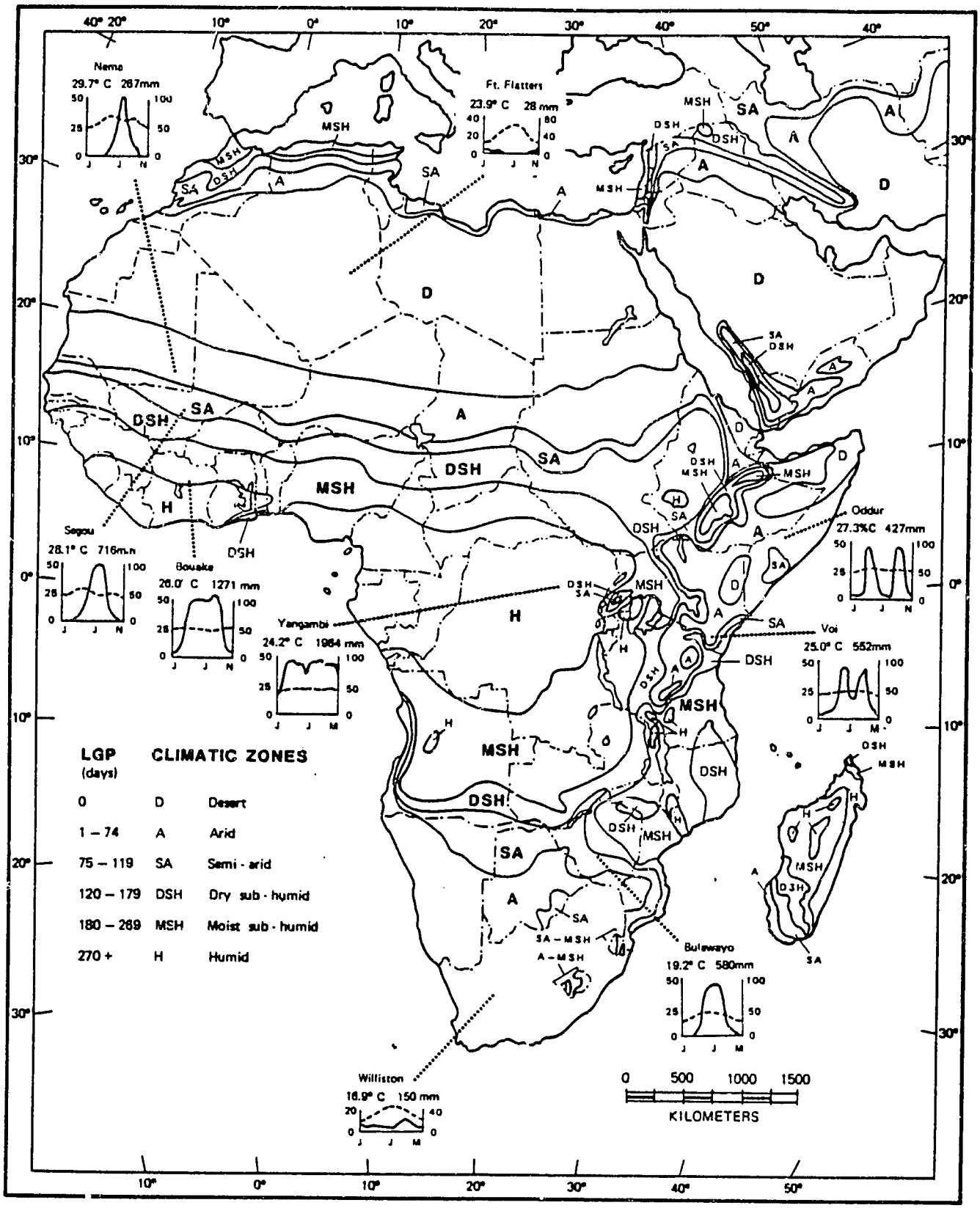

Figure E.2 Climate Zones of Africa and the Near East. LGP is the length of the growing period. The temperature/rainfall graph shows the mean annual and monthly temperatures and rainfall for each recording station. The data are plotted for Jan-Nov (Dec) above the Equator, Jul-May (June) below the Equator. Source: FAO, 1986b, 1982c.

Climatic Zone	LGP (days)	Moisture availability	Area (Million ha)	Rainfall	Vegetation	Land use	Problems
Desert (Saharan)	0	Deficit	822	Less than 100 mm annual rainfall	Very occasional desert thorn dwarf scrub with some semi perennial grasses	(a) Hunters and gatherers (b) Nomadic pastoralists (camels and goats, no cattle) on opportunistic basis on the Southern edge of Sahara Pastoralists come here below in the Sahelian (c) Subsistence agriculture irrigation around oases (d) No rainfed agriculture and no potential	
Arid (Saharan-Sahelian and Sahelian)	1-74	Deficit	408	Single short, extremely variable rainy season; long dry season (8-9 months in Sahelian; 10 months elsewhere) 100 - 400 mm rainfall	Sparse scrub, some perennial grasses. Annual grasses become dominant in entire part of the zone. Acacia - Commiphora woodland in East Africa.	Extensive grazing of sheep goats and camels by nomadic pastoralists, plus some cattle in entire part of the zone. Some millet and sorghum cultivation in depressions, in entire parts of the zone.	Increasing animal populations have resulted in overgrazing, which combined with the effects of forces of cultivation, and pressure on woody vegetation for browse and fuel - exacerbated by drought - have led to land degradation and desertification
Semi-arid (Sahelian-Soudanian)	75-119	Deficit	233	Single short, 3-4 month rainy season. Dry season with cool night temperatures; but before the rains these temperatures increase to 45° C with high relative humidity. 400- 600 mm rainfall	Combretaceae tree and shrub grassland. Annual grasses with some perennial grasses present, but not dominant. Acacia - Commiphora woodland in East Africa.	The zone where nomadic pastoralists and cultivators meet. The driest area where rainfed cultivation is attempted. Millet and sorghum the main crops. Cowpea, groundnut beans, and groundnuts and other short-cycle crops. Irrigation pastures are not possible and fodder crops are difficult. Rice cultivation being attempted in the cooler part of the zone in East and Southern Africa.	One of the most critical areas in Africa. The potential for rainfed cultivation is low due to the extreme variation in annual rainfall. Cultivation expands in good years, to be followed by crop failure, degradation and desert encroachment in "drought" years. Low night temperatures in dry season limit diseases, but also constrain winter season cropping.
Dry Sub-humid (North and South Soudanian and Southern and Northern Guinean)	120-179	Adequate	314	Up to six months humid Rainfall 600- 1 200 mm	West Africa: Partly - Butyrospermum - Parkia woodland and tree and shrub grassland and Andropogon spp. grasses. Central and Southern Africa: Brachystegia and Julbernardia woodland (Miombo) and tree and shrub grassland. Perennial grasses. East Africa: Lowland Combretum-Acacia woodland; and highland Juniperus - Olea forest	The zone of arable crop production, traditionally used by nomadic pastoralists (mainly cattle, sheep and goats) during the dry season and in drought years. Many have now partially settled; and the influx of nomads is in the wet season. Tsetse used to limit access to small areas; but with increasing destruction of the fly habitat this is no longer so. Main crops: millet, sorghum, maize and groundnuts, also cassava and cowpeas, cotton, some potatoes, tobacco, rain fed rice, yams, sesame, cashew nuts. Zebu and Taurine cattle; dwarf sheep and goats. Fodder crops and some pastures possible (e.g. Stylosanthes)	There is considerable pressure on the land resources, and consequent disruption of the traditional cultivation pattern, with resultant decline in yields and degradation. Rainfall deficit, or crop scarcity is widespread.
Moist Sub-humid (North Guinean)	180-150	Adequate	308	Up eight months humid. The wetter rainfall in the north African area is taken as effective as the warmer rainfall in the west of the area. Rainfall 1 250-1 500 mm	Forest, S. Guinean evergreen forest and woodland; and the so-called "derived savanna".	A transition zone for agriculture. It tends to be too wet for seasonal arable crops, and too dry for tree and shrub crops. Palm and cassava are extensively grown in the tropics, also yam, bananas, pineapple, sugarcane and rice. In wetter rainfall areas, wheat and barley are grown; and they are in the highlands of East Africa.	Severe tsetse infestation limits animal exploitation.
Humid (Southern Guinean)	260	Excess	400	Virtually humid throughout the year, often with biomodal patterns Rainfall over 1 500 mm	Tropical rain forest	Tree crops: oil palm, rubber, cocoa; shifting cultivation, based on root crops (yam, cassava, etc). Also some sorghum/maize; bananas, pineapple, sugarcane and rice. Few livestock are kept: some Taurine cattle, but mainly dwarf sheep and goats and poultry. Tropical hardwoods are a valuable resource, where forests remain.	High rainfall may cause problems with annual cultivation.

Figure E.5. Climatic characteristics, land use and associated problems.
Source: FAO, 1986b.

The intertropical convergence exhibits a periodic movement from the south (near the Equator) in the winter to the north (Sahara regions). Not only are weather fronts and rain associated with these areas, but they also set up important wind patterns. In general the winds flow into areas of low pressure associated with the intertropical convergence. To the North of the front winds flow southwest, while to the south they flow northwest. Along the front winds generally flow east/west and facilitate movement and orientation of the locusts and grasshoppers.

Climate is a major force associated with locust breeding in other ways as well. Changes in rainfall between years have often been suggested as key factors in plagues. Wet years are breeding times for locusts. Long periods of drought lead to reductions in populations of locusts, although populations regain quickly when rain returns. Thus populations are keyed to rainfall.

While vegetative or crop production cannot be linked exclusively to any single climatic factor, there are two factors that do exert a dominant influence, namely temperature and rainfall.

E.1.3 Terrestrial resources

E.1.3.1 Soils

The six major regions can be further characterized by the occurence of main soil associations. The continent is covered by 5,000 different map units characterized by the occurrence of different soils, hardened layers in the subsoil, texture of the surface soil and slope. It would be beyond the scope of this report to analyze the soils pattern in such detail. To provide a general overview, the soils of Africa are grouped in ten major associations (Figure E.4 and Figure E.5).

It should be stressed that the main soil associations do not have a homogeneous soils pattern, but are classified as: Desert soils, Sandy soils, Saline soils, Acid soils of tropical lowlands, Soils of tropical highlands, Dark clay soils, Ferruginous tropical soils, Mediterranean soils, Poorly drained soils and Shallow soils.

The distribution of these major soil associations broadly corresponds with the climatic and vegetation zones. This combination of soils together with climate and major types of vegetation lies at the base of the environmental framework of this study.

Soil conditions vary tremendously among and within Africa's six major regions. Recognizing this variability, and matching land use with soil and climatic potential constitutes one of the more crucial

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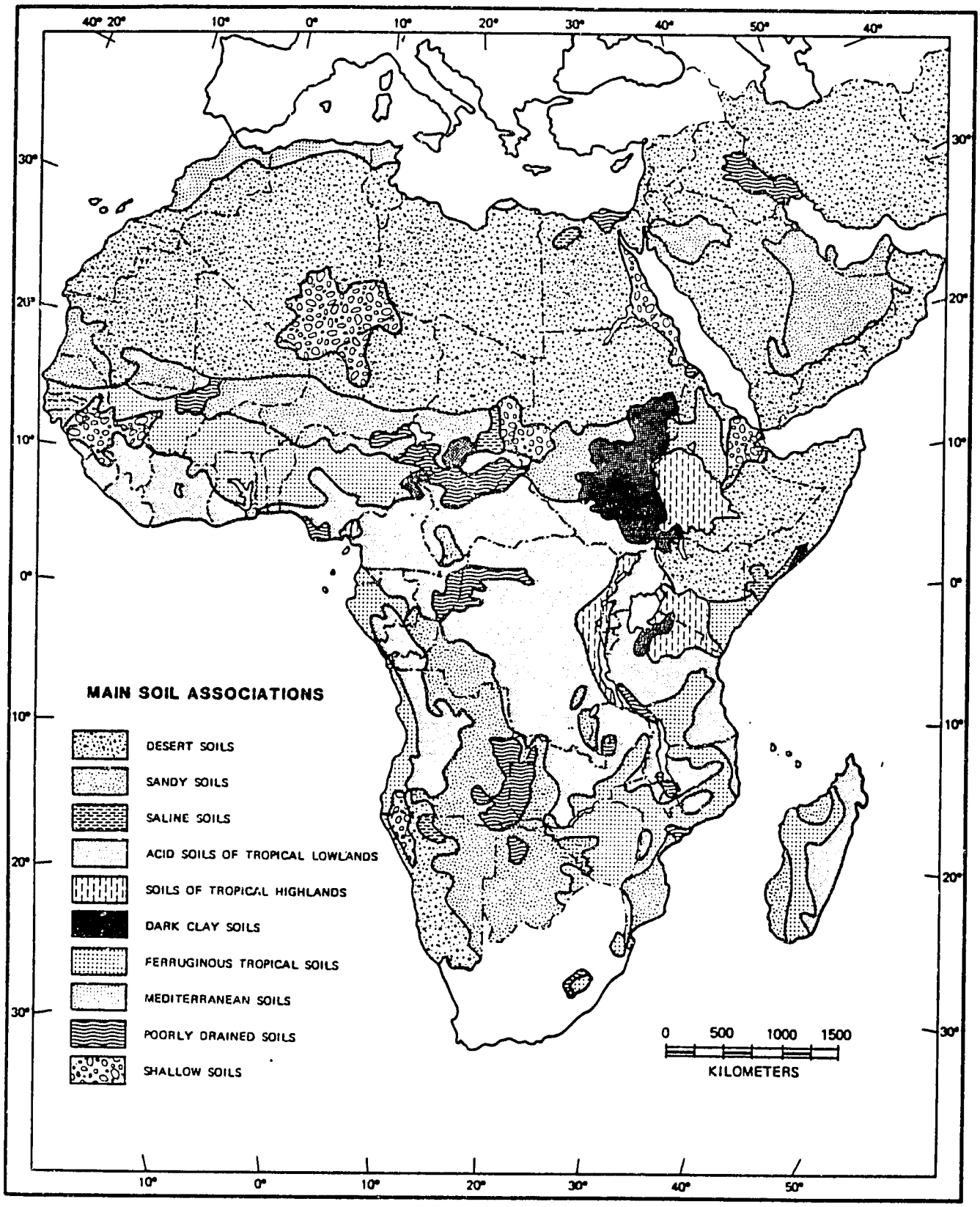

Figure E.4. Main Soils Associations of Africa and the Middle East.
Source: FAO/UNESCO, 1986b and 1977a, b.

Main soil associations	Composition	Soil development	Potential for rainfed agriculture 2/	Limiting factors	Major land use
1. Desert soils	Yermosols, Xerosols; inclusions of saline soils, sandy areas and shifting sands	Weak soil development, generally limited to accumulations of lime, gypsum or salts	Nil to very low	Moisture deficit through drought and coarse textures	Nomadic pastoralism in the least arid part of the desert belt
2. Sandy soils	Arenosols and Regosols; locally Ferralsols; inclusions of Cleysols	Weak development in coarse textured materials; strong development in podzols	Low to medium depending on management	Moisture stress, low water retention capacity, low nutrient contents	Pastoralism in dry regions; forestry and low intensity food cropping in more humid areas; shifting cultivation
3. Saline soils	Solonchaks, Solonetz; saline phases of other soil units	Varied accumulations of salts, sodium or both	Low, however if reclaimed can reach a medium production potential	Toxic levels of salt or sodium or both	Pastoralism; food cropping when reclaimed
4. Acid soils of erosional landscapes	Ferralsols, Acrisols, Dystric Nitosols	Highly weathered deep soils, high levels of iron & aluminium oxides; clay accumulation in Acrisols & Nitosols; low nutrient retention capacity	Medium to high with good management	Soil acidity; aluminium toxicity, phosphate fixation, erosion hazards for Acrisols	Food cropping under shifting cultivation; permanent tree crops; forestry
5. Soils of tropical highlands	Dystric Nitosols and Andosols	Deep to moderately deep soil development on basic rocks or volcanic material	Medium to high with good management	Phosphate fixation	Food cropping, permanent tree crops; cash crops; forestry
6. Dark clay soils	Vertisols and vertic groups of other soil units	Deep cracking clays	Medium to high with good management	Hardness when dry, sticky when wet; tillage problems; temporary waterlogging	Grazing and less cropping; some waterlogging and workability problems
7. Ferralitic tropical soils	Ferric Luvisols; Ferric Cambisols & Orthic Luvisols as inclusions	Highly weathered soils with clay accumulation and high base saturation	Medium with good management	Low nutrient retention capacity; surface crusting; erosion hazards; frequent gravel layers and iron pans	Mainly shifting cultivation for food crops
8. Mediterranean soils	Chromic Luvisols; Cambisols; inclusions of Vertisols	Moderately weathered soils with clay accumulation, and high base saturation	Medium to high for food and horticultural crops	Erosion hazards; surface crusting when dry; moisture stress	Food crops, vine and olives
9. Poorly drained soils 3/	Gleysols and Fluvisols	High groundwater influence; accretion of fresh sediments in Fluvisols; accumulation of pyrite in brackish water deposits	Medium to high with water control, low for acid sulphate soils	Waterlogging; workability when flooded; acidity in sulfidic soils	Food cropping; forestry in acid sulfidic soils
10. Lateritic Soils	Lithosols and lithic subgroups	Weak soil development	Low	Shallowness and steep relief	Shrub or local grazing or forestry depending on climatic zone

1/ These descriptions are very much simplified. Full information on soils and land use is given in the explanatory volume VI to the Soil Map of the World dealing with Africa (FAO, 1978).

2/ The production potential of certain main soil associations can be considerably increased with irrigation especially the dark clay soils and the Mediterranean soils. Other soils also offer a considerable irrigation potential.

3/ This major soil association groups both alluvial soils and inland soils suffering from waterlogging. A clear distinction needs to be made with regard to use and fertility levels but this separation could not be made at the scale of the map.

Figure E.5. Characteristics of the Main Soils Associations in Africa. Source: FAO, 1986b.

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responsibilties of today's agricultural planners and those concerned with natural resource management.

E.1.3.1.1 Soil productivity

Soil productivity may be affected by locust and grasshopper control programs. Three main factors which affect soil productivity are the nutrient supply, the moisture retention capacity and rooting conditions. The long-term overall production capacity is strongly affected by soil degradation or conservation, and by the ratio between the periods that the land is cultivated or in fallow. When higher production is required, fallow periods need to be shortened and the nutrients removed must be replaced by using organic manures or mineral fertilizers.

Soils have greatly varying abilities to supply and retain nutrients and to respond to fertilizer applications. Most soils require added nitrogen and phosphorous is grossly deficient in many African soils. Other nutrient deficiences are not uncommon, in particular potassium, sulphur, calcium and micro-elements such as zinc, copper and molybdenum. Soil acidity may be a constraint.

E.1.3.2 The nature and distribution of African vegetation

The major vegetation types of Africa can be described as; forest, with its altitudinal and edaphic trees such as montane, swamp, mangrove, and bamboo forests; thicket; mixed forest-grassland formations, such as woodlands, wooded savannas, tree and shrub savannas, and steppes; grasslands, such as grass savannas and steppes; desert and semi-desert vegetation; and nilotic vegetation (Figure E.6).

Among the various classifications of African vegetation this so-called "Yangambi classification" remains the most widely used. It was adopted in 1956 by a meeting of specialists in African phytogeography sponsored jointly by the Scientific Council for Africa South of the Sahara and the Commission for Technical Cooperation in Africa South of the Sahara. It was adopted by UNESCO and the "Association pour l'Etude Taxonomique de la Flore d'Afrique Tropicale" (AETFAT) for the preparation of the "Vegetation Figure of Africa South of the Tropic of Cancer" (1959).

The areas throughout Africa occupied by the main vegetation types are subject to change (Figure E.7). In West Africa, for example, forest land in the shifting cultivation cycle will, after cultivation, successively change from shrub and bushland fallow to woodland, to secondary forest and back to forest proper in the course of twenty years or so. There are many areas

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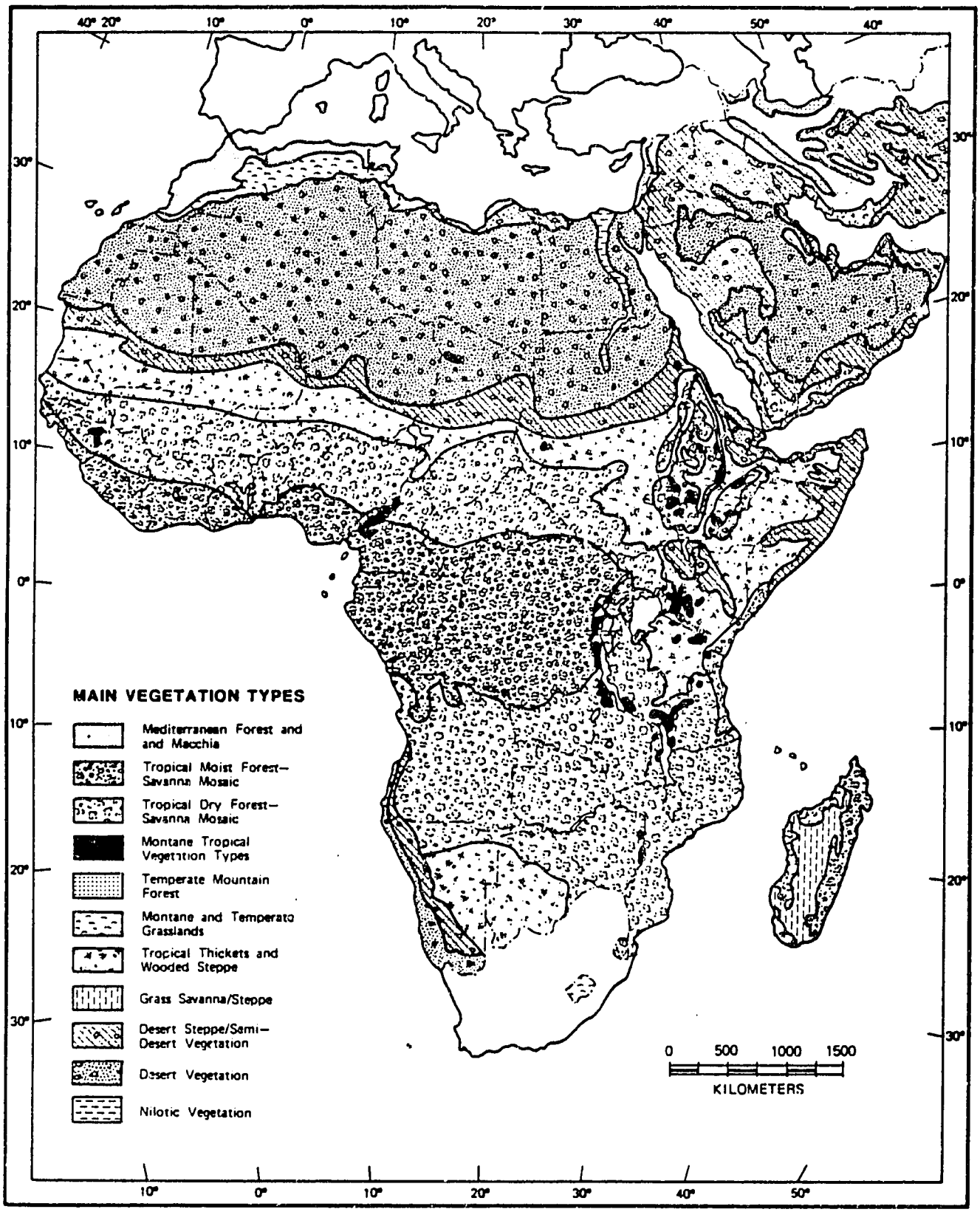

Figure E.6. Main vegetation types of Africa and the Middle East.
Source: FAO, 1986b, and FAO/UNESCO, 1977a, b.

1985 (in 1 000 ha)

Region	Tree formations				Fallows		Shrubs	Woody formations and fallows	
	Closed 1/	Open 2/	Total	% 3/	Tree	Bush		Total	% 3/
Mediterranean and arid North Africa	1 361	8 070	9 431	1.64				9 431	1.64
Sudano-Sahelian Africa	2 933	108 475	111 408	13.17	610	25 750	16 675	304 443	35.99
Humid and sub-humid East Africa	14 326	35 070	49 396	23.53	37 082	23 845	49 735	160 058	76.25
Humid Central Africa	168 855	110 575	279 430	68.87	18 115	16 850	39 210	353 605	87.15
Sub-humid and mountain East Africa	15 775	31 671	47 446	17.99	3 857	12 405	66 440	130 149	48.92
Sub-humid and semi-arid Southern Africa	8 251	204 165	212 416	37.76	6 720	32 670	121 065	372 871	66.28
AFRICA TOTALS	211 501	498 026	709 527	24.79	66 384	111 520	443 125	1 330 557	46.49

1/ Roughly equivalent to Humid Forests.
2/ Roughly equivalent to Dry Woodland.
3/ As percentage of total land area of Region.

Figure E.7. Estimated areas of natural woody vegetation and related fallow.
Source: FAO, 1986b

however, where fallow periods become shorter and woody vegetation does not re-establish itself. Clearing land for wood products or new agriculture is also occurring.

Looking to the future, it is clear that deforestation will continue and that forest and woodland will be converted to crop production and other uses. At present the annual rate of deforestation is some 3.7 million ha.

The distribution of the vegetation in Africa is closely correlated with climatic conditions, locally modified by topography and soil. Most of the vegetation has been disturbed, often severely, by man. It does however, provide food, fodder, fuel and building materials, as well as protecting the land from erosion and helping to restore its fertility. The use and conservation of vegetation is therefore an essential ingredient of any strategy to increase agricultural production in Africa.

E.1.3.3 Animal life

Africa's varied and important wildlife is comprised of the familiar and popular species including the large predatory cats (lion, leopard, cheetah), the large and spectacular elephant, rhino, hippo and giraffe, monkeys and apes, colorful animals like the zebra, hundreds of bird species, large and small reptiles, myriad small mammals, and the large array of antelopes and gazelles.

Many of Africa's wildlife species are familiar either because they are spectacular or they have been so often photographed and popularized.

It is important to realize however, that Africa's various habitats support many more less spectacular species of wildlife that comprise carefully balanced communities.

For example, the Serengeti plains of Tanzania are known for the variety of wildlife they support; many species in large, concentrated numbers. Prides of 20 to 30 lions are not uncommon. Thousands upon thousands of gazelles roam the plains, as do millions of wildebeeste. However, the biomass of all these mammals does not equal that of the largely unseen insects supported by the plains.

Different habitats are characterized by different wildlife communities, but the most telling characteristic of Africa's wildlife is the variety. Because of the vast savannas and grasslands across Africa, this variety of wildlife is often easily apparent -- unlike wildlife characteristics of forests. The grassland area is also likely to diminish, due more to degradation than to conversion to cropland.

Natural vegetation provides the habitat for Africa's varied and important animal resource. The importance of the wildlife resource includes, but is not limited to:

1. Wildlife, including small mammals, birds, and invertebrates, as well as larger species, contributes significantly to the protein

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portion of some local diets: as much as 66% in rural areas of Botswana, 70% in Liberia and 75% in Ghana.

2. Compared to domestic livestock wild mammals are more efficient converters of natural vegetation to meat, are better adapted ecologically with greater disease resistance, and require less management. Attention is therefore being given to methods of exploiting them more effectively. Small rodent breeding for food has potential in this context.

3. National park and wildlife based tourism is an important source of foreign exchange revenue in some countries, and has potential in many others.

4. Animals are a unique part of the African environment and play a significant role in ecological processes. Without the fauna found in all habitats, these processes are interrupted, leading to myriad detrimental spin-offs for local and broad ecosystems, including the disruption of biological diversity.

E.1.3.4 Vegetation use by man

Locusts and grasshoppers occur in both cultivated and non-cultivated (wild) areas. In very general terms, cultivated areas, which are where locust and grasshopper damage occur, are 1) floodplains and banks of river and lakes, 2) irrigated agriculture, and 3) rainfed agricultural areas. Often floodplains after flooding are prime breeding areas for species such as African Migratory Locusts and grasshoppers. These are prime survey and spraying areas for grasshoppers. Cultivation may affect locusts and grasshoppers in two contributing ways: bringing extra moisture to soil through irrigation and distrubing egg pods in cultivated fields. Rainfed areas, which are often marginal farming areas in Africa, may suffer proportionally more from locust and grasshopper damage than other cultivated areas. Perhaps most importantly, farmers act as sources of information on locust populations; their pattern of reporting may strongly influence our recognition of what problem exists (Rainey, 1977).

Grasslands provide a large proportion of the food requirements of the livestock and game populations. Grass biomass production is variable and ranges from 400 kg/ha in the semi-arid zone to over 3,000 kg/ha in the dry sub-humid zone (Boudet and De Wispelare, 1976). In addition to the grass, herbaceous and woody plants are also eaten. Different classes of livestock have different preferences. Sheep and cattle prefer herbaceous plants, although sheep tend to be more selective, while goats and camels graze on shrubs and trees.

E.1.4 Aquatic resources

E.1.4.1 Rivers and surface water

The hydrology of the African continent is dominated by four major river basins: the Nile, the Zaire, the Niger and the Zambezi. Most of the

African rivers remain relatively unmodified and are associated with extensive wetlands in the form of flood plains, swamps and lakes, all of which are considered critical habitats. In general, Africa has less available surface water per unit area, higher evaporation and (a consequence of the first two factors) less runoff into the sea per unit area than other major region of the world. The principal river basins are shown in Figure E.9 and in Figure E.10.

E.1.4.2 Aquatic plant and animal life

The African continent has a wide variety of water bodies including lakes, rivers, reservoirs, floodplains, lagoons, estuaries, mangroves and small natural and artificial water bodies which support fisheries plus a growing number of aquaculture activities. Because of the great seasonal changes in the water levels of many of these bodies (in particular the floodplains) it is difficult to determine the precise areas of these waters but they total more than 450,000 km or about 2% of the total continental area. See Figure E.8.

FIGURE E.8

Surface areas of some fished systems of the African continent

Type of system	Surface area (km^2)
Large lakes (> 100 km^2)	196,800
Large reservoirs (> 10 km^2)	40,000
Floodplains	169,200
Coastal Lagoons (> 1 km^2)	10,200
Estuaries (> 1 km^2)	16,900
Mangroves (forest, creeks and backwaters)	34,500
	467,600

Source: FAO Fisheries Data Bank

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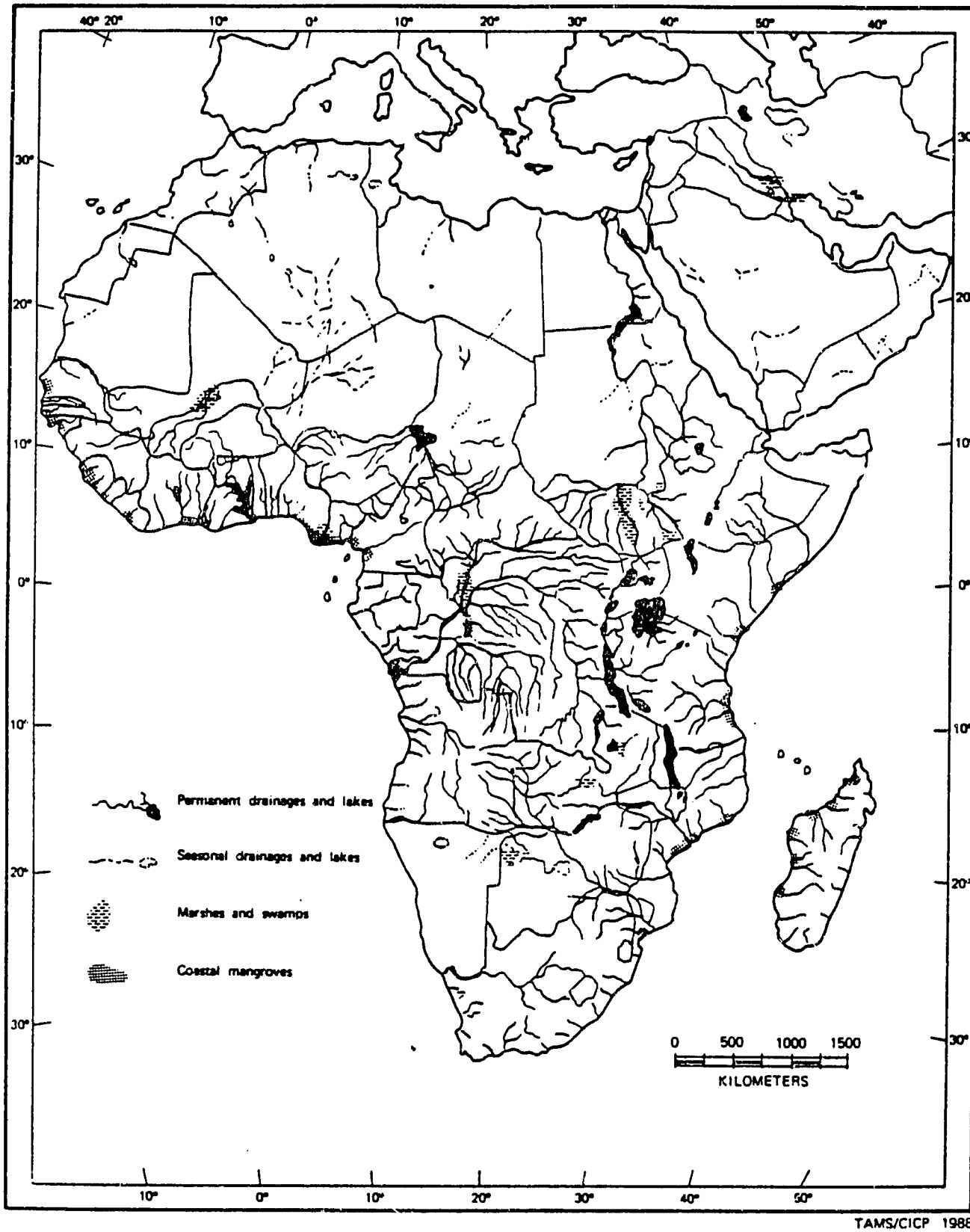

Figure E.9. Rivers, lake basins and major wetlands of Africa and the Middle East. Source: FAO, 1986d, and FAO, 1982c.

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Areas and Discharge of the Principal River Basins of Africa

Basin	Principal countries	Basin Area (km2)	Mean annual discharge (km3)
Discharge into the Mediterranean			
Nile	Egypt, Ethiopia, Sudan, Uganda	2,800,000	84.0
Discharge into the Indian Ocean			
Shebelli	Ethiopia, Somalia	205,400	2.5
Juba	Ethiopia, Somalia	168,100	n.a.
Tana	Kenya	42,217	4.1
Athi	Kenya	n.a.	1.3
Wami	Tanzania	36,450	2.5
Rufiji	Tanzania	158,000	30.0
Ruvuma	Mozambique, Tanzania	155,400	n.a.
Zambezi	Angola, Mozambique, Zambia	1,250,000	103.4
Save	Mozambique, Zimbabwe	88,395	5.0
Limpopo	Mozambique, Zimbabwe	412,000	5.3
Discharge into the South Atlantic			
Zaire	Congo, Zaire	4,000,000	1,325.0
Ogooue	Gabon	203,500	148.9
Sanaga	Cameroon	131,500	65.2
Discharge into the North Atlantic			
Niger	Guinea, Mali, Niger, Nigeria	1,215,000	179.8
Volta	Burkina Faso, Ghana	394,100	39.8
Gambia	Gambia, Guinea, Senegal	77,850	5.0
Senegal	Guinea, Mali, Mauritania, Senegal	338,000	21.8
Discharge inland			
Awash	Ethiopia	113,700	n.a. into Danakil Desert
Chari-Logone	Central African Republic, Chad, Niger, Nigeria	n.a.	43.2 into Lake Chad
Omo	Ethiopia	77,200	16.1 into Lake Turkana
Okavango	Botswana	53,000	0.6 into Okavango Swamp
Gash	Sudan	23,500	0.6 into Gash Plain

Figure E.10. Areas and discharges of the principal river basins of Africa. Source: FAO, 1986d.

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The limnological characteristics of African waters vary enormously and thus their productivities, but almost all except the high saline lakes of the Rift Valley provide the basis for commercial or subsistence fisheries.

Fish or fisheries are economically and socially very important in Africa as a source of employment and income, food or foreign exchange in different proportions depending on the kind of fishery. For some half dozen countries fish represents over 10% of the total protein supply from all sources while in some 12 or so countries consumption of fish is equal to or exceeds that of meat. The importance of fish in the dietary pattern of many African countries is considerably enhanced by the fact that it helps to correct a basic protein/caloric imbalance due to the generally heavy dependence on grains or starchy roots. Where fish play a prominent part in national dietary patterns, inland fisheries provide a significant proportion of total supplies. Lakes and reservoirs account for about half the freshwater fish production, and the construction of new reservoirs adds to this each year.

E.1.5 Public health

E.1.5.1 Human settlement patterns

The human settlement patterns in tropical Africa are characterized by five major features:

1. Rural-urban migration leading to rapid and uncontrolled population growth, particularly in squatter areas at the fringes of larger cities.

2. Migration into new areas of agricultural development.

3. Another important population group are the traditional nomads who travel along the main stock routes of West and East Affrica.

4. There is another group of highly mobile people whose whereabouts and population dynamics are even more obscure, i.e., the migrant labor force. Their presence in temporary villages near the site of their employment is often not documented.

5. Finally, there are the traditional villages and communities.

Figure E.11 depicts the distribution of the population density in Africa. Areas of heavy concentration exist in North Africa, in the valley of the Nile, around Khartoum, in the high plateau of Ethiopia, in Kenya, Burundi and Uganda, and in West Africa in Nigeria, and along the coast. In contrast, the Sahelian countries have low population densities. Here communication is poor and access to health services difficult.

Of particular interest to assess and reduce the potential health risks of pesticide use are the settlement patterns in newly developed agricultural areas.

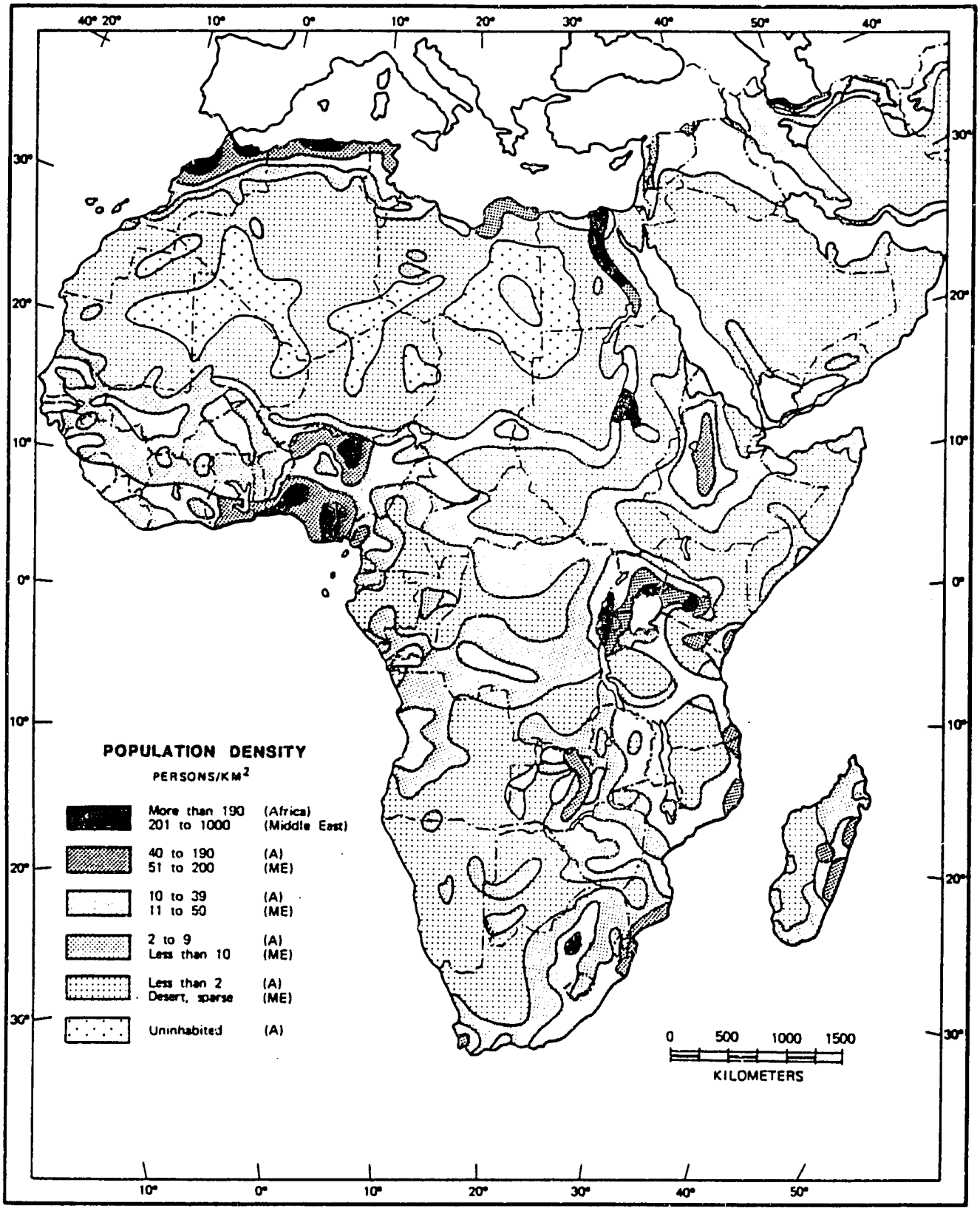

Figure E.11. Population density. Source: FAO, 1986f, 1982c.

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With regard to pesticide exposure, knowledge of the specific human settlement patterns must include an assessment of the construction types of houses, sources of water supply by season, sanitation practices, traditional agricultural activities, and climate.

E.1.5.2 Human health standards

As a continent, Africa has the lowest health care standard in the world. There are, at present, a number of major international efforts to cope with the public health problems caused by tropical diseases. Those that have a direct bearing upon projects in which pesticides are being used include the following: the Program for Research and Training in Tropical Diseases (TDR) of WHO/UNDP/IBRD, the regular program of WHO which amounts to about 2% of the total global health resources; the Onchocerciasis Control Program (OCP) in 11 West African countries; and a large number of bilaterally assisted disease control programs for malaria, trypanosomiasis, leishmaniasis, lymphatic filariasis, yellow fever, and other arthropod-borne diseases.

A second group of disease control and prevention projects involve health conditions that may either be adversely affected by the effects of heavy pesticide exposure or lead to increase of pesticide toxicity. These projects include the Diarrheal Disease Control Program; the Extended Program of Immunization; the Child Survival Program; the Vitamin A and other nutritional projects in the Maternal and Child Health program; schistosomiasis control programs; and a number of smaller disease control projects.

In all of rural tropical Africa, in most squatter areas and shanty towns at the fringes of large cities, and even in some larger towns malaria has remained practically uncontrolled. Malaria control must always be considered when plans for pesticide use are made for other targets.

Other important vector-borne diseases that have major control programs in which pesticides are applied for vector control include systematic larviciding against blackflies in the 11 countries of the Onchocerciasis Control Program, tsetse fly control in trypanosomiasis, Culex and Anopheles control in filariasis, Phlebotomus control in kala azar and other forms of leishmaniasis, treatment of water sources with temephos for control of Cyclops in dracontiasis, of Chrysops in loiasis, and for the control of the ectoparasite vectors of rickettsioses, relapsing fever, etc. The control of urinary schistosomiasis may include the mass treatment with the drug metrifonate which is itself an organophosphate compound. Patients treated with metrifonate which suppresses cholinesterase may develop severe reactions when exposed to organophosphorous pesticides. Inevitably, the use of pesticides for the control of human diseases of public health importance overlaps with similar applications for control of the vectors of zoonoses and of agricultural pests.

When ever the disease patterns in a given area change because of rural development projects, man-made water impoundments, new roads, or agricultural development which includes the large-scale use of pesticides, an appropraite professional assessment of the local disease patterns and of the potential health risks must be made on the spot. The results of this

assessment must be translated into appropriate training programs that must include the personnel at the primary and secondary health care levels.

E.2 Description of the Environment of the Near East and South Asia

Locusts and grasshoppers have been reported throughout the Near East, Middle East and in south Asia. Most recently outbreaks have been reported in Yemen and Saudi Arabia.

E.2.1 Soils

Studies of formations and soils in general are still in transition, particularly in the Middle East, owing largely to the great and recent interest in mineral and oil exploration. Approaches have been made to classify soils on the basis of environment, with climate the dominant factor. Soils have been distinguished for the true deserts, the arid steppes, the sub-arid and sub-humid areas. A summary of these varied soils follows. Main soil types of the Middle East are shown in Figure E.4.

A. Desert zone (lithosols). Soil forming processes are at a very early stage. The main feature of these soils is the physical breakdown under temperature changes, strong winds, and flash floods. Coarse, loose sand, gravel, and slate efflorescensces are common in desert soils. The accumulation of salt deposits in natural basins form salt pans. Given sufficient water these low areas, or pans become extremely important for wildlife.

B. Arid steppes. Several general soil types occur here, including sandy steppe soils, sierozem soils (Both low in humus or organic matter), and gypsum.

C. Semi-arid to humid areas. As aridity becomes less pronounced, soils of different qualities are found, including brown or brown-yellow soils (clays and clay loams), infill and bench soils (limited to shallow areas and tiny depressions and crevices, thus limiting distribution of plant life), and alluvial soils, where waterlogging occurs temporarily.

Characteristic of most soils in the Middle and Near East is the occurance of a hard, calcrete crusting. These can have important social and economic affects as this crusting promotes highly specialized forms of sustainable agricuture, requiring hard work and promoting both concentrations of people during good growing seasons as well as nomadic behavior.

E.2.2 Vegetation types

A. Mediterranean vegetation is characterized by having restricted distribution along wetter, coastal areas, particularly coastal plains. It includes vines, wheat, olive,

fruit, shrubs, and herbs. Plant associations or groupings include maquis or macchia, densely set evergreen oaks, myrtles, broom, thorn bushes and shrubs.

B. Steppe vegetation, or Irano-Tunonian vegetation evolved under the influence of steppe climate, a wide seasonal variation in temperature together with a lower rainfall. This steppe vegetation makes up a recognized botanical province and includes scattered carob, juniper and terebinth trees, and expanses of Christ thorn and wild plum in a park-like structure. More than half the steppe vegetation disappears in summer.

C. Desert vegetation, often referred to as Saharo-Sindian vegetation, is characterized by showing a remarkable adaptation to dry and saline conditions. Thorns in particular demonstrate this ability.

D. Mountain vegetation is represented by four distinct types; three are forest growths and one is Alpine pasture or heath. The forest growths are:

(1) of mixed evergreen, decidiuous, and coniferous trees, and
(2) of primarily hardwoods (oak, hazel, alder, and others associated with an undergrowth of brambles, ivy, and other creepers, and of
(3) the Colchian or Pontic forest with large hardwoods and dense undergrowth as abobe, but with widespread occurrence of rhododendron.

E. Savanna vegetation is characterized by grasslands interspersed with trees (acacias in the drier areas) and an intermixture of broader-leaved deciduous species.

F. Riverine vegetation is found along alluvial lowlands (along rivers and major waterways). The riverine vegetation is characterized by aquatic grasses, papyrus, lotus and reeds. Scattered willows and alders occur in these alluvial lowlands but the most common tree is the date palm. Mangroves are predominant in coastal and near-coastal estuaries and inland wetlands, and associated with vegetation between riverine and Mediterranean types. Mangroves are found extensively throughout the Near East and South Asia.

Overall, the Near and Middle East is less than 3% forested (compared to nearly 30% for eastern Europe; 50% for the U.S.S.R.). The main vegetation types of the Middle East are shown in Figure E.6.

E.2.3 Climate

Climatic conditions are dependent on and determined by the combinations of winds from air drawn over the Middle and Near East from somewhat varied origins. These air streams, influenced by jet streams, dictate climate including pressure, humidity, rainfall, and temperature.

For example, air drawn over the Middle and Near East from several sources during the summer include dried-out monsoonal air and other dry air masses giving almost no rainfall. Towards autumn, bursts of maritime air from the Mediterranean disturb summer air. These maritime airs are characterized by higher humidities and lower temperatures. Following the season of hot winds, during winter and spring waves of cold air from Eurasia bring rainfall and, in some regions (particularly higher elevations) snowfall.

Temperatures are generally high in summers, with cool nights attributed to cooling by radiation. Temperatures through this control area range generally from -11° C to 40° C, with 29-30° C being typical for average July temperatures. Humidity is characterized by considerable local variation, with 70-75% being usual.

Rainfall throughout the area is characterized by a Mediterranean rhythm of summer drought and winter rain, with variations from 70-900 mm per annum. (Jerusalem has recorded from 307-1060 mm). Exceptions to this rhythm are coastal regions of northern Iran and the Yemen uplands. The key description of rainfall, like for climate for the entire control area is: considerable local variation. Climatic zones based on "length of growing period" are shown in Figure E.2.

E.2.4 Animal life

From mangrove swamps, to tropical forests, to Alpine forests, to semi-arid and semi-humid steppes to true deserts, the variation in the physical features and vegetation is mirrored by the variation in the plant and animal life. Neither has received the attention wildlife in Africa has gained, but the plant and animal diversity is no less spectacular.

From the hundreds of thousands of different forms of insects, largely undescribed, to the conservative estimate of 1,500 vertebrate animals throughout the area (including snakes, mammals, frogs, lizards and fishes) the vertical ecological structures from below-ground on the desert to aboreal conditions in forests harbor representatives of all trophic levels.

The Paleartic region (biogeographical region including northwest Africa and across the Arabian peninsula is bordered by what historically has been considered a barrier of mountains, seas and deserts for the movement of plant and animal life. A few hundred species of migratory birds cross this barrier, however, and are found mixing with permanent avian residents throughout the area.

Antelopes, gazelles, wild asses, sheep, and other ungulates are found in rich variety in different habitat types (from desert to mountain), as

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are birds ranging from partridge and bustards to passerines found at elevation up to 17,000 feet. Predatory birds and reptiles are well represented as well.

Shrinking forested lands and more importantly, the rapid decline in woodland edge areas have caused declines in several forms of plants and wildlife. The disappearance of species and habitats in Africa receives ample attention. This phenomenon in the Middle and Near East is no less significant. In South Asia habitat losses for wild flora and fauna are receiving increased attention, but goes on at alarming rates vis-a-vis the tremendous increase in human populations and the adverse affect that has had, and is having on critical habitats -- particularly forests, wetlands, and transition zones.

E.3 Amounts and Location of Pesticides Used

To adequately assess potential environmental consequences of pesticide use for locust and grasshopper programs and to set these effects in perspective with other pesticidal uses, we have summarized available information on the amount and locations of pesticides used.

E.3.1 Locust and Grasshopper Insecticides

The best and most relevant reporting of pesticides use on locusts and grasshoppers is for 1985-1986 (Figure 12, Figures E.13, E.14, and E.15). In seven Sahel countries total pesticide usage varies from 34 to 1014 metric tons (Figure E.16). FAO has been involved in complex locust and grasshopper control programs throughout most of Africa over more than 1.3 million ha over 11 Sahelian countries (Figure E.13). The types and quantities of pesticides provided by these countries is available (Figure 12) although the role of precise quantification is not taken by most of the donors. Thus, there are often differences in the number of countries, types of pesticides or total programs differ markedly. These 1987 figures are presently incomplete; although AID reports large shipments of pesticide to Burkino Faso, Chad, Gambia, Mali, Mauritania and Senegal. The lack of reliable information -- complicates the problem in defining pesticide risk due to locust control programs.

E.3.2 Other Pesticides

No single organization seems able to provide complete or accurate information on the qauantities or types of pesticides used in Africa for <u>any uses</u>. It appears that a comprehensive review of pesticide use is essential in order to be able to define the relative risk due to pesticides in the locust/grasshopper programs. Previous efforts to assess pesticide use in Africa showed that estimates of total pesticides imported (based on a survey of manufacturers) was exceeded by the estimates of the amounts used on crops.

PESTICIDES USED IN 1986 SAHEL COUNTRIES' GRASSHOPPER AND LOCUST PROGRAMS

	MAU	SEN	GAM	MLI	BRF	CHD	NER	TOTAL
Propoxur dust 1%	--	--	5925 kg	--	--	--	141T	592T
BHC dust 3% gamma	--	--	--	511T	--	--	23T	534T
Lindane 5% dust	--	--	--	--	--	--	155T	155T
Propoxur dust 2%	628T	--	--	248T	314T	362T	--	1552T
Fenitrothion dust 1.8%	10T	--	--	--	--	--	--	10T
Unspecified liquid	--	--	--	--	--	1236001	--	1236001
Fenitrothion 20%	--	--	--	--	--	--	45081	45081
Fenitrothion 50 EC	--	--	5541	--	--	--	--	5541
Fenitrothion 50 ULV	83051	--	550001	1630001	--	--	--	1668001
Sumicombi 50%	234301	920001	--	18001	--	--	--	18001
Fenitrothion 96 ULV	--	--	550001	325001	454401	--	930251	2918951
Malathion 50 EC	--	--	11641	--	--	--	--	11641
Malathion 50 ULV	122601	--	--	--	--	--	--	122601
Malathion 90 ULV	118901	--	--	--	--	--	--	118901
Malathion 96 ULV	--	3865001	18001	170001	--	--	--	4053001
Diazinon 90 ULV	99601	--	94001	90001	145201	--	--	428801
Diazinon 95 ULV	--	330001	--	--	--	--	--	330001
Decis ULV +EC	--	--	--	--	--	--	246891	246891
Cypermethrin (EC)	--	--	19201	--	--	--	--	19201
Endosulfan 35 EC	--	--	6431	--	--	--	--	6431
Trichlorfos 50 WP	--	--	1200 kg	--	--	--	--	1200 kg
Carbaryl 85 WP	--	--	1050 kg	--	--	--	--	1050 kg

Source: Assessment of 1986 Program for Locusts and Grasshoppers, FAO, 1986

Figure E.12 Pesticides used in 1986 Sahel countries' Grasshopper and Locust programs
Source: Assessment of 1986 Program for Locusts and Grasshoppers, FAO, 1986

Figure E.13

PESTICIDES USED IN LOCUST CONTROL PROGRAMS, 1985-1986

COUNTRY LOCALITY	MONTHS	TYPES OF INFEST-TATION	AREA TREATED (km sq)	INSECT-ICIDE USED (l or kg)	*METHOD OF APPLICATION
ALGERIA					
Southern Sahara	May	Ad	1	BHC bait	G
BOTSWANA					
Baralong Farm	Apr-Jun	Ho,Ad	3.6	288 l Fenitrothion	G
BOTSWANA	Feb-May	Sw,HoB		5000 l Diazinon 30%	G
				1500 l Diazinon 40%	
				30000 l Fenitrothion	
				1000 l Cypermethrin	
				5000 l Alphamethrin	
EGYPT	Dec-May/86	Ho Sw			
EGYPT					
SE'ern Desert	Feb-May	Ho,Ad	200	3850 BHC dust	G
				200 Malation 57%	
				440 Lindane 15%	
				50000 BHC bait	
ETHIOPIA					
Cam Cewa	Aug	Ho,Fl	6		ENS
ETHIOPIA					
Eritrea	Aug	Ho	2400	Dieldrin	A
	Sep		15		G
GHANA	Jan-Mar	Zo			
INDIA					
Rajasthan	Aug	Ho	2	4650 kg BHC dust	G
MAURITANIA					
Lake R'Kiz	Oct-Nov	HoB	285		
Boutilimit	Nov-Dec	HoB	100	Sumicosbi Liquid	G
				Fenitrothion	G
				Dieldrin	G
MOROCCO					
Merzouga	Jun	Ho,Ad	4	DDVP	G
				BHC	
SAUDI ARABIA					
Najran	Sep		30	Malathion	ENS
				BHC dust	
Hail	Sep-Oct		10	Malathion	ENS
				BHC dust	
SAUDI ARABIA					
Darma	May	Sw	1		
SAUDI ARABIA					
N'ern Tihama	Feb-Apr	Sw,HoB	600	1500 Malathion	ENS
				1375 BHC dust	
Nejd	Apr-Jun	HoB,Sw	55	Malathion	ENS
SAUDI ARABIA					
Lith, Qunfidah	Dec-Feb/86	Hob,Fl	3000	17650 BHC dust	D
				2375 Malathion	ENS
				1050 Fenitrothion	ENS
SUDAN					
Red Sea coast	Nov-Dec	Groups Ho,Ad	69	1070 Fenitrothion	A

A = air
Ad = Adults
D = dusters
Fl = Fledglings
G = ground

Gr = Grasshoppers
Ho = Hoppers
HoB = Hopper Bands

Lo = Locusta
RdL = Red Locusta
Sc = Schistocerca
Sw = Swarms

Zo = Zonocerus

Figure E.13(cont.)

		w/ Lo		26000 BHC bait	G
SUDAN					
East/Centr grassld	May-Nov	Ho,Ad w/ Gr		38867 l Fenithn. 96%	A and G
				1000 l Fenithn. 60% EC	
				95213 l Diazn. 60% EC	
				10860 l Endosulphan 50%	
				67580 l Deltamethrin ULV	
				25814 l Cyplemethrin ULV	
				124486 l Chlorpyrifos ULV	
				6769 l Phosalone ULV	
				214800 kg BHC bait	
Red Sea coast	Nov	Gr,Ad	1160	1070 Fenitrothion	A,G
	Dec	(also So)		26000 BHC bait	
SUDAN					
Red Sea coast	Jan-Mar	Sw,HoB		28080 Malathion	A
		(w/ Lo)		Diazinon	G
				Fenitrothion EC	
				Dieldrin	
Kassala Province	Aug	Ho,Ad	110	Diazinon	G
				BHC bait	
SUDAN					
Red Sea coast	Jan-Mar	Sw,HoB	20	080 l Malathion	A,G
		(w/ So)		Diazinon	
				Fenitrothion EC	
				Dieldrin	
SOUTH AFRICA				NO DETAILS	
SOUTH AFRICA		Sw,HoB	300000		A,G
TANZANIA					
Wembere	Sep	Ad	11.9	617 l Fenitrothion 96%	A
				540 l DNOC 20%	
TANZANIA					
Wembere	Mar	Sw	1.5	150 l Fenitrothion 96%	A
	Aug-Sep	Sw	1	40 Fenitrothion 96%	A
TANZANIA					
Wembere	Feb-Mar	Ho,Ad	30	Fenitrothion 96%	A
Kahema	Apr-May	Sw		115 l Fenitrothion	A
Iku-Kitavi	May	Sw	80	169 l Fenitrothion	A
YEMEN AR					
Highlands	Jun	Ad		800 l aldrin	
				20% BHC dust	
YEMEN AR					
Ihsan Bilad	Aug	Ho	50	4000 Dieldrin 20%	
Shabwa		Ad	50	21000 Fenitrothion 96%	
Hayrut	Sep			2000 BHC 10% dust	
ZAMBIA					
Nakambala	Sep-Nov	Ho,Ad	3.5	1205 Fenitrothion	A
		(w/ RdL)			
ZAMBIA					
Kafue	Aug-Nov	Ad (w/ Lo)	9	1480 l Fenitrothion	A

FIG. E.14

PESTICIDES USED IN GRASSHOPPER CONTROL PROGRAMS, 1985-1986

COUNTRY LOCALITY	MONTHS	TYPES OF INFEST-TATION	AREA TREATED (km sq)	INSECT-ICIDE USED (l or kg)	*METHOD OF APPLICATION
BENIN	Jul	Ho	100	BHC dust	G
BURKINA FASO	Sep-Oct	Ho,Ad	116	15000 kg Propoxur 1%	G
GHANA	Oct-Dec	Zo		Sumithion	G
MALI	Aug-Nov	Ho,Ad	1610	53700 l	A
MAURITANIA	Oct	Ho	93+	2760 l Fenitrothion ULV	G
				5450 kg Fenitrothion dust	
				4950 kg Fen. + Fervalerdi	
				125 kg Propoxur	
				650 kg BHC	
MAURITANIA	Sep-Oct	Ho,Ad	6.3	dust	G
SENEGAL	Sep-Oct	Ho,Ad	125		
SUDAN	Jul-Nov			190 920 BHC bait	G
	May-Nov	Ho,Ad (w/ Lo)		38887 l Fenitrothion 96%	A and G
				1000 l Fenithn. 60% EC	
				10000 l Malathion	
				95213 l Diazinon 60% EC	

A = air
Ad = Adults
D = dusters
Fl = Fledglings
G = ground
Gr = Grasshoppers
Ho = Hoppers
HoB = Hopper Bands
Lo = Locusts
Sw = Swarms
Zo = Zonocerus

FIGURE E.15

AREAS TREATED DURING THE 1987
GRASSHOPPER CONTROL PROGRAM CAMPAIGN
(in ha)

Country	Ground	Air	Total
Niger	75420	230834	306254
Chad	42428	212555	254893
Mauritania	22365	225200	247565
Senegal	36556	134872	171428
Mali (1)	2329	166866	169195
Nigeria			60000
Gambia	12104	41940	55044
Cameroon	54000		54000
Burkina Faso			9062
Guinea Bissau	9000		9000
		Total	1336531

(1) Including the Stromme Foundation

Source: FAO, 1987

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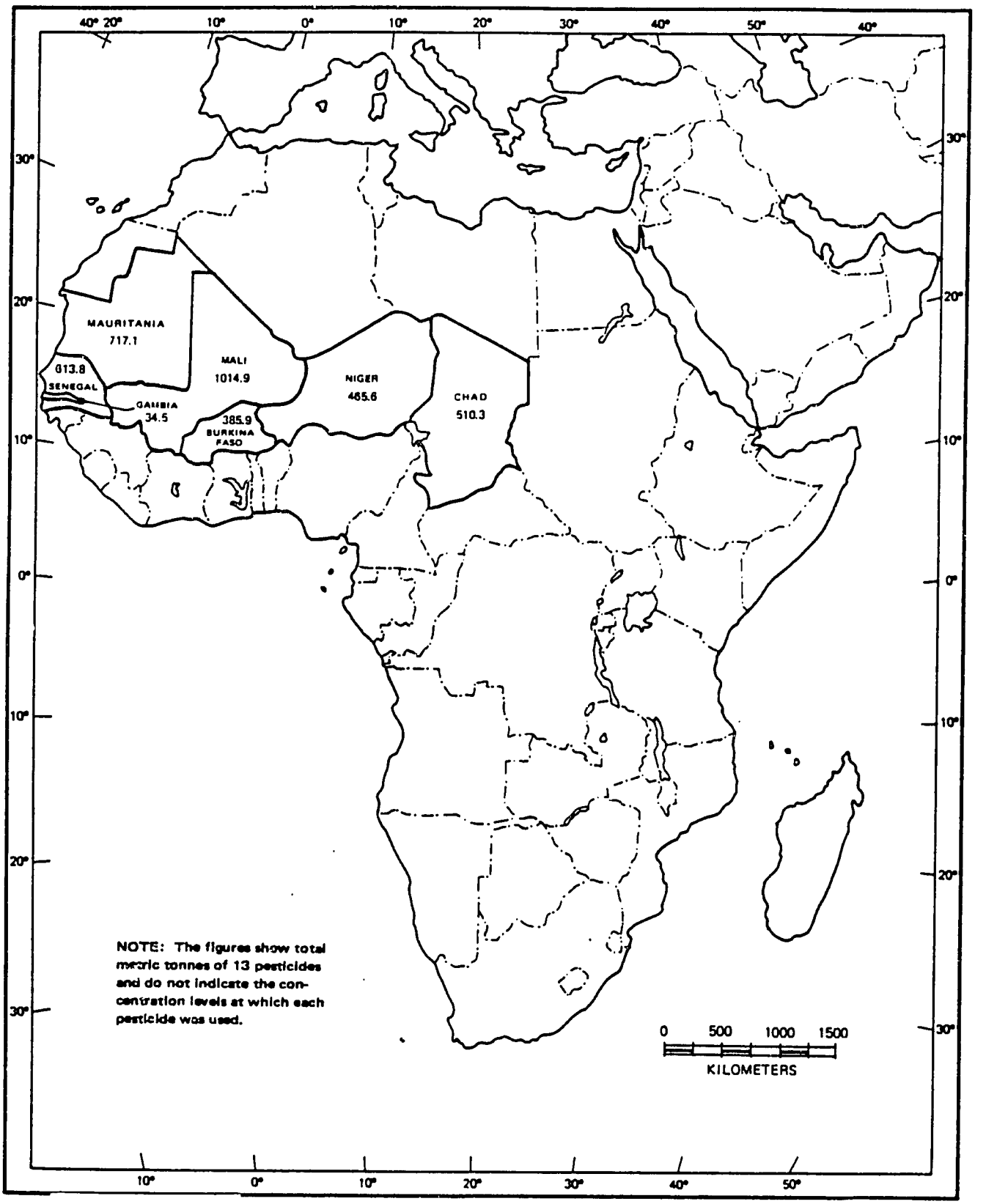

Figure E.16 Pesticides used in 1986 in Sahelian grasshopper and locust programs. Source: FAO, 1986.

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Even well-known programs for human disease control (malaria, onchocerciasis, schistosomiasis, or yellow fever) may use far less pesticide than is used by farmers in pest control programs. For instance, it is estimated that Sudan (to take perhaps the most extreme case) uses one hundred times more pesticide on the cotton crops than are used in malaria control programs along the Nile.

Pesticide use was examined throughout Africa. We learned the following:

Pesticides are in Mali mainly used in the Sahel Zone districts of Kayes, Nioro, Nara, north of Tombouctou and Gao. Lindane was used 130 t/y from 1973-77, but has largely been replaced by carbamate and propoxur. In 1982, fenitrothion, an organophosphorus insecticide with moderate persistence was widely used on millet, sorghum and maize. Some treatment against birds (Quelea quelea) was made with fenitrothion in the rice zones. Health control programs have regularly used DDT. And a pilot project on schistosomiasis uses the molluscicide, Miclosamine, in unspecified quantities in stagnant waters. The onchocerciasis program of the World Health Organization treated rivers with Temephos in southern Mali as part of a 800,000 sq k (Abate) (Calamari, 1985).

Pesticides in the Ivory Coast are used in large quantities on cash crops such as cotton, cocoa, coffee, banana and rice. 2,000,000 ha of cotton are treated five times per year -- twice with organophosphates associated with Pyrethrins (6-10 g/ha) and three times with Pyrethrin alone (12-15 g/ha). Approximately 240,000 ha of cocoa are treated with 3335 g/ha of propoxur during July to December. Dieldrin and fenitrothion are used against the Variegated Grasshopper.

In the health control programs large quantities of Tenephas (Abate) are used, along with Chlorphoxim. For instance, 16,000 l of it were used in 1983. The effects of these pesticides have been studied extensively as part of this program. Leveque, et al (1982) concluded after a five year research program that the release of Temephos has no detectable effects on the fish population of the rivers. Large nutrient enrichment (probably due to sewage and erosion) has lead to eutrophication, which, due to anoxia, has killed fish in several areas. It is reported by Calamari that pesticides such as Paraquat are illegally used to harvest fish, and has resulted in several case of "intoxication".

Over one million ha of cocoa in Ghana is treated with two carbamates, propoxur and dioxicarb at a rate of 250-500 g a.i./ha. Substantially fewer quantities of organophosphates or carbamates are used on other groups. Articifical pyrethroids are used in the Greater Accra region at a rate of 15,000 l per year.

Ghana participates in the Onchocerciasis Control Program. The Institute of Aquatic Biology in Accra has monitored the effects of treatments on non-target fauna, both in the field and laboratory. They report that the effects of Abate from changes caused by the Akosombo dam and development on Lake Volta. Approximately 40,000 t per year of freshwater fish are harvested, mainly from Lake Volta.

Lindane is used in Cameroon in cocoa cultures at 2 l/ha, as is diazinon. Cocoa and coffee plantations use approximately 1,000,000 l of diazinon, 145,000 l of fenitrothion and 186,000 l of Chlopyrifos. Unspecified pesticides are used against Quelea in the north of the country (Calamari, 1985 and Leveque et al, 1982).

As reported by Alabaster (1981) studies in Sudan by George and El Moghraby (1978) report as follows. The main usage of pesticides occurs in the large tract of irrigated land in the Gezira area south of Khartoum, lying between the Blue and White Nile. Half of all the cotton crops are grown here, and are heavily treated with repeated applications of a variety of pesticides at a total rate of 4 kg/ha/yr. Fish mortalities are reported in the irrigation channels and pesticide residues have been found at moderately high concentrations in the fish, although no regular monitoring program is undertaken. Moderately high concentrations of residues have been found in the diapose tissue and milk of humans in this area and levels comparable to those found in developed countries are reported. One major source of pesticides in water, although of short annual duration, has been the use of 2,4 D in the control of water hyacinth along 1800 km of the White Nile from Juba to Jebel Aulia, applied at a rate of 4.4 kg/ha. There have been high mortalities of fish in the past, and most of the ecosystem has been affected (El Moghraby, 1985). Total pesticide use in the Nile in 1983-84 exceeded one million l (Malaret et al., 1983).

In Egypt, the use of pesticides on cotton crops reached a peak in 1974 at 9901 t, and has averaged 8411.2 throughout the 1970's. Pesticide use on other crops, vegetables, fruit trees and weeds average 1452, 8550, 7393, and 222 tons, respectively, for a total of 26,028 t. (Plant Protection Department of Egypt, 1977).

In Niger, the government reported use of fenitrothion, lindane, propoxur and fenitrothion in excess of 100,000 l in 1982 and 1983 (Niger CPS, 1981; Niger CPS 1982).

In the health control programs for aquatic midges, mosquitoes and snail hosts of schistosomiasis, chemicals that may be very toxic or of "low toxicity" to fish are used (Alabaster, 1981; El Moghraby, 1985; George and El Moghraby, 1978).

5000 tons/year of pesticide are used in Kenya on coffee, cotton, maize and horticultural crops in irrigated areas.

Unspecified quantities of aquatic herbicides are also used in rural areas.

Pesticides and their breakdown products have been found in water and aquatic organisms (including fish) (Kallquist and Meadows, 1977) and there is concern that concentrations are approaching those that may have adverse effects. There is no systematic monitoring or data on adverse effects.

Unspecified quantities and types of pesticides are used on crops near the Rizizi River in Burundi (Autrique, 1977). This river drains into Lake Tanganyika, possibly affecting the nursery growth of several important species. Limited sampling of fish in 1971 and 1972 for pesticide residuals (Deelstra, 1977) found concentrations below effects levels; however, no regular monitoring program has been instigated.

In Tanzania, the use of pesticides in agriculture is not widespread. In the central region, about 5 t/year of phenothion has been used to control quelea birds. In the Kigoma region to the west, it has been reported that 75 t/year of 5% DDT was used on maize, and it is speculated, following an accidental spillage during transshipment in Kigoma harbor, that this might present the greatest danger to fisheries in Lake Tanganyika, rather than agricultural run-off. In 1979, a special tsetse-control project was started in the northwest part of the country between Rwanda and Lake Victoria, in relation to a new cattle-ranching experiment, which involved 5 aerial sprayings of endosulphan at 6.8 g/ha at 14-d intervals; Lake Ihimpa and Lake Burugi are in the area concerned but no studies were made of the possible side effects on fish; however, the scheme has not been abandoned. In the area near Nbozi near the northern part of Lake Nyasa, very heavy applications of copper fungicides have been used on coffee, the consequences of which are already causing concern because yields have been depressed by the high concentration in the soil, but no information is available on effects on drainage water and fisheries.

There is reported heavy usage of pesticides on maize, sugar and other crops in Zambia, in the Mazabuka area near the Kafil River (Kaoma and Slater, 1979). Tsetse fly control, using endosulphan, is centered south of the river (near Figureanzaa and Machee) and near Mumbwa in the north.

DDT and its metabolites were detected in fish, but no regular monitory program is being implemented (Alabaster, 1981). High levels of BHC and DDT were found in the eggs of crocodiles taken in the Zambezi River (Wessels et al, 1980). Lower levels were found in fish from Lake Kariba.

Pesticide usage in Malawi is mainly concentrated on cotton grown along the lake shore and particularly in the Shire Valley, though other treated crops include tobacco, maize and tea. Fisheries are important in the Shire Valley producing about

12,000 out of a total of 70,000 t/year. Between 1973 and 1978 fish from the Elephant Marsh near the cotton growing areas, and also from Lake Makoka near the Agricultural Research Station, have been sampled and analyzed for DDT (Pickering et al, 1980). Concentrations of DDT and its metabolites in the fish are generally too low (average less than 0.04 mg/kg in muscle) to cause concern, although a relatively high concentration (2.7 mg/kg) in the ovaries of one individual Clarias gariepinus raises the question of whether it could be high enough to cause adverse effects on reproduction.

E.4 Environmental Consequences of Pesticide Use

Background

To determine the effects of chemical control methods on wildlife, aquatic organisms, and human health, three assessments must be made: hazard analyses, exposure analyses, and risk analyses. This section presents the results of these analyses on terrestrial (Section E.4.1) and aquatic ecosystems (Section E.4.2).

Hazard analyses addresses toxic properties of each chemical used and the doses that are deemed safe as well as doses considered harmful.

In the use of any chemical, in this case pesticides used for control of locusts and grasshoppers, it is only prudent to ask what hazard is posed and what risk to humans and non-target organisms may be involved. To answer this question requires a three-part analysis.

First one must assess the hazard posed by the chemical by answering the following questions in as quantitative manner as possible:

- Q. What is the innate toxicity of the chemical and the method of toxic action?
- Q. What is the sensitivity of the various species to the chemical, i.e., are the non-target species who may be exposed more or less tolerant than the target species?
- Q. How persistent is the chemical in the environment and though perhaps not highly toxic accumulate to levels producing an adverse effect?
- Q. How "mobile" is the chemical in the system? Is it such as to result in a high probability of exposure?
- Q. How is the chemical to be handled in transport, storage, application and disposal of any waste?

A number of factors should be considered in hazard assessment. Some of these factors are often ignored and in their stead, tenuous assumptions are employed in the assessment. Obviously in the case of the chemical, if there is no exposure there can be no risk to the organism. However, in the use of

pesticides, there is always the likelihood of exposure. Because many of the effects produced by chemicals follow a dose response relationship, the level of exposure becomes important in hazard assessment. Thus, at very low exposure levels the hazard becomes correspondingly small.

One of the factors in exposure is the properties of the chemical. Thus, such properties as solubility, vapor pressure, absorbability, partition coefficient and the thermodynamic characteristics are important determinants in the level of exposure to which man or other organisms might be subjected during use of the chemical. These properties will influence the extent of vapor contamination of the air, water contamination, biological availability, and persistence of residues. To be sure, the behavior and fate of the chemical, while a function of these properties, is also influenced by environmental factors, e.g., light, temperature, moisture, etc. Another factor bearing on routes and rates of exposure is the manner of use and the amount used.

In chronic toxicity, the total dose ingested may be equal to or greater than the single dose that causes acute toxicity. The difference is that the organism has established some equilibrium between the amount of chemical taken in and that which has been metabolized and excreted. To be sure, in many instances there will be a deposition of the chemical in certain organs or tissues, e.g., fat, but even in this case, an equilibrium between intake and metabolism/excretion will be established unless either the metabolic pathway or excretory pathway have been impaired. If, during the course of time, the exposure is stopped, then the metabolism/excretion will result in elimination of the chemical from the body giving rise to the concept of pharmacodyamic half-life, that is the time required for one half of the administered dose to disappear from the body.

The term hazard implies the risk or likelihood of an adverse effect. On the other hand, toxicity is an innate property of the compound and is the potential for harm, but only if several other factors operate simultaneously. It was observed as early as the 16th century that it is the dose that determines whether or not a chemical will have a toxic effect. More recently in the Secretary's Report (Mrak Commission Report) it was pointed out that it is the manner of use that determines the hazard or probability of toxic effect.

The second aspect of risk in the use of pesticide involves those factors that are under the control of man. These include the following:

1. the precautions taken in manufacture, storage and transport,
2. the nature of the formulation -- many of the chemical and physical properties can be modified and controlled by proper formulation,

3. the manner of application -- proper application can reduce the amount of chemical lost from the target area,
4. the place where used, and
5. the amount of chemical applied in any one continuous area.

Knowing the properties of the chemical and taking steps to apply the controllable factors can substantially reduce the risk of adverse effects on man or the environment. Similarly, the knowledge of these factors and their proper application and the use can reduce the likelihood of the development of resistant varieties of the target organism.

Exposure analyses address which organisms are apt to be exposed to chemicals from spraying (or other applications) and how much insecticide is likely to enter their bodies. Not only must the matter of whether or not exposure occurs is to be considered but the route, level and duration of exposure as well. If exposure may come through more than one of the three routes (dermal, oral or respiratory) what is the total amount of chemical received?

Risk analyses utilizes data from hazard and exposure analyses and assesses how non-target organisms could be effected by the dose received. Thus the third and final step in the assessment is the one of crucial interest since it is this that indicates whether an adverse effect has a high or low probability of occurring. This is done using the available empirical toxicological data on the compound. These data are interpreted and applied on the basis of three fundamentals of toxicology, to wit:

1. All chemicals, whether natural or synthetic, can be toxic if given in sufficently large doses over a long enough period of time.
2. Unless the chemical reached a vulnerable site in sufficient quantity, no observable adverse or toxic effect will occur.
3. As the dose of the chemical increases, the toxic effect increases and the time to effect may be shortened.

One can approach the problem by looking at cases of damage (fish kills, loss of aquatic bird populations, etc.), it is almost always impossible to even correlate cause with effect, let alone prove a link, especially in light of the many events occurring in the environment. We will make use of both approaches in the following sections.

It should be noted that most risk analyses are based on exposure analyses that represent the highest possible exposure (dosages) an organism would receive from a pesticide treatment via oral, dermal, and inhalation exposure routes. Thus

calculations for risk analyses are conservative and it is difficult to extrapolate results from exposure and risk analyses to predict affects at population levels.

E.4.1 Terrestrial ecosystems

To determine the effects of chemical control methods for locusts and grasshoppers on non-target components of terrestrial systems requires analyses for the control method's effects on soil, vegetation, wildlife, water quality, aquatic organisms, public health and safety, air quality, cultural resources, and socioeconomics.

There are few, if any, hard data for hazard analyses in Africa, or as a result of the locust/grasshopper control program there. The few accounts of the effects on non-target organisms that have been recorded are discussed below in Section E.4.1.3.

No exposure analyses have been done which could realistically estimate chemical doses to plant and animal species present in the areas of locust/grasshopper control. By considering environmental (biotic and abiotic) components of an ecosystem typical of a spray area, and examining their interrelationships, it is possible to describe what would be exposed, and how.

Thus, specific scenarios have not been discussed. However, it should be noted that exposures can be (and should be) conducted when more specific information is available.

One important point to consider throughout this section is that locusts and grasshoppers follow greened areas, animals which feed on these insects follow the insects (including nomads with their livestock), and spray operations focus on these greened areas. Thus exposure can and will be concentrated for the non-target organisms at these green sites, where water is temporarily found as well.

From a spray application on a treatment area, direct dermal exposure to the insecticide would reach non-target invertebrates and vertebrates, both secondary (predators) and primary (herbivores) consumers of plant material, which would also receive direct dermal exposure. Animals subsequently coming in contact with contaminated vegetation would receive indirect dermal exposure. This would include all of the above groups. Animals feeding on contaminated vegetation would become exposed yet again through ingestion of the chemical. Likewise, predators would become exposed yet again through the ingestion of contaminated prey, which has been exposed to the chemical by any or all of the routes of direct dermal, indirect dermal, and ingestion. This form of exposure through ingestion would include the eating of aquatic organisms, e.g., fish, which became exposed via runoff from the spray area.

In addition, non-target organisms would become exposed to the chemical through inhalation of the spray material.

To further complicate the matter of exposure analyses, spray applications on treatment areas can, and generally do drift away from the treatment area through wind action. The myriad routes for potential exposure thus must be examined away from the treatment area as well as on the application site itself.

Depending on a chemical's persistence properties, the formulation used, evaporation properties of both, the condition of the ecosystem treated, i.e., soil types, vegetative cover, and numerous other factors, the exposure to non-target organisms could be protracted, certainly complicated, and possibly even magnified as it moves through complex food webs.

On top of all this, exposure to the chemical reaches the organisms which depend upon all animal and plant material ultimately, i.e., the decomposers. Even for chemicals that degrade relatively rapidly and do not bioaccumulate, some degree of exposure is shared by all in a terrestrial ecosystem.

Analyses of non-target organisms representative of major classes of animals in typical feeding levels found on rangelands in the U.S. treated for grasshopper control can be used as a gross indication of risks to organisms in these categories. Results of such analyses and their implications for African ecosystems are given in Section E.4.1.3.

Risk analyses, therefore, for African ecosystems typically found in areas of chemical control for locusts/grasshoppers must necessarily be extrapolated from these available analyses in the U.S. and applied to subsequent recommendations and guidance comments of this report.

E.4.1.1 Soils and associated fauna

Soil animals are important to the maintenance of soil fertility by contributing to the breakdown of soil organic matter in several ways:

1. They disintegrate plant and animal tissues and make them more easily invaded by microorganisms.
2. They selectively decompose and chemically change parts of organic residues.
3. They transform plant residues into humic substances.
4. They increase the surface areas available for bacterial and fungal action.
5. They form complex aggregates of organic matter with the mineral part of the soil.
6. They mix the organic matter thoroughly into the upper layers of soil.

Most of the multicellular animal species which comprise

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soil organisms and perform these functions belong to several classes in the Phylum Arthropoda, commonly known as arthropods, including such animals as millipedes, mites, spiders, pseudo-scorpions, and myriad insects; the most important being springtails, flies and beetles. Other animals important in the cycling of soil nutrients are earthworms, potworms, and nematodes. Of the hundreds of thousands of animal types represented in these taxa, only a few species are considered pests.

Consequences of pesticide use on soils vary greatly depending upon factors such as soil types, chemical properties vis-a-vis retention in various soil types, condition of range including vegetative cover, and population levels or concentrations of soil organisms.

Virtually all soil organisms are exposed to pesticide applications and most beneficial animals are affected to some degree. Those effects, however, can be quite complicated. For example, while direct exposure to a pesticide can kill certain animals, if the kill is of a particular predator of an unexposed soil organism, relatively more of the prey will survive an application and yield proportionately more in a resultant biomass.

Affects of chemical control could be direct or indirect, harmful or beneficial. Direct effects occur if persistent chemicals alter the ability of soils to support plant communities. Indirect affects include altering microorganisms' structure (population losses) required to break down organic matter. For example, applications of chlorinated hydrocarbons such as aldrin have been reported to produce a 70% kill of mites, springtails, flies, larval stages of beetles and flies, and centipedes -- and sometimes a complete kill of centipedes (Edwards, 1969). Macroorganisms, both vertebrate and invertebrate can be exposed as well, affecting such soil characteristics as drainage, and chemical and water transfer.

On the other hand, chemical control methods that reduce insect pressure on plant communities can yield or provide vegetative cover for soil.

An additional factor influencing consequences of pesticide use on soils is the correlation observed between grasshopper population explosions and overgrazing (Holmes, et al., 1979). Clearly there are indications one condition can have a multiplier affect on the other relative to the condition of the soil and the affects chemical exposure may have on that soil.

In general, soils with higher organic content are able to absorb and retain much more chemical exposure than are sandy soils (APHIS FEIS 87-1, 1987). Thus, the direct and indirect affects of chemical application on soils is likely to be of more concern when soil chemistry, physical characteristics, and

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soil-related organisms are most affected for protracted

periods. This can occur for chemicals that do not biodegrade rapidly, that are retained for long periods, and that are applied at rates of concentration exceeding either recommended or requisite levels.

However, in addition to soil type, climate and pesticide structural properties influence persistence of chemicals in soils (Kearney, 1977). The chlorinated hydrocarbons have long been shown to be highly persistent in soils. Organophosphorous insecticides, on the other hand, are dissipated rather quickly -- a matter of weeks, versus several years for the chlorinated hydrocarbons (El-Sabae, 1977).

Chlorinated hydrocarbon pesticides demonstrate limited mobility in soils, i.e., ability to move downward through soils by leaching. This means these pesticides tend to remain on or near the surface of the ground, where they can be moved by surface erosion to aquatic environments, i.e., runoff. Chemicals with more vertical mobility, those with acid bases, are more readily leached down into lower depths, where their toxic properties can affect soil organisms for as long as the pesticides persist.

These qualities, moderate to rapid vertical mobility in soils and relative nonpersistence (Kearney, 1977; El-Sebae, 1977) suggest nonchlorinated hydrocarbon pesticides may have less long-term detrimental affects on non-target organisms. That argument has been used widely and for a long time. For sandy soils, however, the short-term affects of pesticides which are rapidly absorbed downward on non-target organisms can apply to carbamates and organo-phosphates as well as to chlorinated hydrocarbons (Edwards and Thompson, 1973; Cole et al., 1975). These studies, along with several other reports, demonstrate that pesticides in soils affect not only animals (non-target) essential for breakdown of materials into organic and inorganic components, but inhibition of soil enzymes as well.

Long-term consequences of pesticide applications to soils thus are dependent on the affects on individual and local populations of non-target soil organisms which are responsible for soil fertility, structure, etc. These affects in turn are dependent on myriad factors in various combinations. That non-target soil organisms are adversely affected is clear. However, whether changes in numbers or in local populations in relation to other local populations of beneficial, non-target soil organisms have a net adverse effect on the local ecosystem is often difficult to assess and/or determine.

One measure of the long-term consequences of the initial detrimental affects is two-fold: how quickly do non-target soil organisms response in the area of pesticide application, and is the response, in population or biomass, equal to pre-application

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levels. To measure either parameter requires pre-application testing -- or a carefully designed test of nearby areas with nearly identical conditions -- and/or regular monitoring throughout areas representing potential outbreaks for pesticide use.

To effectively and accurately measure either parameter is probably not practical when determining overall consequences of pesticide applications for locust/grasshopper control. There are numerous reasons for that assessment. Three are given to demonstrate the difficulty of obtaining meaningful information or data:

(1) lack of precise information in advance of treatment regarding areas in which outbreaks will occur and for which pesticides will be applied, thus not allowing sufficient time for pretreatment sampling;
(2) lack of complete information regarding pesticide applications, e.g., sites, chemicals used, particularly around wet and green areas, formulations and dosages used, timing of use;
(3) lack of knowledge about all other pesticides used for all other reasons vis-a-vis use for locust or grasshopper control.

One additional and significant consideration to be made when assessing environmental consequences of pesticide applications of African soils is that much of Africa is already characterized as having degraded soils (see page E-6): soil fertility limited in overcultivated areas, which also have severely disturbed natural vegetation; sheet and gully erosion leading to massive runoffs and soil loss; soil chemistry severely disturbed, ranging from toxicity from metals to potassium and phosphate deficiencies; soil and vegetation loss for overgrazing; soil loss due to desertification and excess but nonfertile soil buildup from desert encroachment; and soil crusting. The latter blocks the entrance of water into the soil, increases runoff, and leads to erosion.

Superimposed on these situations are excessive clearing of vegetation for fuelwood and to promote agriculture, followed by the loss of nutrients to excess cropping. African soils have poor nutrient retention properties/capacities, so are heavily leached.

High rates of desertification in Africa correspond in many instances with overgrazing, poor soils, and locust/grasshopper outbreaks. While the outbreaks have potential for devastating affects in these areas, the consequences of chemical applications to poor soils are compounded by runoffs, excessive leaching, and short-term toxicity for non-target organisms which are in many cases far below carrying capacity

already (Figure E.17).

Sustaining and improving agriculture may depend far more on soil conservation measures than on curbing any affects of chemicals on soil properties, structure, or organisms.

E.4.1.2 Plant life

Consequences of pesticide applications on vegetation include any direct toxicity (phytotoxicity), the removal of pollinators, particularly insect pollinators which would affect plant reproduction, and indirect affects on non-target organisms dependent upon plant material for primary food.

Direct phytotoxicity to the very agricultural crops being eaten by locusts and grasshoppers clearly compounds the consequences of the control applications. Aerial applications of fenitrothion ULV have been reported to cause severe, yield-reducing phytotoxicity in sorghum (Schaefers, 1986; FAO, 1986).

Malathion ULV, carbaryl and carbaryl diluted with diesel fuel have been reported as having little or no phytotoxic affects on other than ornamentals and algae (Pimentel, 1971; APHIS, 1987) when used in recommended dosages and rates. Both, however, can be phytotoxic when applied in excessive dosages, particularly to certain fruits.

These two chemicals, as well as others (see Section D.4.4) are highly toxic to insect pollinators, and thus application can affect the reproduction of endagered plants dependent upon wild pollinators. Any bees in a locust/grasshopper control area during or immediately after spraying are likely to be killed either by direct contact with the spray, sprayed surfaces, or by consuming pollen that has chemical residues.

Diazinon is particularly toxic to bees and pollinators, and as with malathion and carbaryl will cause complete kills of resident plant pollinators (Eister, 1986).

E.4.1.3 Animal life

When the exposure or estimated environmental concentration (EEC) of a pesticide exceeds the LD-50 (oral toxicity) the Environmental Protection Agency deems the chemical a significant risk, leading to possible restriction of the pesticide. EPA judges EEC's exceeding the LD-50 to be unacceptable risk levels.

Risk analyses have been carried out for representative classes of animals covering various tropic levels and feeding

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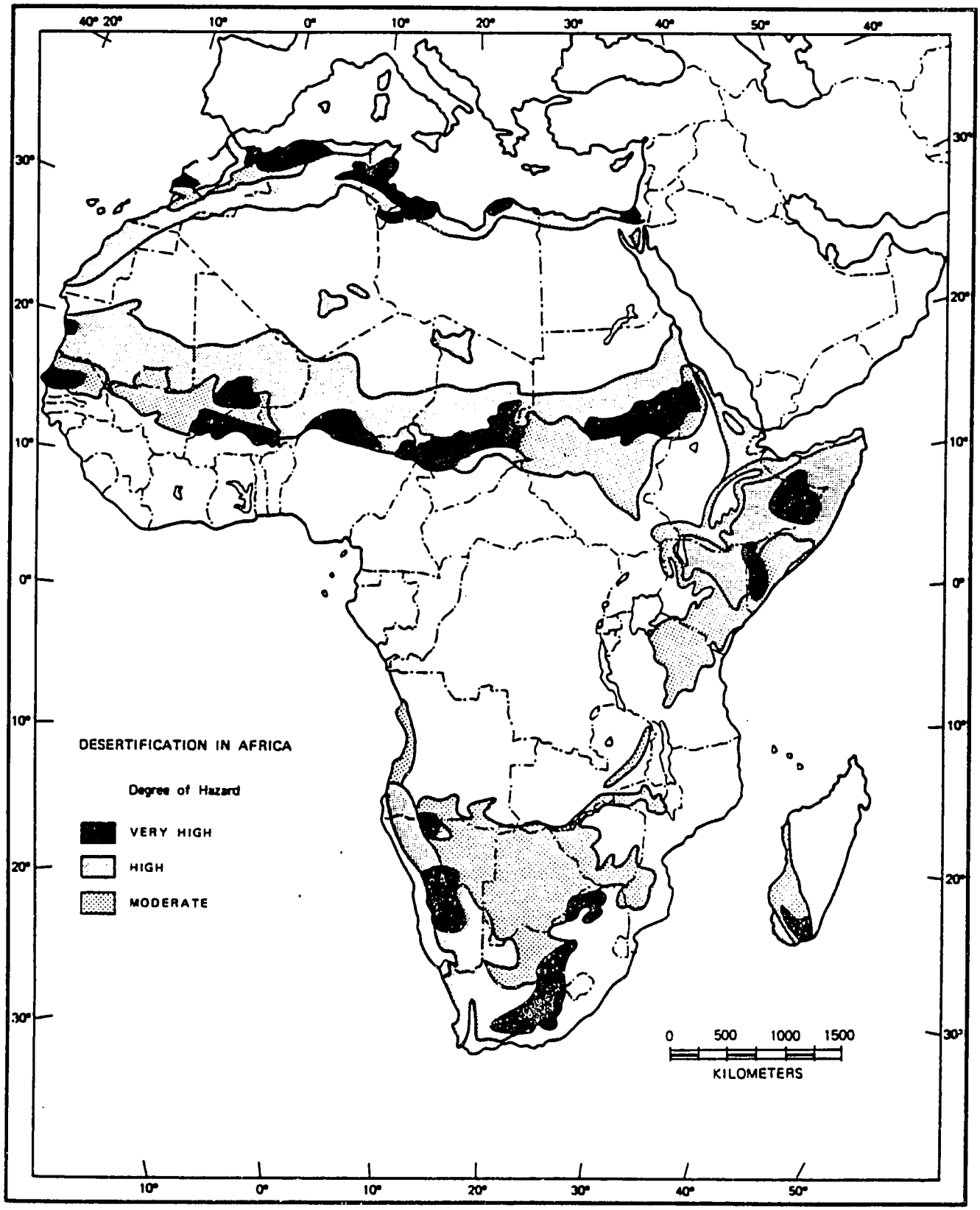

Figure E.17 Desertification in Africa. Source: FAO, 1986f.

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habits: birds, mammals, reptiles, and amphibians. These analyses and data for acute toxicity are more complete for some pesticides than others.

Impacts on non-target animals are generally direct, i.e., pesticides cause mortality or serious harm to individual animals by its toxic properties. Indirect affects may be seen if the pesticide removes the food source, e.g., insects, upon which an animal depends, particularly during reproductive periods.

Further direct/indirect affects include removal of natural invertebrate predators (if prey is relatively unaffected) leading to increases in herbivore populations, at least locally, or displacement of predator populations.

In general, risk analyses, exposure and hazard analyses conducted in the U.S. indicate overall wildlife populations are not adversely affected by recommended pesticide dosages during treatment. However, the pesticides of concern in this report range from slightly toxic, to moderately toxic, to highly toxic to individual birds and mammals. Further, recommended dosages may not always be followed in locust and grasshopper control operations. Thus, not only can individuals be adversely affected, but local populations or concentrations of animals can be harmed or removed as well.

Toxicity ranges for chemicals used in locust/grasshopper control are from moderately toxic to mammals (malathion), to moderately toxic to highly toxic to birds (fenitrothion), to slightly toxic to birds (carbaryl), to highly toxic to bees and other invertebrates (all three). A pesticide's toxicity to wildlife varies greatly, however, among species of any broad group of animals.

Aerial spraying of organochlorine pesticides, such as aldrin dieldrin, at one time seemed the ultimate approach to grasshopper/locust problems. However, problems with organochlorines (e.g., chlorinated hydrocarbons) including their residues in foods and in wildlife food webs, their persistence and mobility in the general environment, and their adverse effects on wildlife have resulted in their being replaced by insecticides such as malathion (an organophosphate) and carbaryl (a carbamate) and other organophosphates.

It is now accepted widely that use and registration of pesticides for grasshopper/locust control should be limited to those that have the least direct affect on non-target wildlife, that degrade rapidly in the environment, and that have been thoroughly tested in the field as well as in the laboratory.

Chlorinated hydrocarbons, like polychlorinated biphenyls, do not meet those criteria. Myriad studies and post-treatment field results have been documented to indicate the

unacceptability of these groups of pesticides for locust/grasshopper control.

Data for organophosphates are not as clear. However, a significant amount of research has been conducted on the affects of this group of pesticides on wildlife within the last decade. From results of these studies, some trends are developing and indicate the organophosphates can and do yield adverse affects on non-target terrestrial organisms.

Organophosphates act by inhibiting the enzyme cholionisterase (ChE), ultimately causing a disruption of nerve function (O'Brien, 1967). Mortality is the most obvious effect organophosphates have on wildlife and is characterized prior to death by anorexia, lethargy, antagonistic behavior, muscle incoordination, convulsions or tetany (O'Brien, 1967). ChE levels are generally measured as brain ChE activity: 50% depression generally attributed to poisoning from organophosphate exposure.

Grue, et. al. (1983) present a thorough review of hazard assessment of organophosphates to wildlife, the mode of action of this groups of pesticides and criteria used to assess exposure. He reached three conclusions based on available data:

1. organophosphate applications do result in mortalities of wildlife,
2. sublethal exposure to organophosphates can affect physiological and behavioral characteristics required for reproduction and survival of no-target animals, and
3. organophosphate applications have the potential to alter both distribution and abundance of wildlife species.

An overview of acute toxicity to wildlife and birds is presented in Figure E.18. The Denver Wildlife Research Center has conducted a number of studies to determine the effects of organophosphate pesticide applications on non-target wildlife species. In one such study the direct affect on birds varied with chemicals applied, spray rates, and conditions. Applications for grasshopper control that killed birds and resulted in significant populations decreases were: fenitrothion and diazinon. Baygon caused bird population reductions but without mortality, as did fenitrothion at lower rates. Applications for grasshopper control that were without observed affects on non-target wildlife species included carbaryl and malathion (McEwen, et al., 1972).

When mallard eggs were exposed to malathion, diazinon, and parathion, all three chemicals caused significant depression of plasma and brain ChE activity in hatchlings (Hoffman and Eastin, 1981).

Figure E.18

ACUTE TOXICITY OF LOCUST/GRASSHOPPER CONTROL PESTICIDES TO TERRESTRIAL ORGANISMS

Chemical (Axx/kg)	Rats (oral)	Rats (dermal)	Rats NOEL	Rabbits	Japanese Quid	Mallard Ducks	Pheasant	Pigeons	Starlings	Bees	Bobwhite Quail
malathion	2800	4100	--	--	--	--	4320	--	--	0.7/mg/bee	3497
carbaryl	850	>4000	--	>2000	2230	>2179	>2000	>1000	--	highly toxic	25.9
fenitrothion	800-890	1200	5	--	650	1190	55	--	--	--	27
propoxur	90-128	--	250	--	--	--	--	--	15-20	--	--
diazinon	300-850	900	--	--	167	3	4	--	--	--	--
lindane	88-125	900-1000	--	--	490	7200	--	--	--	toxic	--
dieldrin	37-87	60-90	--	45-50	70	381	74	--	--	toxic	--
bendiocarb	40-156	556-800	10	--	--	--	--	--	--	--	--
chlorpyrifos	135-163	2000	--	1000-2000	17	75	--	--	--	--	--
lambda-cyhalothrin	56-79	632-696	--	--	--	>3950	--	--	--	less toxic	--
tralomethrin	99-3000	--	6	--	2510	--	--	--	--	--	--
cypermethrion	251-4123	2460	100	--	--	--	--	--	--	toxic	--

Source: Hudson, R. H., et al., Handbook of Toxicity of Pesticides to Wildlife, US Dept. of Interior, Res. Pub. 153, 1984;
Hill, E. F. and M. B. Canardese, Lethal Dietary Toxicants of Environmental Contaminants and Pesticides to Coturnix, US Dept. of Interior, 1986

Diazinon has been reported to decrease egg production in bobwhite quail (Stromberg, 1981), and physiological affects from intoxication in mallards and pheasants (Hudson, et al., 1984).

Studies of the affects of carbaryl applications on non-target organisms have shown it to be slightly- to non-toxic (Hoffman and Albers, 1984; De Weese, et al., 1979). As is malathion, carbaryl is generally considered to degrade quickly in the environment, and rates low in direct toxicity to terrestrial wildlife (McEwen, 1971; McEwen and Ells, 1975).

Although fenitrothion appears to have a low persistence in most environments, it is toxic across a broad range of non-target invertebrates with a potential for greatest mortality to flying insects, and is highly toxic to birds (Anonymous, 1978).

Fenitrothion has also been shown to cause frequent and significant intoxication in birds, to cause territorial abandonment in birds, and to result in 100% mortality of soil dwelling invertebrates (Anonymous, 1978). Little or no adverse affects on mammals were shown when fenitrothion was applied at recommended dosages in forest systems (Anonymous, 1978).

Risk analyses reported by APHIS in their Rangeland Grasshopper Cooperative Management Program's Environmental Impact Statement (1987) show EEC's exceeding the 1/5 LD-50 for malathion for some birds (lark bunting, bobwhite quail, kestrel) and for the rabbit. Similar analyses for carbaryl show EEC levels exceeding the 1/5 LD-50 for the grasshopper mouse. Lindane used for wheat pest control showed no adverse affects on Canada Geese (Blus, et al., 1984), or on reproduction for mallard duck eggs when they were treated with lindane formulations found in aerial applications (Hoffman and Eastin, 1982).

An example (Figure E.19) is provided of estimated exposure to the North American wildlife due to spray 1400 g/ha of carbaryl -- which is far in excess of that used in locust and grasshopper control programs. In this case many species of birds may be exposed to concentrations of carbaryl in excess of lethal dosages. Such examples could be developed for Africa when more specific information becomes available. In this table all representative species are assumed to receive doses through all three principal exposure routes: oral, dermal, and inhalation. All representative species and their food items are assumed to receive surface contamination on their total surface area. Prey items are assumed to have a total day's body burden of chemical to contribute to a predator's oral exposure. There is no loss of chemical assumed to occur from an animal's body to the environment either by rubbing off from the fur or feathers or through normal chemical breakdown processes. Losses form the fur or feathers by grooming are assumed to constitute oral doses for mammals and birds. Dermal penetration is assumed to occur within the first day of spraying at the penetration rate determined in

Species	Direct dermal dose	Oral dose via grooming	Inhalation dose	Dose from food	Total dose	Dose in mg/kg
Lark Bunting	2.63×10^{-2}	0.58	8.63×10^{-6}	1.74	2.35	71.10
Sage Grouse	0.50	1.74	1.63×10^{-4}	15.01	17.26	11.50
Bobwhite Quail	0.11	0.89	3.05×10^{-5}	7.36	8.36	49.17
American Kestrel	8.33×10^{-2}	0.82	2.41×10^{-5}	4.58	5.48	43.85
Grasshopper Mouse	3.73×10^{-2}	0.63	1.01×10^{-5}	1.44	2.12	66.10
Blacktail Jackrabbit	1.04	2.18	3.55×10^{-4}	26.84	30.05	11.04
Pronghorn	7.01	5.80	3.41×10^{-3}	247.16	259.98	5.64
Beef Cow	32.60	13.36	2.12×10^{-2}	1007.11	1053.09	2.32
Coyote	3.37	3.94	1.43×10^{-3}	3.53	47.89	3.09
Horned Lizard	6.03×10^{-2}	0	1.40×10^{-6}	1.59	1.65	65.98
Yellow-Bellied Racer	0.33	0	1.40×10^{-6}	1.68	3.25	8.23
Rocky Mountain Toad	0.30	0	2.94×10^{-6}	0.94	1.24	56.46

Figure E.19 Estimated carbaryl doses to wildlife (in mg.). Source: APHIS, 1987

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the laboratory over a number of days. Thus the analysis is structured to anticipate the most hazardous outcome of a spraying operation in terms of toxic consequences to an individual animal.

Studies have revealed significant declines in bird populations and/or reduced reproductive capacities for some avian species in areas treated with malathion, carbaryl, and fenitrothion (Moulding, 1972; DeRosa et al., 1976; Dimond, personal communication).

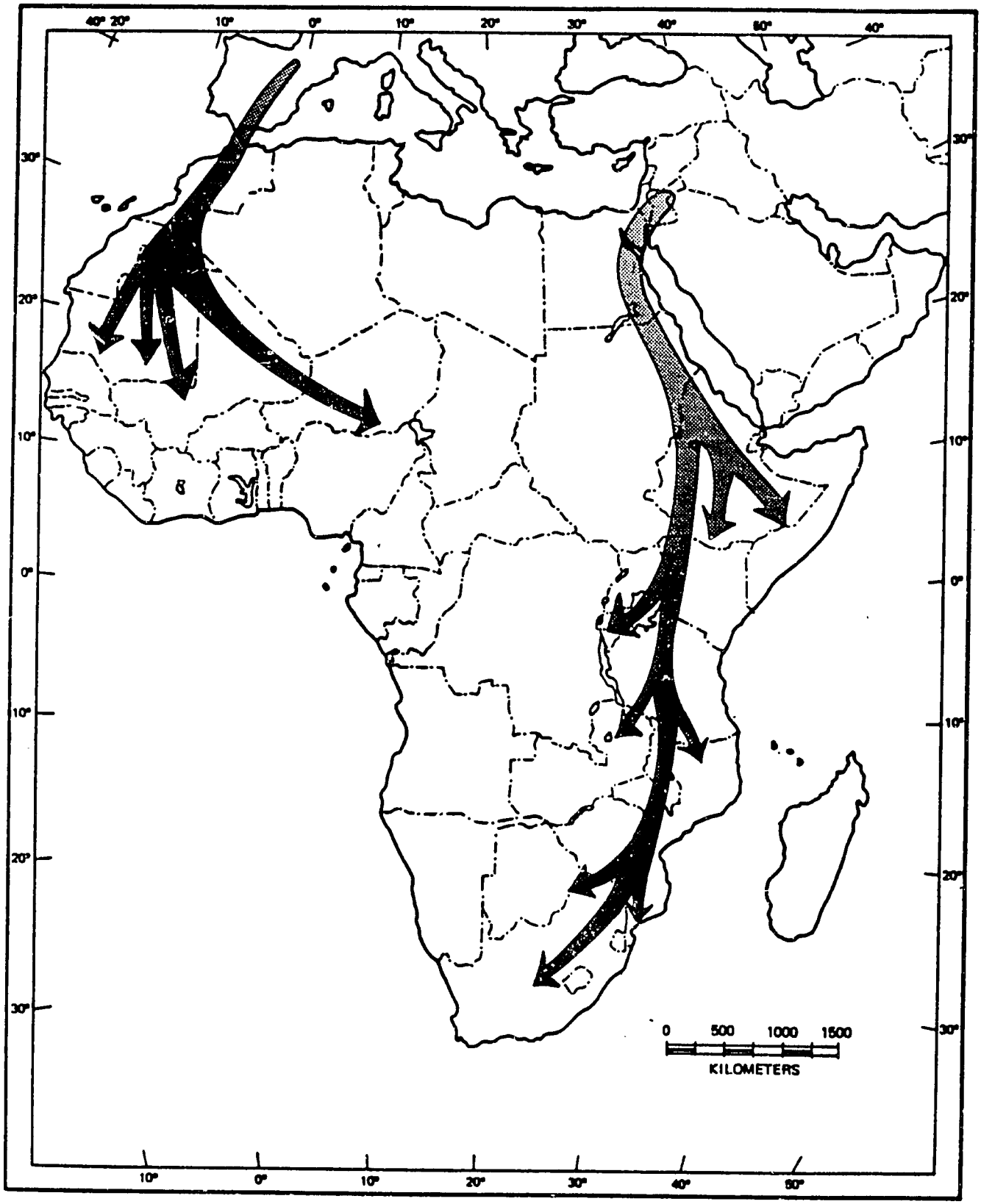
These reports, though varied in their results do show a trend and do indicate all wildlife can be at some risk of fatality and behavioral or physiological alterations that adversely affect individuals and/or local populations when exposed to these pesticides.

In general, however, long term affects of organophosphate pesticide applications on non-target wildlife are unknown, while short term affects show moderate to high toxicity for terrestrial invertebrates and birds, with less adverse affects on mammalian species.

Nonetheless, toxicity levels, however varied, are known for these pesticides for birds and mammals and must be taken into account during spraying operations. Of particular concern vis-a-vis numerable organisms and situations include: concentrations of birds feeding on locusts/grasshoppers during the migration of birds. (There are nearly 170 individual maps showing migration routes. We present one general map showing the major migration routes, [Figure E.20]). Also of particular concern are bird breeding and nesting sites, particularly of predatory birds such as falcons, eagles, and fish-eating avian species; protected, rare, threatened, and endangered species; protected areas such as National Parks, reserves, wilderness areas; critical habitats such as wetlands; large concentrations of natural pollinators.

The direct consequences in the short-term to wildlife can be reasonably predicted, i.e., detrimental affects on non-target invertebrates (natural predators of locusts/grasshoppers, pollinators, soil organisms, other beneficial insects) and vertebrates (bird losses, reduced avian reproduction, displacement of insectivirous birds, reduction of local populations of small mammals). The long-term consequences are more difficult to ascertain. These indirect affects, however, are often complicated and it can be argued whether they are truly detrimental in the long term or are manifestations of temporary, and often unnatural phenomenon.

For example, one indirect affect suggested for white storks from pesticide applications to control locusts/grasshoppers was the resultant shortage of food for migrating storks (Schultz, 1986). Periodic outbreaks of locusts/grasshoppers, however, do not necessarily coincide with



TAMS/CICP 1988

Figure E.20 Major bird migration flyways. Diagram shows typical flyways as drawn from many sources.

annual stork migrations, thus this may be an artificial shortage of a food that would not be normally available in any case. The storks would therefore not be normally or always dependent on it (the outbreak) as a food source.

Sinclair (1978) described how some migrating birds key into localized "blooms" of insects, such as locust swarms. Some species of migrants can follow the movement of the swarms. On the one hand, these avioids directly compete with resident bird species for food resources. On the other hand, these migrants, or any other birds that feed primarily on locusts while following the swarms (e.g., black-winged and red-winged Pratincoles) become vulnerable to pesticides used for locust control. A list of birds associated with locusts and grasshoppers is provided in Appendix 11.

Another indirect affect to storks suggested by Schultz (1986) is long-term reduced fertility and eggshell thickness from pesticides. However, no data are available to very that for Africa. Further, data from white storks collected in Germany show carcasses from breeding areas there contain much higher concentrations of pesticides applied there than chemicals applied in Africa (Schultz, 1986).

Major white stork mortality appears to be more closely related to other pest control programs than to locust and grasshopper programs. Cases have been reported, however, for increased stork mortality following pest bird control operations using fenitrothion. Schultz (1986) discusses one instance of 200 storks dying after feeding on poisoned Queleas in Sudan. There are also reports of storks dying after feeding on armyworms poisoned with fenitrothion in Africa, although quantitative data are not available (Schultz, 1986). Storks have been reported feeding on locusts poisoned with applications of lindane with no apparent affect, however (Schultz, 1986).

Gunn (1979) reports one species of antelope in South Africa as being exceptionally susceptible to dieldrin poisoning, apparently from aerial applications for tsetse fly control.

One indirect affect from locust outbreaks and subsequent pesticide control involves rats and granivorous birds. Both may appear in huge numbers following a locust invasion as the locusts provide the rats and birds with a supplementary food source (Launois, 1986). This supplementary food source may even stimulate reproduction. Following pesticide applications achieving high control rates for locusts, these rats and mixed-diet birds can present a significant threat to crops when deprived of adequate insect food resources (Launois, 1986). Thus, the long-term affect of indirect consequences (like long-term affects of direct exposure) of pesticide applications are difficult to ascertain.

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Pre-treatment population levels, nesting and breeding area statuses, and interrelationships between insectivorous birds and mammals without the sudden build-up of locust/grasshopper numbers must be determined or at least described. Without that prior knowledge, adverse affects on populations and ecosystems (versus individuals and local populations) cannot be accurately assessed.

Post-treatment monitoring and sampling are also required to determine consequences for populations and systems over the long-term.

Some preventative measures can be taken to mitigate adverse consequences. These include predicting outbreaks to reduce aerial spraying while employing other approaches including localized, ground applications of pesticides to minimize broadcasting; enhancing natural and encouraging introduction of invertebrate and biological organisms which reduce locust/grasshopper numbers, adhering to recommended pesticide dosages; maintaining buffer, no-spray zones of at least one mile adjacent to all protected areas and known habitats of endangered, threatened, and protected species, and continuing the policy of not using the chlorinated hydrocarbon group of pesticides nor others which are deemed by EPA to have unacceptable risks.

As with soils, determining the consequences of pesticide appplications on wildlife is further compounded by a lack of knowledge of the myriad chemicals applied throughout Africa for myriad purposes (Section E.3.1). Chemicals applied for locust/grasshopper control may be overshadowed by broad-scale applications on agricultural lands, making it, at best, difficult to obtain any meaningful pre-treatment or long-range post-treatment data to assess consequences. Without such data, certain predictable risks must be accepted by spray operation supporters.

Greater Spotted Eagles winter in the Sudan and Eritrea and are said to "feed greedily on locusts". This species distribution may be correlated with locust distribution. Brown (1971) reports that the control programs for locusts in the desert regions have achieved sufficient success over the past 20 years to have influenced the distribution of the Greater Spotted Eagles. Ornithological research in Africa does not have enough of a history to determine if this species has changed its distribution in direct response to the control programs, but it is a good example of why a monitoring program should now be established, before further insect eradication occurs.

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E.4.2 Aquatic ecosystems

Introduction

The aquatic ecosystem modifies the form and distribution of chemicals and defines the context in which the populations of interest exist. By the network of ecosystem interaction, direct effects of chemicals at one site of influence are translated into indirect effects elsewhere. As described previously, the risk (consequences) of using pesticides near aquatic resources is a function of exposure and risk.

The exposure of aquatic resources to pesticides used in the locust/grasshopper programs is determined by specific patterns of spraying. As described in Section D, locust and grasshopper species occur historically throughout Africa and Asia Minor, and spraying programs are conducted throughout most of these areas. The details of these spraying programs have been described in Section E.3.

E.4.2.1 Aquatic hazard analysis of chemical control

The toxicity of the 13 pesticides proposed varies from nil to severe on fish and aquatic invertebrates (Figure E.21). However, operational procedures call for no treatment adjacent to water bodies. Thus, with adequate buffer zones, pesticides would reach water only through spray drift and run-off after rains. Pesticides that are sprayed directly on water bodies inadvertently are expected to have long-term effect to any species of aquatic organisms. Populates of fish or aquatic insects could be reduced in transient bodies of water and lakes and ponds. Effects of streams and rivers can be expected to be temporary, since these areas can be repopulated from other areas.

When pesticides are applied directly to water bodies -- for instance, for the control of grasshoppers in rice paddies, fish, aquatic insects and invertebrates could be severly affected. There might also be population reductions of aquatic invertebrates in streams and rivers downstream from the site.

The hazard analysis for pesticide spraying in Africa is limited by several constraints. In most cases indigenious species of fish, invertebrates and aquatic plants have not been tested; therefore the hazard analysis for pesticide spraying in Africa must be based on testing of North American species.

Pesticides can be extremely species specific and most of the species studied are of North American origin. There is a range of from 6.4 mg/l Daphnia pulex (water flea, a member of the zooplankton food-base) to 1,900 mg/l for Procambarus (crayfish) to 20,000 mg/l for Ictalurus melas (black bullhead) for the pesticide carbaryl (Johnson and Finley, 1980). While African

FIGURE E.21

ENVIRONMENTAL TOXICOLOGY AND PERSISTENCE OF 13 PESTICIDES TO AQUATIC SPECIES

Chemical	Daphnia*	Gammerus	Rainbow Trout	Goldfish	Fathead Minnow	Black Bullhead	Channel Catfish	Bluegill	Tilapia	Algae	Log Persist-ence c/	Log P	BCF pot-ential d/
malathion	1.4	0.0007	0.06	10.7	9.8	11.7	8.3	0.057	2.0	--	-5.94	2.89	L
carbaryl	6.4	0.026	1.57	13	12	20	11	7	--	0.03 a/	-4.09	2.36	L-M
fenitrothion	0.013	0.003	2	2.6	4.0	--	5.4	3.2	--	--	-2.57	4.4	M
propoxur	--	0.034	8.2	--	25	--	--	4.8	--	0.01 b/	-0.40	1.58	L-M
diazinon	0.008	0.02	0.090	--	--	--	--	0.168	--	--	low-modrt	3.31	M
lindane	0.460	0.036	0.032	0.118	0.079	0.064	0.047	0.051	--	0.3 a/	high	moderate	H
dieldrin	0.250	0.640	0.0015	0.017	0.0038	0.010	0.00815	0.0081	0.0097	--	-0.025	5.3	H
bendiocarb	--	--	1.55	--	--	--				--	--	--	M
chlorpyrifos	--	0.011	0.0071	0.18	--	--	0.250	25	--	--	-0.70	5.0	H
lambda-cyhalothrin	--	--	--	--	--	--	--	--	--	--	--	--	M
tralomethrin	--	--	0.0016	--	--	--	--	0.0043	--	--	--	--	M
cypermethrin	--	--	.002-.0028	--	--	--	--	--	--	--	--	--	H
acephate	--	0.750	>100	9550	--	--	-- 2050		--	--	--	--	L

Note: toxicity is 96-hour; LC-50 in mg/l
* = 48 hour

a/ = chlorella cell inhibition
b/ = O2 reduction in 4 species
c/ = This is a measure of the persistence of the chemical, as measured in a 32-day microcosm study. -5.99 is low persistence; -0.70 is higher persistence. By comparison, p-DDT is -0.46.
d/ = low, medium, high

Source: Mayer et al., 1986; Traballa and Gartera, Jr., 1982; and Vershuen, 1985; Freed, Virgil.

species might be expected to have different sensitivites than the North American counterparts, we can gain some insight by looking at the range of sensitivities of different species. North American salmonids and cyrrinids, which we generally find at the surface or mid-water areas are far more sensitive to pesticides, they are bottom-dwelling or bottom-feeding organisms such as catfish and carp. It is expected that African species will fall into that range of sensitivities, but that needs to be confirmed experimentally. The few African species which have been tested, cichlids and tilapia, do fall within the range of toxicity to North American species.

Pesticides and other toxic materials can affect ecosystems directly (by killing organisms, preventing reproduction, causing developmental effects on the young, causing cancer and other tumors) or indirectly (by loss of food organisms, loss of suitable habitat, etc.).

Once pesticides or other foreign chemicals are released into the ecosystem, the first effects likely to be observed are those on individuals. But many effects can be seen at the ecosystem level, such as changes in light penetration (through plant growth). Many effects are expressed only in terms of interspecific interactions between individuals. Chemicals may reduce an individual capability to resist infection or shift competitive balances, affect pollination systems, or weaken a prey's ability to escape predation. For instance, toxicity can act as a selective stress when the prey species is more strongly effected by the toxicant than is its predators. It has been demonstrated that sublethal concentration of Mirex decrease the survival of grass shrimp subject to predation by pinfish (Tagatz, 1976).

Food chain transport processes can carry contaminants from prey to predator to higher predator, and increase the concentration of contaminants as one goes up the food chain. Thus, a concentration of only a few g/l can be translated into lethal doses for higher organisms, or to serious teratogenic (birth defects or developmental problems) in humans.

Several physical properties of chemical compounds have been found useful in predicting their risk; among these Log p, persistence, and laboratory measure of acute toxicity -- either the LD-50 or LC-50 (the dose or concentrations required to kill half of the experiemental animals in the specified time [usually 96 hours]).

Toxicity of the 13 pesticides of interest are described in Figure E.22. Concentrations higher than these, if found in the environment, can cause mortality. The level of toxicity varies considerably with each of the 13 pesticides). Acephate, propoxur, carbaryl, fenitrothion and malathion are far less toxic to fish than are the three synthetic pyrethroids -- lambda-cyhalothrin, tralomethrin, and cypermethrin and dieldrin.

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Diazinon, lindane, bendiocarb, and chlorpyrifos are of intermediate toxicity. Toxicity to invertebrates are considerably different. Here, the three cyclenites, lambda-cyhalothrin, tralomethrin, and cypermethrin, fenitrothion, diazinon, propoxur, and chlorpyrifos are of high toxicity; malathion, carbaryl and acephate are of low toxicity, with lindane and dieldrin of intermediate toxicity.

E.4.4.2 Exposure analysis of chemical controls

Analyses of areas sprayed with pesticide was made in Section E.3, while detailed information on the environmental fate properties of these pesticides are described in Section D.4.4. This section describes this information and discusses it relative to environmental effects.

With respect to aquatic ecosystems, the principal chemical properties of importance are persistence and bioaccumulation potential. Chemical concentration of pesticides may decrease biotically (principally through bacterial action) or abiotically (through hydrolysis, evaporation or absorption). In addition, dilution may occur as materials are transported to larger bodies of water.

The persistence of the 13 pesticides varies from low (malathion, carbaryl, fenitrothion), moderate (Biazinon, bendiocarb, propoxur) to high (lindane, chlorpyrifos, and dieldrin. We define low as days to weeks, moderate as weeks to months, and high as months to years of residue in the environment. All of these relationships are predicted by the long persistence developed in 33 day microcosm studies in which all these pesticides were tested on a consistent basis. In natural environments, persistence is dependent on specific environment processes, and one would expect considerable variation in persistence. In the case of propoxur, a very long persistence (which indicates very high persistence) apparently overstates the persistence in the environment, which is moderate (Freed, personal communication).

Sediments may act as areas of deposition or sorption of organic materials. These sites may contain much higher concentrations of contaminants than the water volume itself--especially since many inorganic materials have a tendency to sorb to organic materials. Because of this phenomena, organisms that live or feed near sediments are exposed to greater environmental risks.

FIGURE E.22

RELATIVE TOXICITY OF 13 PESTICIDES
TO FISH AND INVERTEBRATES

Chemical	Relative Toxicity Fish	Relative Toxicity Invertebrates	Persis-tence	Bioaccumu-lation
dieldrin	H	M	H	H
lindane	M	M	M-H	H
acephate	L	L	L	L
chlorpyrifos	M	H	M-H	M-H
diazinon	M	H	M	M
fenitrothion	L	H	L	M
malathion	L	L	L	L
bendiocarb	M	M	M	M
carbaryl	L	L	L	L-M
propoxur	L	H	L-M	L-M
cypermethrin	H	H	M-H	H*
lambda-cyhalothrin	H	H	M	H*
tralomethrin	H	H	M	H*

H = high
L = low
M = moderate

* based on Log P

The tendency for a material to sorb -- known as its lyophilicity (or hydrophobia) is measured by the octanol-water partition coefficient, and is signified by log P. A high log P (over 3) indicates that a material is likely to sorb and be removed from the water column.

While it is impossible to calculate pesticide concentrations for all the scenarios in Africa (which depend on rainfall, steepness of land, type of soil, and the size of receiving water bodies), an average estimation of effective pesticide concentrations has been made (Figure E.23).

We have estimated exposure of water bodies (and resident biota) to pesticide spray. In this analysis, a worst case scenario is used. This assumes:

1) pesticides are applied at maximum recorded field applciations rates (Section D.3),
2) pesticides are applied directly over water bodies,
3) the water body is only 1 m deep and 10 ha (10^5 m^2) in area, and
4) no degradation occurs during the application period.

If pesticides are applied adjacent to water bodies; rather than directly on them, the pesticide concentrations will be determined by aerial spray drift and run-off of pesticides from the soil surface.

Spray drift has modeled extensively by APHIS (1987). They have shown that depending on the steepness of the terrain and weather conditions, deposition was similar to direct applicator rates and decreased to 0.25% at 152 m (Figure E.23). To reduce the exposure of water bodies a buffer of greater than 152 m is needed to ensure that less than 1% of the spraying reaches it.

FIGURE E.23

DEPOSITION OF PESTICIDE SPRAY ON
ADJACENT AREAS (from APHIS, 1987)

Scenario	Deposition as % of Application 10m	152m
Steep terrain, mild wind	100	7.5
Gentle terr., turbulent wind	0.7	0.25

The type of soil will greatly influence the run-off rate. Soils with high clay content and/or low porosity will allow greater concentrations of pesticide to runoff to adjacent water bodies. In sandy soils, which are more commonly found in Africa (Section E.2.1), precipitation seeps into the soil volume and pesticides concentrates in receiving waters are low. In general, the contribution of pesticide in runoff to the pollution load in water bodies is less than 1/10th of that which occurs with direct spraying. Once again suitable buffer areas will be needed to ensure that runoff does not reach water bodies. However, because of the nature of African flood plains (see below) this buffer needs to be considered very carefully and depending on the resources to be protected, may necessitate buffers of many kilometers.

Actual environmental concentrates of these pesticides have not been measured; estimated concentrates are based on stated assumptions. Larger water bodies will provide greater dillution so that exposure concentrations may be lower. Streams and river systems provide rapid dilution and are expected to have lower exposures -- although they maybe subject to repeated or continuous exposure from a variety of sources.

E.4.2.3 Risk analysis for chemical controls

Based on an analysis of potential exposure and toxicity scenarios described above, the 13 pesticides proposed for use in the locust control program of each chemical fall into categories of toxic, moderately toxic, and low toxicity as described earlier.

In order to conduct risk analysis, the concentrations of pesticides from field application rates (previous Section) and the toxicity of each pesticide was compared (previous Section) (Figure E.22). Those concentrations that are higher than toxicity of the pesticide are expected to severely affect biological communities.

Pesticides that appear to allow little or no safety margin in toxicity to fish (and therefore will cause detrimental effects) include lindane, chlorpyrites, diazinon, malathion and the three synthetic pyrethroids (Figure E.24). Acephate, propoxur, carbaryl, and bendiocarb appear to have a sufficient safety margins. Dieldrin, which appears to have a sufficient safety margin, is not acceptable because of high persistence and high bio-accumulation potential. Fenitrothion appears to be relatively non-toxic to fish, but is extremely toxic to invertebrates. Thus, its use may be acceptable in or near the aquatic environment.

All of the 13 pesticides, with the exception of propoxur, acephate, and dieldrin are very toxic to aquatic invertebrates and do not meet acceptable safety margins. However, unless exposure is repated or continuous, these populations generally recover quickly through immigration into the area.

Aquatic area are of particular concern because of the nature of African floodplains, water cycles in semi-arid regions, and the timing of locust control programs. African floodplains incorporate the main channel of the river and a series of flats, which are often flooded during the annual flood cycle. These areas often are associated with extensive lake systems (Figure E.25). While there may be distemal entites geographically, they are ecologically completely integrated into the river/floodplain system. Pesticides applied to areas near water bodies may quickly be innundated during other parts of the flood season. Thus buffer areas must occur outside of the general floodplain of a river in order to avoid exposure to these chemicals.

Locust and grasshopper population growth is closely associated with rainy seasons. Typically early (phase 1) inverventions are made during the onset of the wet season. A late intervention (or phase 2), which is less frequently used, occurs at the end of the wet season, when floodplains have started to recede and water bodes are shrinking. At these times aquatic animals can easily be exposed to pesticides during spray programs.

In a similar fashion, semi-arid regions tend to form large series of transient water bodies during the rainy season. Thus, even in deep-sand areas, aquatic exposure is possible for wildlife (especially birds) and humans who like these as sites of drinking water.

Grasshopper control programs in rice paddies may represent the greatest exposure of aquatic resources to pesticides. We take as an example the scenario in the Senegal

COMPARISON OF ENVIRONMENTAL EFFECTS FOR USAGE RATES FOR 13 PESTICIDES IN LOCUST CONTROL

Insecticide	Field Rate (g/ha)	Effective Dose (mg/l)	Toxicity (mg/l) Fish	Toxicity (mg/l) Invertebrates	Safety Margin
dieldrin	35	0.003	0.006-0.02	0.250-0.64	N*
lindane	300	0.03	0.03-0.1	0.04-0.50	N
acephate	140	0.014	>100	705	Y
chlorpyrifos	100	0.01	0.007-25	0.01	O
diazinon	600	0.06	0.04-0.02	.0002-0.008	N
fenitrothion	350	0.035	2-5	0.003-0.01	Y
malathion	700	0.07	0.05-12	0.0007-1.4	N
bendiocarb	200	0.02	1.5	--	?Y
carbaryl	225	0.02	1.6-20	0.03-6	Y
propoxur	150	0.015	5-8	0.03	Y
cypermethrin	36	0.004	.002	--	N
lambda-cyhalothrin	20	0.002	--	--	N
tralomethrin	.20	0.002	.002-0.004	--	N

1/ = No, Yes and Occasionally
*due to bioconcentration

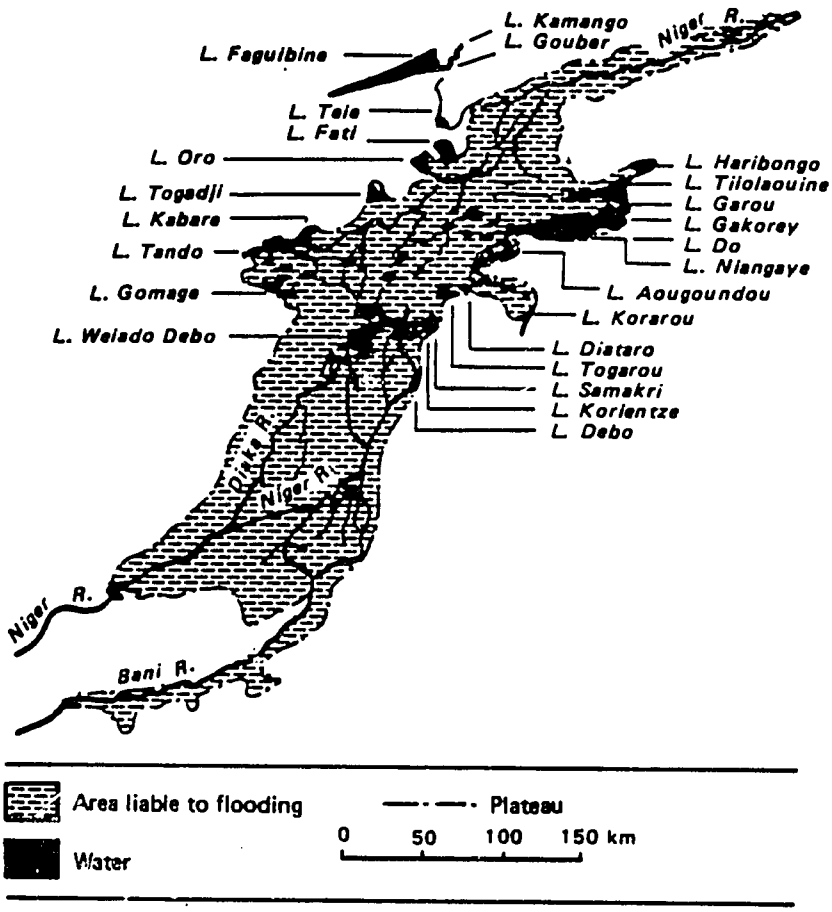

Figure E.25 The internal delta of the Niger River and its tributary, the Bani
Source: Welcomme, 1986

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River Basin. Precise information on quantities or types of pesticides used was not available. Neither was the approximate area of rice paddies. However, this scenario is analagous to that of direct spraying of a water body (previously discussed). Pesticide concentrations are expected to exceed most toxicity levels for fish and invertebrates. It is expected that all but one the most resistant species of fish would be killed, along with all aquatic invertebrates. Until dilution of at least 100 occurred, species downstream would also be expected to be adversely affected.

E.4.2.4 Synergism and effects of other pesticide programs

Interviews with over 30 individuals throughout the Sahel confirmed that their best estimates were the pesticides used in locust/grasshopper programs were a small percentage of the total pesticide use in Africa. This is not to say that exposure to pesticides in the program is low (which we discuss in Section 4.6), but that the relative exposure appears to be minimal compared to other uses.

While relative total exposure to pesticides from the locust programs in Africa is low, a significant increase in pesticide exposure occurs in semi-arid regions. These areas are of marginal agricultural productivity, so that few pesticides are used because of the expense. Locust control programs probably represent a major increase in the quantities of pesticides used in Northern Mali, Mauritania, Niger, Chad, and Ethiopia. Sudan may also have a similar trend, although the enormous pesticide use for cotton may allow sufficent transport out of the primary use areas to constitute the major pesticide use even in non-irrigated Sahel regions of Sudan. We have shown that fish appear to be at risk, and their food species may be affected by pesticide use. Since semi-arid regions in West Africa are major fish production areas, this possibility should not be dismissed lightly.

Application of pesticides for locust/grasshopper control in "deep-sand" areas in many cases may allow aquatic exposure. During the rainy seasons, which is when this application occurs many open bodies of water form. There will be some runoff associated with this -- often into oases. Wildlife (especially birds) congregate near these areas. Exposure is possible due to the presence of pesticides in the lenses of water that may appear in the desert oasis. The water quality in these areas has not been tested and may indeed form a risk to migratory birds, and indigenous human populations.

Locust/grasshopper spraying programs are generally conducted during or close to the time of seasonal rains. While

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pilots are told to avoid aquatic areas, there may be sufficent run-off during these seasons to add pesticides to these systems. And of course these instructions may have no effect on uncontrolled pesticide uses in dusts, baits, or hand spraying.

E.4.3 Critical habitats

Contrary to what many suppose, Africa is not dominated by rain forest but by savanna and grasslands. While the continent supports major rivers, lakes, wetlands, vast deserts and mountain ranges, with the exception of selected wetlands it is within the savannas and grasslands that protected and/or critical areas are most often gazetted.

Protected and critical areas are not necessarily synonymous. Protected areas are characterized as having some degree of legal status, e.g., as national parks, as forest reserves, wildlife reserves, controlled hungtin areas, tribal reserves, etc.

A recent Sierra Club (1986) inventory of Africa, looking only at contiguous areas greater than 4,000 km^2 (1 million acres), shows that 9.2 million km^2 (30%) of the continent is comprised of wilderness areas. Of those areas, 702,100 km^2 of areas larger than 50 km^2 have been set aside as protected for the conservation of these resources. These protected areas, of which there are 368 each covering over 5,000 na comprise nearly 88 million ha, representing less than 7% of African wilderness, or roughly 2% of the continent. Protected areas are shown in Figure E.26. Some 50% of this total is found in sub-humid and semi-arid Southern Africa.

Critical areas are generally those areas which support unusual, sensitive, rare or threatened species, or species of particular local, national or international significance -- or are areas upon which important plant and/or animal species, populations, or communities depend. Areas are considered critical for the above reasons and because even minor disruptions, including the introduction of chemicals and the subsequent imbalances from, e.g., mortality within one or more components of a community can determine the success of other species of life associated with them. These in turn will have an effect upon still others, and ultimately perhaps on the entire system. Often critical areas are delicately balanced, however, if left undisturbed are self-supporting and sustaining. Nearly always they are discretely defined, with a particular set of physical environmental factors that constitute the surrounds of a community.

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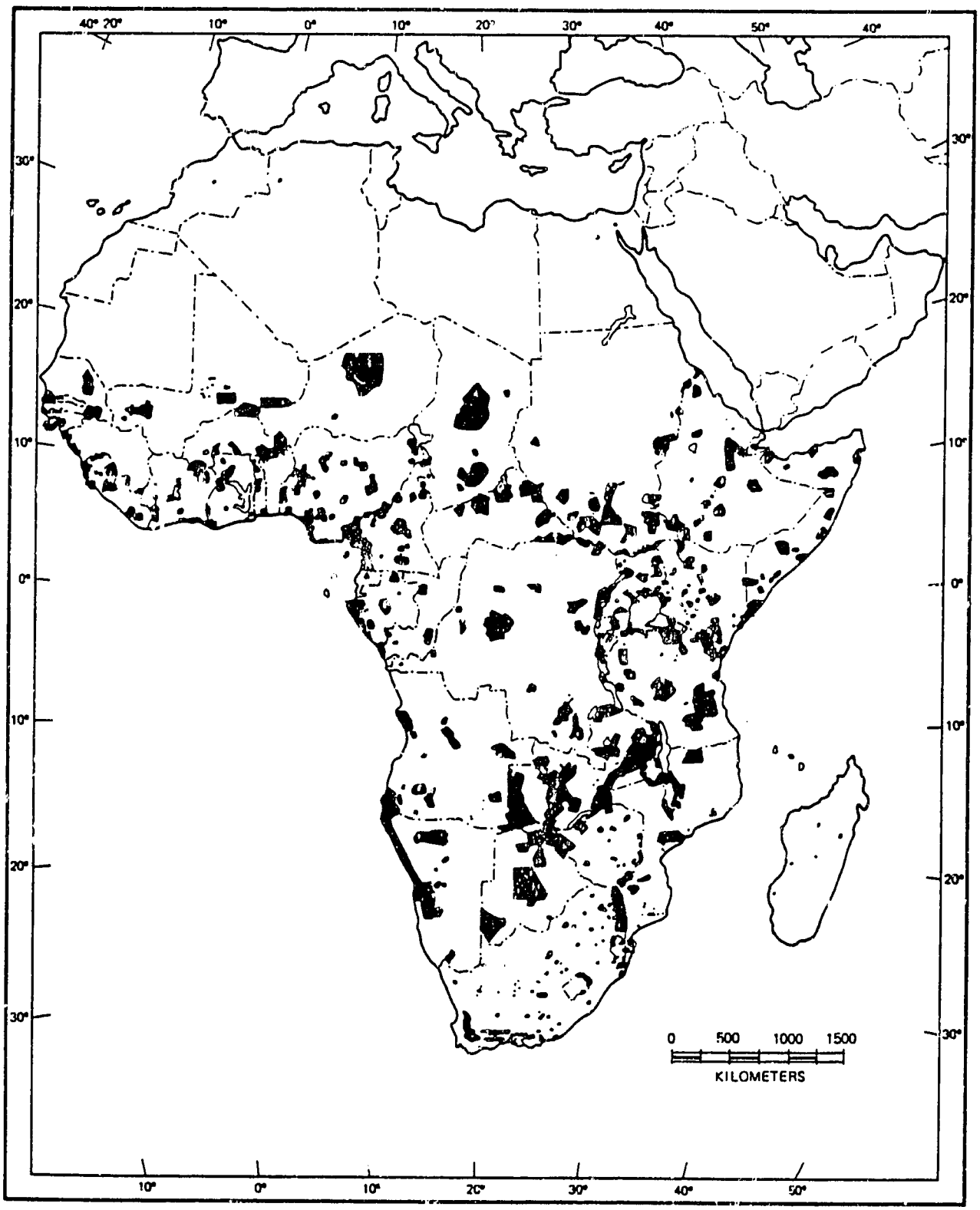

Figure E.26 African protected area boundaries. The degree of protection afforded to each of the areas is not shown.
Source: International Wilderness Leadership Foundation, (undated)

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Protected areas, on the other hand, generally are, or contain critical habitats. Often these are to protect wildlife comprised of numerous species. Africa's national parks and wildlife reserves are examples. As with forest reserves, or any other legally protected areas, these critical habitats can easily be considered for mitigating factors when considering spraying operations. Buffer or protectives zones of no chemical applications can be established around the perimeters of these areas. A recommended buffer strip is a minimum of 1 to 5 km. AID can ensure that spraying is prohibited in these zones.

In general, all wetlands are of significant importance to be considered critical habitats. These are not always easily delineated but whenever they can be recognized should be protected by no-spraying buffer zones. Recommended distances for such buffer zones are 5 km for the borders and 16 km for the areas constituting the origin and, if defined, outlets.

Known sites for breeding, feeding, and nesting of rare, threatened, and endangered species should be protected as critical habitats. It is unreasonable to expect entire ranges of such species to be ocmpletely protected from spraying operations. However, where well-known or defined sites comprising habitats commonly used exist, all measures should be taken to prohibit chemical applications.

AID Mission staff should consult with local public agencies responsible for natural resources and historical areas to ascertain complete listings and designations of locally defined critical areas which may not be apparent at an international level. At all costs, critical areas for biological diversity should be protected from spraying.

E.4.4 Rare and endangered species

The EPA and other Federal agencies', including AID's compliance with the Endangered Species Act (PL 93-205) is currently under review and some questions have been raised regarding the full range of an endangered species being protected for purposes of the EPA's pesticide labeling program. EPA recently embarked upon an intensive pesticide label improvement program aimed at improving its record of compliance with the Endangered Species Act (ESA).

For clusters of pesticides used in agricultural crop production and rangelands, as for label language for forestry-use and mosquito-larvicide chemicals, wording being considered for labels could prohibit the use of pesticides within the "range" of an endangered species.

Other Federal agencies' compliance, including AID's through "Regulation 16", would conform to this or other considered language regarding the protection of endangered species.

This considered wording will undoubtedly be questioned by some Federal agencies, e.g., the U.S. Department of Interior's Bureau of Land Management as being impractical, perhaps unnecessary, restrictive, and economically unsound. In addition, it will be considered confusing for Federal agencies such as AID, since the "range" for a rare, threatened, or endangered species in, for example, Africa will (1) usually be ill-defined, and (2) may include large tracts for which a listed species does not occupy specific and localized habitats, i.e., agricultural lands.

Blanket exclusion on the use of a pesticide throughout a species' range may not, in most cases, be needed to protect the species. Nonetheless, until the efforts to improve compliance are sorted through by EPA, compliance with existing regulations and standards should be followed for any pesticide applications and should include (1) following the EPA label program guidelines, (2) avoid (prohibit) pesticide applications on specific and local sites and habitats where listed species are known to exist and (3) prohibit use of those chemicals, data for which show applications would result in direct and/or indirect harm or mortality for listed species. Indirect harm includes but is not limited to adverse affects on a listed species' food resources, habitat, and biological associations upon which the listed species depends.

Project personnel and AID Mission staff responsible for locust/grasshopper control operations should assume the responsibility to (1) refer to compliance standards with EPA, (2) consult with representatives of the U.S. Fish and Wildlife Service (either through the Permit Office or Scientific Authority Office), and (3) local representatives of Wildlife and National Parks agencies prior to control operations to (1) ascertain all listed species, (2) ascertain all sites and local habitats where listed species exist and (3) ascertain compliance is met. These steps should be followed to ensure no control operations adversely affect any rare, threatened, or endangered species, either as listed by the U.S. Fish and Wildlife Service, by CITES (Convention on International Trade in Endangered Species) or by individual countries as protected species (Appendix 12).

To ensure this protection, AID should be required to thoroughly address the steps above as part of the waiver process before responding to even emergency situations of locust/grasshopper outbreaks, and for other pesticide decisions as well, i.e., ensuring complete protection of endangered species

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and prohibiting use of pesticides when any question of threat or harm to endangered species is involved.

E.4.5 Overlap between locust control areas and sensitive habitats

During the previous sections we have discussed in great detail potential impacts on aquatic and terrestrial biota. Using information concerning the toxicity and envrionmental rate of the 13 pesticides, and making realistic (but conservative) assumptions about the exposure of biota to these pesticides, it appears that many species may be at risk. Thus there are many reasons to argue that locust and grasshopper control programs may be having an adverse impact on the environment.

It should be noted that there are no direct data, other than several anecdotal episodes of environmental impact. This is probably because very few systematic observations have been made -- and we have recommended several monitoring programs (residue analysis, population surveys, etc.) to determine whether impacts are occuring.

It appears that there is a direct overlap between many sensitive habitats and locust and grasshopper control areas (Figure E.27 and Figure E.28). The size of the areas involved is variously estimated at 1000 to one million ha. A thorough inventory of the areas involved is recommended in order to determine a more precise estimate of the degree of problem. If these areas of overlap are large, it appears necessary that a major policy decision be made in each country as to which resources need protection. Presently it appears that locust and grasshopper control programs have priority over protecting these sensitive areas.

E.4.6 Public health

Human exposure to pesticides has a wide range of risks. The three general risk categories are occupational, accidental and mostly, subliminal. In addition to being dose related, the effects of exposure are modified by certain host facotrs than can increase the severity and nature of toxicity inherent in each chemical class of pesticide.

As a group, the handlers of pesticides such as loaders, mixers, spraymen, etc. have the highest potential risk of poisoning. However, in most instances they are also the group that, through training and experience, is more aware of the dangers of pesticide poisoning than the general population in the area. Accidental poisoning represents a category where preventive measures can be expected to have the most important immediate effect on reducing the incidence of the acute episodes

of pesticide poisoning. This has been discussed in more detail in another section of this report.

The most worrisome aspects of human exposure to pesticides concern the subclinical, chronic changes that may result from the cumulative effects of different pesticides to which an entire population in a given area has been exposed unknowingly and without being given a choice to reduce the risks.

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FIGURE E.27

Habitat/Area	Concern/Comment
Desert, grasslands and semi-arid areas in bloom	Pollinators active, increased game, animal, and bird life. Chemicals are applied during brief moist period when all biota are active and reproducing. And all semi-arid zones fragile, simple ecosystems with relatively few species. Areas already under stress due to erosion, desertification, deforestation and overgrazing.
Temporary lakes and marshes	annual fish species, congregates of birds
seasonal (rainfed) cropland	pollinators on bird populations
Rivers/permanent lakes and swamp	Pollinators important on irrigated crops, major fisheries, bird populations. Crops are planted up to edge of receding flood waters, so no buffers possible if crops to be protected. Specific sites on Blue Nile, Niger at Senegal Rivers.
Rice paddies	birds and fish
Permanent inland swamp (Niger Inland Delta and Lake Chad wetlands)	birds and fish
Wildlife reserves and protected areas	Prime grasshopper habitats. Conflict of interest between endangered species, protected areas and locust and grasshopper control.
Human exposure	Nomads/herds in grazing areas; people eat locusts; shallow wells in desert and semi-arid oases.

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FIGURE E.28

Habitat	LOCUST						GRASSHOPPER			
	Desert	African Migratory	Red	Brown	Tree	Moroccan	Senegal-ese	Sudan	Variegated	Other
Desert, grassland and semi-arid in xxx	O,D	--	--	--	--	--	O,F	--	--	--
Temporary lakes and marshes	O 1/	--	--	--	--	--	O,F	O 12/	--	--
Seasonal cropland	--	--	--	O 8/	--	--	O 11/	O 11/	O 11/	O 11/
Rivers, lakes, swamps	O,D 2/	O	O 6/	--	--	--	O,F 13/	O,F 13/	O	
Rice paddies	--	O	--	--	--	--	?	--	--	O 14/
Inland swamp	--	O 4/	--	--	--	--	O 15/	O 4/ 15/	--	--
Wildlife preserves	O,D 3/	O 5/	O 7/	O 9/	O 10/	--	?	?		?
Human exposure	O,D		O	O		O	O,F	?		--

D = dieldrin
F = fenitrothion
O = other pesticide(s)

1 = in south Morocco
2 = runoff into Red Sea
3 = Indus River in Pakistan, Nile in Sudan and Ethiopia
4 = Niger inland delta, lake and wetlands, Blue Nile south of Khartoum
5 = Air Massif, Lake Chad locust outbreak area is protected
6 = Swamp and floodplans are outbreak areas
7 = Major spraying program
8 = Botswana
9 = Botswana, Kalahari Desert
10 = Circumstantial evidence of spraying in Sudan
11 = Pesticide treatment most common at crop sedding and ripening stage
12 = Floodplains are habitat in Nile, Senegal, Niger and Lake Chad
13 = Irrigated areas
14 = Species is hieroplyphus dagenensis, a major rice paddy pest
15 = Senegal River valley

Figure E.29 gives a list of the general types of pesticide poisoning and of those host conditions that, up to now, have been recognized or are suspected to serve as co-factors that can accelerate or worsen the clinical manifestations. A detailed listing of the toxicity of the pesticides used for locust and grasshopper control is in Section D.4.

In the tropics where most persons engaged in agricultural activities do not wear protective clothes other than a pair of shorts, the exposure of large areas of their bare skin to pesticides applied by spraying or present as residues on the parts of treated plants make them highly vulnerable to become the victims of poisoning. The high ambient temperatures of the tropics and sweating can facilitate the percutaneous absorption of the chemicals. Skin ulcers, abrasions and cuts further increase this process.

Little is known about the cumulative effects of repeated pesticide exposure to concentrations below the threshold of causing acute symptoms. The relative and/or attributable risks of individuals with predisposing factors, such as malnutrition (CPM and vitamin deficiencies), liver abnormalities, chronic infections, neurologic disorders, chronic eye infections (trachoma), chronic respiratory diseases, including asthma, are not well known. Case-control and longitudinal studies in populations with different degrees of exposure are urgently needed. Likewise, the possible ill effects of chronic pesticide exposure on pregnant women and, as contributing factors, in the pathogenesis of malignancies must be addressed.

In practice, the situation is even more complicated and human pesticide exposure may be more intense in many areas of Africa where there are uncoordinated projects of agriucltural pest and vector control of human and animal diseases using different chemicals in the same places and at the same time.

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FIGURE E.29

HEALTH CONDITIONS THAT
AFFECT PESTICIDE TOXICITY

Condition	Effect
Skin abrasions, ulcers, wounds	rapid percutaneous absorption of open pesticides
Malnutrition	decreased ability of detoxification, exacerbation of symptomatic Vitamin A deficiency
Liver diseases: hepatitis, cirrhosis, schistosomiasis	impared pesticide metabolism, increased severity of the liver disease
Respiratory infections	increased absorption of pesticides in aerosols; irritation of bronchi and alveoli
Eye infections	increase conjunctival irritation by pesticides; aggravate chronic eye infection, e.g., trachoma
Use of antiparasitic and other cholinergic medications	potentiate the effects of poisoning by organophosphorous pesticides

Pesticides can also enter the human body with drinking water from contaminated rivers, streams and unprotected wells that serve as the normal sources for domestic water supply inmost rural areas of Africa. The chemicals can also be ingested with contaminated food. Irritation of the eyes can result from fingers that contain traces of pesticide.

E.4.6.1 Human Exposure to Pesticides

The humans most likely to be exposed to an acutely hazardous amount of the chemical are those who are engaged in handling, transport, storage, application or disposal of these chemicals. As many studies have shown, the person most likely to receive a sustained relatively high exposure will be those who are mixing and loading the chemicals or applying them with backpack sprayers and dusters. The exposure likely to be suffered by either the mixer-loader, applicator or those engaged in transport, storage and so on, is that of dermal exposure. To be sure, with some of the more volatile materials, under high temperature there can be some respiratory exposure but by far the most significant is the dermal route of exposure. This would arise from spills, splashes, and perhaps being caught in the drift of a spray cloud. Exposure of those working with the chemical can be substantially reduced by wearing appropriate protective clothing, that is clothing that fully covers the body, the use of rubber gloves and shoes or boots to protect the feet, masks and respirators. Other protective devices may also be employed for additonal protection.

Others who may be exposed from the use of the chemicals employed in the present program include, the bystander, that may be exposed to some drift, or individuals eating crops on to which the chemical may have drifted. These would be crops that were growing near to the treatment area, or it could be animals that have picked up a residue of the chemical from consuming forage or otherwise being exposed. However, exposure to such residues would probably be of short duration with the carbamates, organophosphates or pyrethroids used because of the ready breakdown of these chemicals in the environment or in metabolism of plants and animals. Another possible source of exposure to these not engaged in the use of the chemical may be through water supplies that have inadvertently become contaminated. And this should be a relatively short-term exposure in the case of the more label compounds, i.e., carbamates, organophosphates and pyrethroids because of their ready breakdown. The exception might be with where an organochlorine insecticide has been used.

E.4.6.2 Human Health Risk Assessment

<u>Acute Hazards</u>

Based on the probability of exposure to significant quantities of the chemical, it would appear that the ones engaged in working with the chemical are most likely to be at acute risk, and this from dermal exposure. However, the chemicals that would be used in any AID supported program, namely the carbamates, organophosphates and pyrethroids, treated in this report, are not of the highly dangerous category. Moreover, most of them have a

dermal toxicity that requires about three times the amount of exposure to have equal to oral exposure toxicity. Thus with appropriate clothing and other protective measures such as immediately washing off spills and splashes or removal of contaminated clothing, should substantially reduce the risk of acute toxicity from dermal exposure. Of serving these precautions then should minimize the acute hazard to humans. It is unlikely that bystanders or those exposed to residues would be at acute risk.

Chronic Hazard

In the program for control of locust and grasshoppers, applications of the chemical are made during outbreaks of the pests. In any given area, there may be only one or a very few applications and where multiple applications are used an interval of time would elapse between those applications. Hence, with most of the carbamates, organophosphates, and pyrethroids "half-life" has been found to be no more than 14 days in most compartments of the environment to interval of 60 days between applications as a theoretical consideraton would reduce the residue in the environment to less than 18% of the original deposit. Since the rate of applicaton of these chemicals is light compared to some agricultural applications of the same chemical, the remaining residue would be quite small. Therefore, these residues probably would afford, at most, a very low chronic hazard to humans. Those handling the chemicals however, who may sustain a longer period of dermal exposure even to relatively low amounts, may have a greater chronic hazard that would be most likely evidenced by a somewhat depressed cholinesterase activity where the organophosphate and carbamate pesticides are used. However, with appropriate health monitoring this risk would be reduced by removing the worker from exposure until recovery of the cholinesterase.

Carcinogenicity

Of the pesticides proposed either for use or testing in the locust control program that could be supported under AID regulation #16 -- carbamates, organophosphates or synthetic pyrethroids -- none fall into the extremely hazardous category of the WHO classification. For the most part they are readily metabolized and/or excreted. Thus a single exposure is not likely to result in a continuing body burden of any significance. On the other hand, the chlorinated hydrocarbon pesticides -- dieldrin and lindane -- treated in this report do bioaccumulate and remain for considerable periods of time as a deposit in the human body. For this reason as well as their potential for adverse effects strongly contraindicates their use in so far as other materials can satisfactorily be used in their stead.

Among the chronic adverse health effects that some chemicals may produce upon sufficient exposure include neurological, cancer, mutagenic and reproductive. However, with certain chemicals the exposure (actually the dose) required to produce some of these effects approaches that which results in overt sub-acute or acute symptoms. With any given chemical, though, the information at the time may not indicate a risk of chronic effects from normally encountered exposures. New data from more refined or detailed studies may reveal such risks. Thus, with the carbamate, organophosphate and pyrethroid pesticide proposed for the locust and grasshopper control programs there is no information at the time of this writing to indicate that they pose an unusual risk of chronic adverse effects (at the exposure levels expected) that is not to say new information may not reveal some now unexpected effect.

The following tabulation atttempts to summarize the information available on these chemicals as of early 1987. EPA documents were reviewed for the status of chemicals under special review, as well as IARC documents.

Chemical	Comments
Carbamates	
bendiocarb	Most toxic of three carbamates but fairly short "half life". No observable effect on rats when fed 10 ppm in diet for two years. Not expected to be a problem properly used.
carbaryl	Feeding studies with two species produced no tumors. May give reversible cholinesterse inhibition and modified kidney function. Classed as weak mutagen.
propoxur	No observable effects at 250 ppm in diet when fed to rats. Sub-acute effects appear to be reversible.
acephate	At 30 ppm in diet, in two year feeding study, cholinesterase depression only effect seen.
diazinon	No observable effect on dogs at 0.02 mg/kg/day in 90-day feeding study
diclorovos	Fairly toxic to mammals. Cholinesterase inhibitor.

fenitrothion	Absorbed through skin. Has moderate persistence for an organophosphate.
malathion	Tests in rats and mice for carcinogenicity were negative.

Synthetic Pyrethoids

cypermethrin lambda-cyhalothrin tralomethrin	WHO classifies these as HU (hazard unlikely) as far as humans are concerned and under conditions of approved use.

Chlorinated Hydrocarbons

dieldrin	Persistent in environment; has high bioaccumulation potential and forms refractory deposit in adipose tissue. In mammals effects central nervous system. Produces liver damage upon prolonged exposure. IARC concluded that dieldrin was hepatocarcinogenic at least in mice.
lindane	Convulsant at elevated doses; induces liver changes (enzymes). Skin and eye irritant. Has a 2 year "half life" in environment. Bioaccumulates.

It is recommended that anyone involved with pesticides be familiar with Wagner, 1981; Morgan, 1982; Zapatos and Collier, 1982; and Hays, 1984.

E.4.6.3 Interaction with pesticides used for agricultural and public health purposes

In many parts of Africa public health projects for vector control overlap with projects where pesticides are applied to the same environment for agricultural pest control. While the immediate targets of these projects are different and appear separated in space, closer scrutiny reveals that there are ample opportunities for the local residents to become exposed to the pesticides used in both projects. Air pollution,contaminated ground water, water storage tanks, foods, fruits and vegetables can all serve as common vehicles for pesticides.

At present, the most important public health projects based on the use of pesticides for vector control of major diseases include vertical projects and an array of smaller operations that are part of the general health services. The

former include the Onchocerciasis Control Progrm which include Burkina Faso, Senegal, Mali, Niger, Sierra Leone, Guinea, Guinea Bissau, Ivoary Coast, Togo, Ghana, and Benin. Control of the blackfly, vector of the disease, is based on the application of a special formulation of temephos (Abate) by fixed wing aircraft and helicopter to all breeding sites in the project area. Dosing of the pesticide is monitored throughout the area by small radio buoys. The effects of larviciding is monitored entomologically. The program has a special panel of experts which is responsible for a surveillance system to monitor the impact of abate on the non-target river fauna. At some occasions abate was removed from the containers stored at the small bush air strips throughout the area. These were established for refueling the helicopters used for the spraying operations and also for replenishing the tanks for abate aboard the aircraft. As has been reported from other places, the pesticide was then used for "fishing" through poisoning. With the development of resistance at two sites of the project area, alternative larvicides had to be used. Preparations of BTI were found to be effective during the dry season. Other types of pesticide formulations are being developed for backup operations should the need arise. In the past the spraying operations of OCP were carried in predominantly remote areas where agricultural uses of pesticides were absent. This situation is changing rapidly with the massive resettlement of reverain valleys freed from onchocerciasis. It would be prudent to make use of the expertise of OCP now to develope the methodology for integrated pest and vector control and the monitoring of pesticide residues now. By the same token, a realistic surveillance system for human exposure should be established in the area.

All countries of tropical Africa have malaria control projects of some kind. While most of their efforts are directed to chemotherapy (presumptive and radical treatment) and chemoprophylaxis of high risk groups in the ppopulation, residual spraying operations with a wide range of different insecticides, including the chlorinated hydrocarbons (DDT), is practiced in major cities, airports, rural headquarters of plantations, etc. More recently there have been efforts to increase the use of bedneets impregnated locally with pyrethrin. Hence, the residents of all malarious areas are exposed to pesticides. However, the degree of their exposure and the relative risks of the exposed to develop adverse health effects are unknown. Cooperation between different agencies responsible for projects in which pesticides are being used is urgently needed to estimate the total amount of chemicals applied to an area, to study the chemical interactions between different pesticides in the laboratory and under fieldconditions, to measure pesticide concentrations in water, exposed food, meat, and in the soil near human dwellings and in the working area. At the same time epidemiologic studies should examine pesticide exposure by direct

and indirect tests, i.e., pesticide concentrations in small blood samples and, preferably, in excreta; and cholinesterase determinations of blood and plasma. For the latter, it may first become necessary to establish the relative range of "normal" values in a population. With a preliminary list of potential health hazards resulting from excessive chronic exposure of pesticides, a series of well planned case-control and prospective studies should be designed to determine the relative risks as well as the attributable risks of persons with and without specific pesticide exposure for developing disease.

In Uganda, Kenya, Sudan, Tanzania, Zambia, Cameroon, Chad, Central African Republic, Burkina Faso, and to a lesser degree in other African countries, there are control programs for trypanosomiasis, e.g., trypanosoma b. rhodesiense and T. b. gambiae. With shifting foci for tsetse fly control it is essential that these projects be coordinated with other public health and agricultural projects in which pesticides are used.

At the present time there is an outbreak of yellow fever in Nigeria which can be expected to cross the borders and affect some of the neighboring countries. As emergency measures, including not only yellow fever vaccination and but also spraying operations against the urban vectors of the disease can be expected to include areas of locust and grasshopper control, this would be the time of consultation.

By necessity, most of the concern of pesticide use has to deal with the untoward health effects of local residents who are exposed to these chemicals. There are, however, two other areas of pest control that deserve consideration. The first deals with the possible effects of the widespread use of agricultural pesticides on the development of resistance of the arthropod vectors of human diseases, especially of malaria and onchocerciasis. In this context, the subtle change of vector species and sibling species as well as the transmission dynamics need to be studied. The second area concerns the possible potentiation of the effects of public health projects for vector control by agricultural uses of pesticides. An example may be seen in the Gezira area of the Sudan, where the level of malaria endemicity has dropped considerably as a result of residual house spraying plus the massive application of numerous pesticides for agricultural purpose, mainly to cotton fields. With the low level of transmission there was a gradual loss of immunity to malaria. On the other hand, pesticide resistance was slowly emerging. This constellation of low immunity and relative resistance of the vector became critical when heavy rains, combined with leakages from the irrigation canals, immigration of migrant laborers from malarious areas created favorable conditions for a malaria epidemic.

F. TECHNICAL ALTERNATIVES FOR DEALING WITH LOCUSTS AND GRASSHOPPERS, WITH MITIGATIVE ACTIONS

F.1 Technical Alternatives

F.1.1 Alternative A - No control measures and mitigative actions

Under this alternative AID would no longer participate in locust/grasshopper control. Although AID has no legal obligation to participate in these programs, it has a mandate to help find solutions to problems such as these. A major Agency policy initiative issued in May 1978 directs AID"...to exert international leadership by communicating U.S. policies and experience on pest control and pesticide problems to other nations and international organizations."

As is detailed in B.2, AID has a long history of participation in locust/grasshopper control. Developing nations have come to depend on AID cooperation and assistance, along with that of other donor nations, during emergency outbreaks. Pest control is an integral part of many agricultural development programs in which AID participates. Locusts and grasshoppers constitute one of the major, though cyclical, pest problems. Therefore, selection of this alternative could threaten the successful completion of a number of agricultural development projects aimed at improved crop production. Other agricultural and non-agricultural projects might also be affected. Without AID assistance to finance locust/grasshopper control, national funds could be syphoned off from them to pay the cost of controlling outbreaks.

Lack of AID participation could have a major detrimental impact on the way in which future locust/grasshopper control programs are conducted. AID has been instrumental in securing the elimination of the environmentally undesirable pesticides aldrin and BHC (HCH) for locust and grasshopper control. Although, dieldrin is still on the FAO recommended use list, AID succeeded in limiting its recommended use to control of migrating locust hopper band. Many African nations, Regional control organizations and even some FAO experts call for its more widespread use, but AID maintains a policy of not participating in control efforts in nations or with regional organizations which continue to use dieldrin. Without continuing AID pressure, these undesirable pesticides could quickly stage a comeback for locust/grasshopper control due to their wide spectrum of efficacy, persistence, and low cost. It has long been recognized that grasshopper outbreaks are favored by poor vigor and low density of range vegetation caused by factors such as overgrazing and drought (McEwen, 1982). Given that most outbreak areas in Africa and the Middle East are characterized by poor rangelands

and/or crop monocultures, no action by AID for locust/grasshopper control would have several consequences.

1. AID could be criticized as being unresponsive to potential economic disasters.

2. Other governments and organizations could be expected to pick up the slack in control operations.

3. If other organizations do not pick up the slack, economic losses could result.

4. Factors favoring healthy ecosystems, such as decreased grazing pressure and decreased planting of extensive monocultures, could be promoted directly or indirectly by other AID-funded projects. This might reduce the likelihood of grasshopper outbreaks.

5. If other organizations followed AID's no-action strategy, there would be fewer adverse effects of pesticides on fragile ecosystems and nontarget organisms.

6. AID would receive less criticism from environmental groups for its use of pesticides overseas.

Acceptance of this alternative would release funds that could be used for other development projects that provide benefits comparable to the technical as well as humanitarian achievements of locust/grasshopper control programs. , chances are that a no-action strategy by AID would change little. Other organizations would probably pick up the slack, insecticide use for locust/grasshopper control and other purposes would continue unabated, and poor range conditions will continue to be an overriding problem in spite of projects trying to improve the situation.

F.1.2 Alternative B - Non-chemical control

This non-chemical control alternative covers locust and grasshopper control measures other than chemical and biological control, which are Alternatives C and D (See F.1.3 and F.1.4). Under this alternative, AID-supported crop protection programs would stop using insecticides against locusts and grasshoppers and employ only botanical, mechanical and cultural control methods.

Necessary actions and the various pest control approaches available now and in the future are described in the following sections. Medium and long-term options are of necessity speculative: those described may not reflect the actual timing of research and development. Presently unforeseen mechanical, botanical and cultural control methods may become available and should be considered although they are not mentioned here.

F.1.2.1 Short-term actions

At present, the only non-chemical acridid control methods available apart from biological control are the mechanical and cultural methods described in D.2.1. These include collection and/or destruction of locusts and grasshoppers and their eggs, the adjustment of crop planting dates, and altering the environment to the detriment of the pests through reforestation, upgrading of rangeland and similar measures.

Wherever these methods are practical and effective they would be implemented. Destruction of Variegated Grasshopper oviposition fields (D.2.1.1.) would appear to be simple, practical, and immediately applicable. Implementation of this and other currently available non-chemical methods would mainly require increased emphasis in training courses for pest control and extension officers, and extension programs for organizing farmers.

AID-funded applied research on the production and use of neem antifeedant at the village level (see D.2.2.3) would continue, with results expected in the medium term.

F.1.2.2 Medium-and long-term actions

On the longer term, acridid-resistant crop varieties with antifeedant characteristics may be identified and available. Neem or other topically applied antifeedants may reach the implementation stage, as might laser control (though chances of this must be considered small at present). All new non-chemical control methods would be evaluated in Africa and the Middle East for effectiveness and economy by AID-supported locust and grasshopper control programs.

Improved pest forecasting may be operational, and to a degree would allow more effective employment of certain nonchemical measures. Farmers might choose a resistant crop variety or certain planting dates when heavy infestations are forecast for the coming season, or might prepare especially large quantities of neem antifeedant. However, since relatively few locusts or grasshoppers can be destroyed with mechanical measures and the rest of the non-chemical methods (excepting the

highly speculative laser weapon) are not lethal, even timely intervention with non-chemical controls could not prevent an impending outbreak. The pests would simply shift to vegetation other than the protected crops, if alternative food sources were available.

F.1.2.3 Effectiveness of the alternative

Alternative B, non-chemical control, does not offer the prospect of effective locust and grasshopper pest management. As discussed in Section D.2, all of the current and future control methods under this alternative have serious drawbacks. Mechanical destruction of pests or their eggs could make only scant inroads in an acridid outbreak except in a few specific cases, and mobilizing people for these efforts is getting harder. Erosion and desertification of the very large affected areas, unpredictable and often inadequate rains and other problems leave little latitude for changing cultural practices or for favorable alterations in the environment. Antifeedants, whether as applied chemical or as crop varietal characteristics, will not work well in certain key situations, such as in irrigated crops after surrounding vegetation has dried up and locusts and grasshoppers have no other food source.

The great advantage of non-chemical controls is, of course, their relative lack of adverse impacts on human health and the environment. For this reason, they should be used as much as possible.

Because they cannot provide effective control of locusts and grasshoppers, we do not recommend that AID adopt non-chemical controls alone. Rather, they would be used to maximum advantage in the context of an integrated pest management (IPM) program. Such a program would prefer non-chemical methods, using them as far as they are effective and economic, and would combine them with biological and/or chemical methods to ensure a satisfactory degree of cost effective and environmentally sound pest control.

F.1.3 Alternative C - Chemical control and mitigative actions

F.1.3.1 The control alternative

Under this alternative AID would help control locust/grasshopper upsurges and outbreaks through reliance on chemical insecticides. For the present, at least, the use of insecticides is essential to provide effective locust/grasshopper control. Through proper timing of insecticide applications, the judicious selection of pesticides and formulations to be used, and the use of the most modern and viable application techniques (as detailed in D.3), the amount of pesticides required to

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eliminate pest populations or reduce them to a non-economic level will decrease. Associated human and environmental hazards and the overall cost of operations will also decline.

Control efforts conducted under this alternative should be supported by a detailed plan of action prepared by the recipient nation with AID assistance. When multiple donors are involved, a donor coordinating committee should be established.

F.1.3.2 Mitigative actions

F.1.3.2.1 Choice of insecticides

Pesticides to be provided by AID under this alternative should be selected from one of the following categories, listed in order of priority:

1. Insecticides registered for use for grasshopper control in the United States.

2. Insecticides registered for use for pest control in the United States (except high mammalian toxicity insecticides) though not necessarily for grasshopper control, which through testing in the United States have proven efficacious for locust/grasshopper control.

3. Insecticides not registered for use in the United States, but which have been tested by the United States or other developed nations and found efficacious against locusts/grasshoppers; which are on the FAO list of recommended insecticides; and for which data on persistence and toxicity have been submitted to AID for evaluation and peer review prior to acceptance.

Chemical control efforts should be supported by a strong technical assistance component which could include specialists in survey, aerial and ground application, logistics, environmental monitoring, communications and training.

Figure F.1 rates the 13 insecticides considered in this EA with reference to their persistence in the environment and their toxicity to non-target organisms. Some pesticides that have been or are presently being used for locust/grasshopper control have been banned or their uses strictly limited in the U.S. and other developed countries. These include BHC (HCH), dieldrin, aldrin, heptachlor, toxaphene and lindane. Some of these pesticides are no longer produced but are still present in

the reserve stocks of nations and regional locust control organizations in Africa and the Middle East. Because of their relatively long persistence, their greater bioaccumulation within organisms, and their high levels of toxicity to birds, mammals, fish and non-target invertebrates these insecticides should not be considered for use by AID for locust/grasshopper control.

FIGURE F.1. TOXICITY TO NON-TARGET ORGANISMS

Chemical	Persis-tence	Bioaccumu-lation	Birds	Mammals	Fish	Aquatic Inverte-brates
carbaryl	L	L-M	L	L	L	L
diazinon	M	M	M-H	L	M	H
dieldrin	H	H	H	H	H	M.
fenitrothion	L	M	H	L	L	H
lindane	M-H	H	M-H	M	M	M
malathion	L	L	M	L-M	L	L
propoxur	L-M	L-M	L-M	M	L	H
acephate	L	L	L	L	L	L
bendiocarb	M	M	M	M	M	M
chlorpyrifos	M-H	M-H	--	M	L-M	H
cypermethrin	M-H	H*		L	H	H
lambda-cyhalothrin	M	H*	L	H	H	H
tralomethrin	M.	H*	L	L	H	H

*based on log P

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Pesticides with high persistence should be selected for use only in those instances where persistence is required. Two examples are barrier treatments for marching hopper bands and formulation into baits.

Chlorpyrifos rated among the top four pesticides in terms of efficacy in 1987 tests in Mali. Though is has a somewhat higher toxicity to non-target organisms than either malathion or carbaryl, its persistence may recommend it for use as a barrier spray for gregarious locust hoppers, or incorporated into baits. These uses should be included in any new series of pesticide tests for locust/grasshopper control in which AID is a participant.

Carbaryl has advantages over the two most widely used pesticides for grasshopper/locust control in Africa, malathion and fenitrothion. It has relatively low toxicity to birds, which are numerous in the areas where locust/grasshopper outbreaks occur. Due to its persistence (up to 21 days in the United States), carbaryl may prove to be a viable alternative to dieldrin as a barrier spray for the control of locust hopper bands, or may work well incorporated into a bait. Limited tests in Mali (Cavin, 1986) with carbaryl on rice husks provided favorable results, but results or similar test in Senegal (Huddleston, 1987C) were poor. Insecticide baits using peanut hulls have been widely used in Sudan for several years, reportedly with good results. Additional testing appears warranted, including feeding tests to determine suitable carriers. Both rice hulls and peanut hulls have little or no commercial value and are readily available in much of the Sahel. The use of such carriers could substantially reduce costs.

However, carbaryl has a decided cost disadvantage: it costs nearly twice as much as malathion, fenitrothion and acephate. The Sevin-4-Oil formulation required for ULV application must be diluted 4:1 with diesel fuel, further adding to the cost. Also raising the cost is the high volume that must be applied per hectare, approximately double that of either malathion or fenitrothion.

From an environmental standpoint, acephate would be the most acceptable of the U.S. registered products for locust/grasshopper control in Africa. Although registered for use on grasshoppers in the United States, it has not been thoroughly tested under African conditions. There is some evidence that it may not perform well under on dry or curing vegetation (Onsager, 1985 personal communication 1986), so its usage might be limited. This needs to be evaluated further under African conditions. Acephate should be proposed for inclusion in future FAO pesticide tests and included in any new tests conducted under the auspices of AFD.

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Malathion has a long history of use in locust/grasshopper control in Africa. It was the insecticide of choice for locust control in Morocco in the mid-1950's, and is the standard by which most other insecticides for locust/grasshopper control are graded. Its efficiency is high and its relatively low persistence is advantageous from an environmental standpoint. Though not as environmentally acceptable as either acephate or carbaryl its long history of use in Africa without reportable unfavorable environmental effects and its relatively low cost, including that of application, favor its continuance use as the standard locust/grasshopper control pesticide provided by AID.

The use of procurement of diazinon should be conditional on the outcome of a review presently underway.

Propoxur, normally only used as a 1% or 2% dust, merits further consideration in other formulations and for other uses. Its principal drawback is its high toxicity to birds, but its low toxicity to nontarget invertebrates is a definite plus.

Fenitrothion is probably the most widely used pesticide for locust/grasshopper control in Africa. This is somewhat astonishing considering that other insecticides consistently out perform fenitrothion in efficacy trials. Fenitrothion is also highly toxic to birds. However, it is less toxic to fish than many of the alternative insecticides. Other advantages of fenitrothion are its relatively low cost and low rate of application, which further reduces overall control costs. We do not believe that these cost savings are sufficient to override the hazard it presents to birds. It is recommended that fenitrothion be used, with caution toward birds, only near aquatic environments where fisheries might be threatened.

Bendiocarb is expensive, but it has been widely in Sudan. It did not perform as well as malathion, carbaryl and lambda-cyhalothrin in an aerial test conducted in Mali in 1987.

None of the available insecticides is without negative environmental impacts, but, as is shown in Figure F.1, their persistence varies and so does the type of non-target biota most adversely affected. Grasshopper and locust control operations should avoid spraying a given insecticide in the habitats where it is likely to do substantial harm. Guidelines are presented in Figure F.2.

Figure F.2

Habitats to be avoided when spraying with certain insecticides

Chemicals	Habitat(s)
malathion	
carbaryl	
fenitrothion	Bird nesting - Aquatic/wetlands
propoxur	Bird nesting
diazinon	Aquatic
bendiocarb	
chlorpyrifos	
lambda-cyhalothrin	Aquatic/wetlands
tralomethrin	Aquatic/wetlands
cypermethrin	Aquatic/wetlands

Note: 1. All the above are toxic to associated invertebrates, including competitors, predators, and other nontarget species. These are considered to be adversely affected, but will recover.

F.1.3.2.2 Insecticide application strategies

F.1.3.2.2.1 Locust control

The most ecologically sensitive locust outbreak and invasion areas are the outbreak areas of the African Migratory and Red Locusts and some Desert Locust breeding areas. The first two species are closely associated with wetland environments. In the past AID has not been directly associated with the control of these two locusts, having left the work to the independently-funded regional organizations. Although this has enabled AID to sidestep the environmental issues associated with control of these two pests, AID has had little or no influence on the control techniques and pesticides utilized.

Now the situation has changed. With the demise of OICMA, the International African Migratory Locust Control Organization, the National Crop Protection Services of Mali and Chad must assume OICMA's responsibility. If AID continues support to these Crop Protection Services, it becomes involved with the African Migratory Locust. This involvement, with influence on the strategies and pesticides utilized, should go a long way towards mitigating many of the unfavorable actions of the past.

In these ecologically sensitive areas, treatments should be conducted to the extent possible with either ground equipment or helicopters in order to pinpoint the treatment target more accurately and eliminate overspray and drift. Only short-residual pesticides should be used, and only where aggregation and gregarization has occurred. Although there are other more ecologically suitable areas for conducting chemical control measures, none are suitable for plague prevention. Continued chemical control within the outbreak areas is the most limited and effective use of these materials possible, as evidenced by the many years of plague prevention (44 years with the Red Locust).

Within the Desert locust recession area there are several critical habitats that encompass major Desert Locust breeding areas. These include the Tibesti mountains of Chad, the Ahaggar of Algeria, the Air in Niger (a proposed national park protecting several endangered antelope species), and Adrar des Iforas of Mali. These areas, which may produce up to three generations of locusts per year, have been implicated in the development of several locust plagues in the past. Controls in these areas have been advocated when solitary locusts reach population levels of 1,000 per km sq. Treatment of solitary populations should be discontinued. Only aggregated gregarious

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populations should be treated, utilizing barrier strips with baits to reduce pesticide requirements. However, since it is generally considered that only about 10%-15% of hopper bands are ever detected in these remote regions (the reason for the use of barrier strips), the question must be raised as to the need or desirability of locust control in these areas in the first place. We recommend treatment of these areas for Desert Locust be abandoned in favor of operations against swarm concentrations that occur, at certain other mountain barriers to the migration route.

F.1.3.2.2.2 Grasshopper control

Early intervention against the first generation of the Senegalese grasshopper should eliminate the widespread infestations later in the season which have required blanket spraying for control. Wide scale aerial insecticide applications are environmentally unacceptable and are to be avoided whenever possible. (Early intervention has the added advantage that many waterholes and water courses are still dry, reducing the problem of water contamination.)

Insecticide applications against grasshoppers should be withheld until they reach the third instar in order to take full advantage of natural mortality. This may eliminate the need to treat some areas.

Buffer zones should be established around or along watercourses. Only ground or hand applications would be authorized within these zones, and then only when the wind direction is away from the water. Unsprayed buffer zones should be left around human habitations and protected wildlife habitats. This will be difficult to achieve since ground application is generally the responsibility of the individual farmers or the host government. Still, it should be encouraged and incorporated into country plans of work.

It has been proposed that AID participate in grasshopper control only where migrating pests are involved, leaving the more sedentary species for local farmer control. The problem with this approach is that many grasshopper species migrate to a certain extent, moving from dry areas to areas of green vegetation or to locations of preferred food. AID should, however, intervene directly only during widespread outbreaks. Under non-outbreak conditions, AID should limit its pesticide use to small demonstrations and research and concentrate on farmer application training and safety, host country institution building and networking among interested and affected institutions. When an outbreak appears, early intervention and minimal pesticide use will then be assured.

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F.1.3.2.3 Applied research on the economics of locust/grasshopper control

At the moment, it is nearly impossible to rationalize locust/grasshopper control programs on an economic basis. In order to do so, crop loss assessment research with reference to these pests would have to be undertaken. Another useful area of investigation would be the economic thresholds used for insecticide application decision making. The provisional thresholds in use now -- which vary greatly from country to country -- could probably be improved considerably.

F.1.3.2.4 Aerial application

Wide-scale, large-plane aerial applications of insecticides should be avoided on ecological grounds. They are too hard to target effectively and are subject to problems of drift and inadvertent spraying of sensitive areas. Treatment of vast contiguous areas are more damaging to nontarget organisms than are spot treatments, because there are large tracts with not unsprayed refuges. However, aerial applications from planes or helicopters can be useful and even essential under certain circumstances. Effective and judicious use of this methodology requires appropriate equipment, careful planning, and other preparatory measures.

A list of pilots who have performed satisfactorily in the past is a valuable resource. They should be requested to write a brief report of their experience, listing problems and suggestions for improvement. The more senior individuals may be available as consultants to help run future operations.

Contracts for aerial operations should be reviewed based on past experience, making sure that wording covers all requirements for the African environment. National government and donor countries should cover items over which they have control in order to shorten the lead time necessary before work begins. Managers must make sure that flight crews are in fact being supported adequately by their parent companies and not left to shift for themselves while trying to make an operation work.

Contract acceptance should not be base on the low bid. Low bidder inadequacy has been one of the historical problems of aerial spray operations because there is so much more involved than just having a pilot and aircraft on the scene. A formula along the following lines should be used:

Bid price	50%
Past performance	20%
Ownership of proper equipment	10%
Experience of personnel in similar operations	10%
Maintenance and financial resources	10%

Bidders should be pre-qualified on the basis of having ownership and operational of and operational experience in the type of equipment for which they are bidding. Depending upon the size and background of a contractor, there should be limitations on the use of subcontractors or the purchase of equipment that they have not been operating and for which they do not have established spare parts and maintenance experience.

Prior to accepting a contractor who does qualify, a knowledgeable aviation consultant should check their in-country base facilities to review all requirements. Standard items to be checked include aircraft condition and records, pilot qualifications and knowledge of calibration procedures, operations of the particular type of spray accessories being bid (rotary atomizers vs. spray boom), the experience of the maintenance personnel on types of aircraft and spray accessories. If possible, a calibration check should be run on the equipment to be used.

All aircraft should have spray timers or the more sophisticated spray monitoring equipment. Pilots should be well versed in their proper use in order to make accurate ULV applications. Appropriate maps should be prepared so that pilots can maintain buffer zones around environmentally sensitive areas. There is an example of this from the Gambia (Voss, 1987). Guidance systems that will be applicable to the area need to be reviewed well in advance by the operational team. This should also include all radio communication requirements.

An extended swath technique should be acceptable, but based on field calibration and checks of deposit coverage under average wind conditions. This may vary with type of equipment.

Economical but adequate landing strips should be repaired and prepared during the dry season. As far as possible, these should be distributed throughout zones of frequent treatment.

Helicopters should continue to be used for survey and monitoring activities. They are desirable for spray applications

in areas far from flight strips or in broken terrain and for spraying close to ecologically sensitive or protected areas that must be avoided. The larger helicopters may be economical for projects where their volume production and cost will compete favorably with those of fixed wing aircraft.

Safety of operations and proper supervision of each spray contract must be stressed. Local personnel assisting at loading areas need training on safe and efficient operations.

Insecticide, fuel and other supplies must be transported and placed in advance of operations. This in imperative for timely control activities.

Every large-scale operation should be assisted by experienced air operations and logistics consultants. They should use forms and procedures similar to those of the USDA Forest Service for checking contractors' equipment and personnel on the job site and for close monitoring of operations as they progress.

F.1.3.2.5 Health and environmental monitoring

Monitoring of the health and environmental impacts of locust/grasshopper control measures should become part of AID-funded control programs. Expert advice would be sought on the design of practical, meaningful monitoring and reporting schemes. Careful thought should be given to choosing and training officers responsible for this work. AID Regional Environmental Officers might logically play a role in implementation and/or supervision and monitoring of these activities.

Post-treatment monitoring and sampling of selected organisms and/or water and soils must be carried out. Whenever possible, pre-treatment baseline data should be established. The cost of these mitigative steps will depend upon their sophistication, the time allowed (vis-a-vis the emergency or non-emergency status of the control operation) and the extent of the land area under application. In most cases, short-term but thorough post-treatment monitoring of organisms representative of major trophic levels will provide requisite data to assess effects on non-target systems.

F.1.3.2.6 Training

To ensure the judicious use of pesticides in locust/grasshopper control programs, donor agency personnel should be aware of and involved in (1) overseeing control operations and (2) preventive measures to protect systems and

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areas which should be excluded from the spray operations.

This includes ensuring that donor agency personnel (at least one in each country mission) are adequately trained in the appropriate criteria for pesticide acceptability, in the appropriate environmental regulations that apply to the agency, in the interpretation of this report, and in requisite determinations for environmental monitoring arrangements to be made.

Within AID-funded crop protection projects dealing with locust/grasshopper control, ongoing monitoring and supervision of control teams and farmers should emphasize:

- Use of only recommended chemicals.
- Applicator safety.
- Use of economic thresholds for control decision making.
- Safer formulations such as baits in situations where they will be cost-effective.
- Proper mixing and application of minimum dosages.
- Applications under appropriate wind and weather conditions.
- Properly-calibrated application equipment that is in good repair.
- Observance of no-spray zones around bodies of water, wildlife reserves and other ecologically sensitive areas.
- Warning of inhabitants of treated areas.
- Accurate placement of sprays at times when the insects are aggregated and areas infested are still small.

F.1.3.2.7 Pesticide storage and disposal

Additional and improved pesticide storage facilities are urgently required. Features of a properly designed and run storage facility are described in Section D.4.3.2. Training in the management of pesticide stores is also urgently needed.

When requested by national governments to do so, USAID should assist them and other relevant organizations with the disposal of obsolete locust insecticides. (See D.4.3.8 and D.4.3.9).

F.1.4 Alternative D-Biological control

Biological control, which is the use of predators, parasites, pathogens or antagonists to suppress pest populations below population levels at which they are economically damaging,

remains the single most significant force in the environment to keep insect populations in check. The importation of natural enemies to reestablish natural control of introduced pest species and the alteration of crop management systems to conserve and augment indigenous populations of natural enemies remains the most effective pest management tactic in the IPM arsenal. Systems of delivery are being developed rapidly for commercial propagation of microorganisms which can be applied to populations of plants and insects to initiate a population-reducing epizootic. These advances and the historical success of biological control provide encouragement for a biological control alternative in AID locust control programs in Africa. However, in order for this alternative to be fully and most effectively realized, a number of recommendations are made.

A biological control alternative has both a short-term and a long-term scope. In the short term, the only prospect that has been fully developed for field application is Nosema locustae Canning. This product has a United States registration and label, making it a legally usable product. However, there are important points of concern that must be resolved before Nosema could be deployed in the African grasshopper/locust control program.

F.1.4.1 Short-Term actions

F.1.4.1.1 Nosema locustae Canning

F.1.4.1.1.1 Efficacy against African grasshopper species

No data are available which show that Nosema can be used to suppress grasshopper populations in Africa. The available data show that infection can be initiated by application of Nosema baits. The data developed in the United States and Canada for efficacy of Nosema/wheat bran baits has produced highly variable and inconsistent results, with control ranging from 0 to 70%. It is important to point out here that such inconsistent results may not indicate that Nosema will not be an effective biotic agent, given further field research. There obviously are circumstances in which Nosema provides rather spectacular suppression. The data developed on North American grasshoppers is very good; however, it is not directly transferable to African species. The data are not directly applicable because 1) different species of grasshoppers are involved, 2) different physical environments are involved, 3) the formulation and delivery system in Africa is less dependable than in North America, 4) the economics governing the number of applications differs, and 5) suppressive efficacy remains to be demonstrated

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F.1.4.1.1.2 Species differences

The species against which Nosema was developed are not swarming locusts. The control strategy for swarming locusts will be different. Research in North America shows that wheat bran bait is not uniformly attractive to all species of grasshopper. This non-uniformity of attractiveness will also exist among African species. Preference trials will be required to determine the best bait deliver system for Nosema in Africa. The bait requirements may differ for species and for application environments. There are about 58 species of grasshopper which Nosema successfully infects, but the level of infection appears to differ among species. Laboratory results, while not directly comparable, indicate that Nosema may be highly virulent in the African Migratory Locust. Virulence and level of infection appear to differ among grasshopper species.

F.1.4.1.1.3 Environmental differences

The physical environment varies greatly within the African continent and most certainly differs from the cool, arid plains and mountain valleys of the western United States. Efficacy is likely to differ when compared between continents and within Africa. The developmental rates of the grasshoppers and the microorganism are temperature-dependent, thus the phenology of events will be different on the two continents. These temperature differences will affect the biology of Nosema directly and the timing of applications indirectly.

F.1.4.1.4 Formulation, logistics and timing

Formulation methods must be given consideration. Nosema can be stockpiled, but it must be stored at -10 degrees C. or less to remain viable for more than a few days. Arrangements will have to be made to assure that viable and potent Nosema is supplied for application.

The scientists who developed Nosema report that the timing of applications is very important to success, balancing a high rate of nymphal mortality against the initiation of a epizootic in the breeding population. In almost every field experiment, researchers report that timing of the applications should have been improved (see Timing, D.2.2.1.3.2.3). With the reported differences in virulence and infection level among species, proper timing will be a species-specific problem that will need developmental research. Even with adequate knowledge, timing probably will be a major limitation on efficacy due to the logistical problems and inadequate lead time that generally characterize emergency locust control programs.

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F.1.4.1.1.5 Economics of application

Nosema can be applied only one time in the western United States, because economics of rangeland agriculture does not support additional input costs. This may not be the case in Africa, with species such as the Red Locust, African Migratory Locust and others breeding in restricted sites. The economics will differ because multiple applications would be justified as preemptive actions. Even in the case of the Desert Locust, moist breeding sites can be identified for preemptive-type applications, negating the need to treat extensive areas.

F.1.4.1.1.6 Recommended actions to facilitate the use of Nosema locustae in Africa

The infectivity of Nosema has been demonstrated for some African grasshoppers, but the ability to suppress populations of grasshoppers has not. The assumption that demonstrated efficacy in North America assures success in Africa is not realistic. The rather qualified success in North America would seem to require further investigation in Africa.

We recommend that before Nosema be deployed for use in Africa, developmental research be conducted to determine the following:

1) Epizootic dynamics of Nosema for each targeted species. What are the timing criteria to establish high mortality and/or high infection rate and what is the optimal level of each? Research is needed to show that Nosema can be used to suppress populations through direct mortality in the generation to which it is applied. If the strategy is to initiate a continuing epizootic, then this capability also should be demonstrated.

2) Whether Nosema can indeed be used to infect adults that will pass the spores on to the next generation via the egg or materials in the egg pod. Such action is not well documented, but would be a very important benefit of Nosema use. Research should determine if infected females, which because of the infection have reduced flight capability, longevity and fecundity, remain in the migrating and breeding population to pass the spores onward.

3) What is the irreplaceable mortality due to Nosema? Nosema is a living organism and as such cannot be applied like, or expected to have the same impact as, an insecticide. The observed high mortality in early instar nymphs has not been demonstrated

(conclusively) to be due to infection by Nosema, because of difficulties in detecting the low number of spores in these stages. Additionally, it is important that mortality in young nymphal stages be additive to the natural mortality. Mortality is high in early stages of grasshoppers, so high mortality due to Nosema may be only replacing mortality that would occur anyway.

4) Research in Africa should demonstrate that Nosema can be delivered and applied in a timely manner on baits that are attractive. It will be important to establish application technology and formulation and/or storage technology. Alternative baits, perhaps using local products, should be developed if a supply of wheat bran of suitable flake size and quality is a problem.

F.1.4.1.1.7 Educational and training programs

If Nosema proves to be a product of choice in Africa, it is possible that the organism could be produced using native grasshoppers on a cottage industry level. With extension educational programs regarding production, formulation and use, farmers or others in each country might produce the product at a much lower cost. Such an initiative might also encourage active participation in controlling locusts where they occur in localized breeding grounds This might be particularly attractive if a local waste product could be used as the bait.

Nosema is a living organism which interacts with its host and environment. As such, it cannot be used nor expected to perform like an insecticide. The time until knock-down is relatively long and depends upon the nymphal stage infected (it is most lethal to the young nymphal stages). The relatively low daily mortality over the life of the grasshopper (about 5%) is not easily detected or evaluated, but it amounts to about a 50% reduction in generation mortality. Field personnel and applicators must be educated about the mode of action and the kind of population reduction to expect from a microbial such as Nosema.

F.1.4.1.1.8 Interaction with insecticides

Nosema can be used in conjunction with insecticides. It has been tested with carbaryl baits. Field data are not conclusive in demonstrating that the addition of Nosema to carbaryl baits adds significantly to the population suppression obtained from the carbaryl bait alone (see D.2.2 for further data).

F.1.4.2 Medium-term actions

F.1.4.2.1 Entomophaga grylli (Fresenius)

There are other propagated pathogenic microorganisms that appear to hold promise for the medium term. One of these is Entomophaga grylli (Fresenius) (also known in the literature as Empusa or Entomophthora grylli), a grasshopper pathogen which has been reported many times as the causal organism in natural epizootics in North America, Thailand, Australia, and Africa. Two pathotypes have been identified by isozyme analysis and these pathotypes have different host ranges and developmental histories. Other pathotypes have been implicated and research is in progress.

Grasshoppers infected with E. grylli show outward evidence of disease at 8 to 10 days after initial infection. At this time the feeding grasshopper becomes immobile and dies in a characteristic position, clasped to high points on grass and other vegetation. Scientists have suggested that African farmers can collect the diseased hopper adults, grind them up, and spray a slurry of the fungal spores on pest populations. Such a cottage industry would resolve one of the present limitations: that of having no economical method of commercial propagation of the spores. Research on the use of cell culture has shown promise and may offer a means of propagation.

F.1.4.2.2 Insecticidal baits to conserve natural enemies

Research tests have demonstrated that carbaryl-treated baits can be used successfully to reduce grasshopper populations. These baits offer a distinct advantage in that they are a more targeted approach to the use of insecticides. Such directed use of insecticides would allow conservation of the natural enemy complex associated with the various species of grasshoppers. The data show that there is a diversity of species of predators and parasites of all stages of the grasshoppers. These species have provided spectacular rates of mortality in grasshopper populations, but not in a predictable or consistent manner. The elimination of broadcast sprays of insecticide would permit these species to have their maximum impact.

F.1.4.3 Long-term actions

F.1.4.3.1 Development of microbial products for biological control

There are a number of other microorganisms-viruses, protozoans, fungi and perhaps Rickettsia (see Appendix 9, Table

2) - which appear to hold promise for biological control of grasshoppers. This research is in various stages of development and needs to be encouraged by whatever means are available, but in a manner that will make it particularly applicable to the African grasshopper pest problem.

F.1.4.3.2 On-site investigation into the ecology and biology of grasshoppers and locusts

There is ample evidence in the literature that there are large numbers of predators and parasites which attack various grasshopper species in Africa. There are reports of very high levels of mortality occurring in what appears to be an unpredictable way. As with most species, this unpredictability arises largely from lack of understanding of the species and its ecology. Each grasshopper species in Africa has a unique and very dynamic relationship with its host plants and the vagaries of weather. These relationships are in themselves so complex that they largely defy understanding, much less prediction. The natural enemy guild for each grasshopper species has an equally dynamic association with its environment. However, this third trophic level interaction necessarily includes the complexity of the population fluctuations of the host grasshopper and density-dependent feedback cycles between the host and its natural enemies.

While the ecology of natural enemies adds another level of complexity to understanding and predictability, we cannot expect to utilize biotic mortality factors either actively or passively unless the research is done. At best, the present lists of natural enemies tell us little more than which beneficial species are being killed by insecticides. We recommend such research be begun so that in the long-term there will be biological control alternatives. These studies could be done very effectively by collaborative arrangements between biologists, ecologists, and biological control specialists from the developed and the less-developed countries.

F.1.4.4 Effectiveness of the alternative

Biological control agents particularly Nosema locustae and entomopox virus, have shown promise (water, personal communication 1987), and much research is being conducted on the application of these and other pathogens. If biological control agents prove effective under African and Middle Eastern conditions, and especially if good locust/grasshopper pest forecasting allowed for timely preventive applications, biological control alone might bring these pests under control. This would be a very desirable ecological goal, since insecticide use would be eliminated and effects on nontarget organisms would

be nil.

Pending full development of the various biological control measures, or as long as biological control alone does not always keep locust and grasshopper pest populations under control, effective and economically sound biological control measures can be woven into an integrated pest management system as they reach the implementation stage. This will help to reduce the relative importance of insecticides to locust/grasshopper control operations, and therefore could also be expected to reduce adverse environmental impacts (see F.1.5).

F.1.5 Alternative E -- Integrated pest management

Integrated pest management means using the best mix of available control methods for achieving the most effective, cheap, safe, and sociologically and environmentally sound pest control possible. Among the technologies to be integrated to the best effect are chemical, non-chemical and biological control methods, as well as improved forecasting for the early control of pests. Support for applied research on better forecasting and new pest control methods is considered to be part of this alternative.

The discussion and recommendations for chemical, non-chemical and biological controls appear as sections F.1.3 (Alternative C), F.1.2 (Alternative B), and F.1.4 (Alternative D), respectively, in this document. All those sections in combination with this one, including recommendations made, describe the integrated pest management option for AID action. Those other sections are referred to frequently here, to avoid duplication.

As described in section D, grasshopper control programs have traditionally relied heavily on suppressing outbreaks after they occur. The primary means for controlling both grasshoppers and locusts has been broad-spectrum insecticides, often applied on a large scale. An important goal of the IPM alternative is to develop means for both prevention and suppression of acridid outbreaks that eliminate unnecessary use of insecticides while ensuring that any necessary applications are made in an effective and specific manner.

When technologies currently in research and development become operational, AID could conduct environmental analyses of them and perhaps test them in Africa and the Middle East. Successful measures could be integrated singly or in combination into AID-funded acridid control projects. Other factors to be weighed besides health and environmental impacts are efficacy, cost-effectiveness, and sociological considerations such as the acceptability of IPM methods to cooperators and potential effects

on land use or employment Since all of these vary with location, IPM systems will be geographically area-specific.

Various pest control approaches that might become available for acridid IPM are described in the following sections, designated short-, medium-and long-term. This categorization is of necessity speculative, and may not reflect the actual speed of research and development of the different technologies. New possibilities will arise and should be considered although they could not be covered in this document.

F.1.5.1 Short-term actions

For the present, only a limited spectrum of locust/grasshopper control methods is available. These include: mechanical methods for repelling swarms and the collection and destruction of adults and eggs; cultural methods that enable crops to escape or resist acridid attack or which seek to prevent outbreaks by altering the environment to the detriment of the pests; and the use of broad-sprectrum insecticides. Mechanical and cultural methods, described fully in sections D.2.1 and F.1.2, are either relatively ineffective, effective only against a few acridid pests, or impractical or impossible to implement in most situations. Chemical control, which is relatively effective, practical and adaptable to most acridid pest control situations, is the dominant tool available now.

F.1.5.1.1 Non-chemical control

Immediate priority would be placed on non-chemical control measures in situations where they are effective, economical and practical, notably destruction of egg pods in marked oviposition grounds of the Variegated Grasshopper (see D.2.1.1). In practical terms, this means chiefly a change in emphasis of training for extension agents, farmers, and pest control officers.

F.1.5.1.2 Improved field survey operations and chemical control

Current surveillance and chemical control programs should be improved so that their potential value is realized, and to minimize health and environmental damage from unnecessary or improper insecticide applications. These topics are discussed in section F.1.3.2, mitigative actions for chemical control.

F.1.5.1.3 Locust and grasshopper pest forecasting

The goal for improved forecasting is for regional and national pest control organizations to receive regular and quick

delivery of easy-to-use forecast maps showing the location, timing and magnitude of predicted grasshopper and locust infestations. Field intervention teams, chemicals, supplies and equipment could be positioned for quick and appropriate response, suppressing threatened outbreaks before crop damage is appreciable and before pests have time to multiply and spread from initial foci. If this is done early in the cropping season, the necessity for late-season aerial spraying over wide geographic areas should be very much reduced. Crop losses, pesticide application expense, and environmental contamination by insecticides would all be minimized.

Section D.1 describes current activities and research toward achieving this goal. A Desert Locust forecasting system is operational now. End-of-season pest counts linked with oviposition observations and egg pod surveys can presently be used to anticipate the next season's initial grasshopper problems. Mobilization of observers and information quality control need improvement.

F.1.5.1.4 Technology research and development

Applied research on new pest control and forecasting technology would start immediately (some important projects, such as testing locust/grasshopper pesticides under African conditions, are operational now) and continue into the long term. This will broaden control options for improvement of grasshopper and locust IPM strategies. Peer reviews and expert advice can help AID choose among candidate proposals and decide when shifts in funding patterns would be wise.

The amount of research undertaken would, of course, depend on budget available. In general, AID should confine itself to applied research on proven technologies, to validate them in Africa and the Middle East and determine how to apply the technologies under those field conditions.

No AID-funded field evaluation of new technology should be conducted by parties with a scientific or commercial vested interest. Interested parties can and should advise, and be among the resource persons for evaluations.

F.1.5.1.4.1 New pest control methods

High priority subjects for applied research on non-chemical, chemical, and biological control are discussed in sections F.1.2, F.1.3, and F.1.4, respectively.

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F.1.5.1.4.2 Remote sensing and improved forecasting

Work on satellite observation-based vegetation mapping and precipitation and soil moisture estimation for early warning is being conducted by several agencies in the US and Europe. FAO's ARTEMIS, AID's FEWS, USGS's EROS projects (including an AID-funded project on seasonal monitoring for grasshopper control), NASA's Global Inventory Monitoring and Modelling Studies (GIMMS) and the multi-donor supported PRIFAS/AGRHYMET Sahel grasshopper and crop forecasting programs are all working with procedures that are oriented to, or can be oriented to, the same forecasting and early warning goals.

These different organizations do not necessarily totally duplicate efforts because each of the units operates under different mandates: research, application, information production and training. What they produce reflects the mandates and may be appropriate for a particular area or time scale or degree of accuracy that may or may not at first be suitable for locust forecasting. In addition, one organization might supply other organizations with data tapes or other information that each respective organization, including the original supplier, might use in complimentary or different ways. Nevertheless, there is clear duplication of effort and a need for better coordination and cooperation. AID should review the existing and proposed projects on remote sensing for improved pest forecasting. The review should give due consideration to valuable new approaches, while weighing a more productive allocation of funding and responsibilities, along with the strengthening of collaborative ties and cost-sharing arrangements. This includes determining how and why AID and FAO pest forecasting programs will either share information or work separately; or whether AID should continue to sponsor pest forecasting and remote sensing work in the light of technical, funding or policy priorities.

A number of remote sensing researchers are not aware of the grasshopper and locust models that are being developed. More people working with remote sensing for early warning, crop and range assessment, and famine-related analysis should be familiarized with the African acridid population models. If they focused on adapting their output to the constraints of the models and the special needs of pest control, additional useful progress could be made.

Another goal of this alternative is to develop better use of remote sensing information, which includes aerial photography for determining sensitive environments and monitoring conditions in treatment areas. Teams should be made aware of

existing information that can be found in each of the respective countries. Also, there should be additional work aimed at incorporating more geographic information systems (GIS) technology into locust early warning. GIS will enable more information from different data bases to be brought together.

F.1.5.1.4.2.1 Logistics and communications

Most remote sensing research and development, as well as the production of locust and grasshopper warnings for Africa and the Middle East, are the work of expatriate experts using facilities at scientific centers in Europe, the United States, or, as in the case of AGRHYMET, a regional center. One result is that there is a perennial problem getting local pest observations to the centers for analysis, and forecast maps and other advisory information to the field, fast enough for control teams to intercede usefully. Three avenues of investigation might be useful:

- Operations could be decentralized. As Hervio (1987) remarks, the only important early warning technology that has not heretofore been locally available is remote sensing data collection and analysis capability. Now, full, computer-equipped satellite receiving stations are planned for DLCO/EA and AGRHYMET. National experts can generate faster and more meaningful data analyses with specific local data collection and because of their familiarity with the areas in question and with local response capabilities. In addition, national plant protection services are more likely to respond unhesitatingly and swiftly to an alert generated within their own government or region.

- Remote sensing output for pest control should be more flexible. In order to maximize reliability, NOAA satellite data, one of the staples of environmental monitoring programs, is released in ten-day composites. This results in a troublesome delay. Acceptable levels of detail and error in remote sensing maps using single clear image sets, as well as the degree or resolution necessary for pest control fieldwork and the possibility of more frequent data shipments or transmissions need to be investigated. The EROS project is considering telecopying degraded black and white imagery that has been composited at less than 14 day cycles.

- Rapid analysis and communication links are necessary. Data analysis should be carried out by

computer whenever possible, and much remains to be done to develop appropriate programs. The design, aquisition, use and maintenance of reliable, high-speed communications systems (satellite transmission, telecopies, telex, etc.) should be a priority.

F.1.5.1.4.2.2 Modeling

Acridid pest population and migration models are of great potential utility. There is room for work in further depth on the African Migratory Locust, and on different approaches to modeling other key species such as the Desert Locust and Senegalese Grasshopper. USDA/ARS and Agriculture Canada researchers are working on North American grasshopper models. Their expertise could be extended to tropical species in future. Preliminary results of different modeling approaches can be compared and the most effective ones adopted for regional locust and grasshopper forecasting.

F.1.5.1.4.2.3 Field data collection

At present, incomplete and slow acridid pest data collection from the field reduces the effectiveness of the FAO and SAS early warning systems. Without knowing the current situation, there is no basis upon which to forecast future developments. Attention should be paid to simplifying and customizing standard data sheets, giving adequate training in their use, and motivating selected field staff to actually complete and submit them regularly. PRIFAS reporting sheets can provide the basis for a standardized international form for the grasshopper section of national reports.

F.1.5.1.4.2.4 National-level data analysis and decisionmaking

To make good forecasts, historical and current field observations of grasshoppers and locusts must be combined with ARTEMIS-type current and predicted weather and vegetation information. Personal computer-based data processing and expert systems for doing this at the local level would help ensure timely results and also motivate government officers for adequate and regular data collection. There are as yet no projects to develop this aspect of the forecasting system in Africa, but the USDA/ARS Rangeland Grasshopper Laboratory is working on an expert system for the U.S. grasshopper IPM project.

F.1.5.2 Medium-term actions

Simple screening of existing crop varieties may result

in the identification of some that grasshoppers and locusts prefer not to eat. This would be most useful for crops and situations where suitable alternative food is available all or most of the time, such as those in the relatively moist habitat of the Variegated Grasshopper.

In the medium term (2-5 years), remote sensing-based maps of soil moisture, vegetation and potential locust and grasshopper breeding areas probably will be developed, field-tested and widely distributed for use by survey teams. FAO's ARTEMIS expects its products to have field impact in 1989/90 (J. Hielkema, personal communication 1987). These maps will show areas suitable for acridid feeding, breeding and possible gregarization, but field teams would have to check them all to find where actual heavy infestations occur.

The U.S. Rangeland Grasshopper IPM Project, implemented by the USDA and interested universities, is conducting research along several avenues that could result in significantly improved effectiveness and selectivity of insecticide applications. In-flight encapsulation of malathion is being tested, a technology which would reduce the amount of insecticidal active ingredient necessary and increase residual action and rain resistance. Many aspects of baits are being investigated, including: better mixing and application technology; improved formulations using a variety of insecticides as well as various carriers; phagostimulants that could enhance acceptance by target species; and use patterns that will maximize the potential of baits for regulating acridid populations. Standard procedures for estimating economic threshold levels for grasshopper insecticide applications are also under development.

The biological control agent Nosema locustae might be field-tested and available within the medium term. It could offer an effective and much more selective but slower-acting alternative to insecticides, with a single application possibly suppressing acridid populations for several seasons. Since it attacks only grasshoppers and locusts, it should not harm non-target species apart from individual parasitoids developing within infected hosts. Nosema and other biological control agents that are under investigation or are candidates for testing are the most probable means of preventing and controlling acridid outbreaks without the negative health and environmental impacts that accompany insecticide use. These pathogens are discussed fully in sections D.2 and F.1.4.

Pathogens such as Nosema, as well as insecticides, can be delivered on bait. Bait treatments using either one or a combination are particularly amenable to the management of low-level economic infestations in non-outbreak periods, to prevent subsequent outbreaks. Initial insecticide kill with

baits is lower than with sprays, and the full effect is slower to manifest itself, but final mortality levels achieved are comparable.

Since timing of pathogen or insecticide bait applications is crucial, and because pathogens act slowly, fulfilling their formidable potential as acridid population management tools depends greatly on good forecasting and early warning. In order to use them effectively, field control teams must know well in advance not only when and where to expect acridid pests, but also how many and in what stage(s) of development, and whether control action is likely to be necessary to avoid economic losses. In the medium term, remote sensing-generated maps will guide field teams to suitable grasshopper and locust habitats, but models and forecasting will be able to supply only semiquantitative information on population dynamics and movement. Nevertheless, it may be feasible to apply preventive control measures to the first generation of acridid pests in areas where late-season populations in the previous year were threateningly large and egg pod surveys indicate good survival rates.

F.1.5.3 Long-term actions

In the long term (5-10+ years), remote sensing-based maps can probably be made available for other migratory pests, such as armyworm and the grain-eating bird Quelea quelea. For grasshoppers and locusts, models forecasting population dynamics and migration patterns of the major species can be combined with the maps to provide much more geographically accurate, quantitative predictions. This will facilitate planning and further reduce the time and expense for survey and control operations. The impact of control operations could be factored back into the models.

More Nosema strains, entomopox viruses and the fungus Entomophaga grylli may add to the array of useful pathogens. New, highly virulent stains of virus or fungus might eventually provide immediate suppression of heavy infestations. Providing pathogens pass safety tests of their host range, no negative environmental impact would be expected apart from diminishing the food supply of natural enemies of the target pests.

Other acridid control methods that could become available over the long term include specially-bred nonpreferred crop varieties and swarm control using airborne lasers (see D.2.2.1.3.2.3).

Expert systems for use with personal computers could help local pest control managers combine field reports with

forecasts in order to make control decisions. Current local field observations and economic data would be entered into the computer in response to questions asked by the program. Then they would be computer-analyzed automatically in the context of weather reports and predictive models of acridid population and migration. Based on those inputs, the computer would tell the operator what action to take, where and when.

F.1.5.4 Institutional development needs

Once practical and effective forecasting systems are elaborated, data analysis and prediction activities will be decentralized. (This will not detract from the value of central research and technology development centers that should work to improve pest forecasting on an ongoing basis.) FAO, USAID and other donors have already taken steps to build remote sensing expertise in selected regional and national centers. These centers now function as pilot programs for what will be a general pattern. AID might usefully include application of this technology as an integral part of their crop protection service support projects. The World Bank also has a remote sensing unit and is looking at early warning systems. The Bank feels it has a responsibility to and could insure continuity of the NOAA AVHRR data base, encourage member states to use it, and provide training and hardware to member states and their personnel (Brumby, personal communication 1987).

AID and other donors should fund crop protection service support projects so that national pest control services can take care of local problems on an ongoing basis, as well as fill the void left by the demise if some regional migratory pest control organizations. The national crop protection services should be able to respond quickly and efficiently to outbreak warnings, and to mount an effective early-season campaign that would eliminate unnecessary expense and insecticide use.

Surveillance, reporting, and control team networks in individual countries, though often created for grasshopper/locust control, should cover all agricultural pests. This is necessary so that they will be cost-effective even during periods when grasshopper/locust numbers are low.

F.1.5.5 Training

Switching to an outbreak prevention strategy using inconspicuous, slowly-acting control technology such as baits or pathogens presents psychological as well as technical challenges. Farmers, administrators and control officers may be reluctant to believe that the new methods can be as effective as insecticide sprays which produce immediate, easily-observable mortality.

If adoption problems arise with otherwise superior control approaches, specifically-designed training programs, seminars and multimedia communications campaigns can be mounted to inform people about the new methods and their advantages and to change obstructive attitudes. Thorough ongoing evaluation and reporting is necessary for good management and improvement of preventive campaigns. They can also supply the raw material for publicity and seminars designed to convince international donors and national governments to continue funding a successful pest management program in the absence of the outbreak emergencies that have determined funding levels in the past.

Training is one of the most important prerequisites for the actual field-level application of forecasting systems that are now being developed. At present, field programs remain largely untouched by advances that are being made at remote sensing research centers. Non-technical and administrative personnel in management positions must be the object of a vigorous extension effort that will allow them to better understand and encourage the use of remote sensing as a practical tool by their institutions. A cadre of trained field officers must be located throughout the major recession areas to perform various early warning and survey activities, including the interpretation of remote sensing information. The techniques used for locust early warning are similar to those used for other types of agriculture and resources assessment projects, so training in any one of the systems can, with some modification, be applied to others.

Training and technology transfer is part of FAO's mandate, and among the organizations either affiliated with their remote sensing program or providing services or information to it are several dedicated wholly or in part to training. Among them are the Institute of Aerospace Survey and Earth Sciences in the Netherlands (which will be presenting a three-month training course in the framework of ARTEMIS development activities); DLCOEA and the Regional Center for Services in Surveying, Mapping and Remote Sensing in Nairobi; the Centre Regional de Teledetection in Ouagadougou, Burkina Faso; and the SADCC/FAO Regional Early Warning/Remote Sensing Project in southern Africa.

USAID co-sponsors the Nairobi and Ouagadougou remote sensing centers, and is equally strong on fostering technology transfer. A large share of the EROS Data Center work is in training. Perhaps these FAO-and AID-affiliated centers can supply the training that will be necessary in order for field projects to use pest forecasting information generated by remote sensing and models.

F.1.5.6 Effectiveness of the alternative

Since IPM is by definition the best mix of available control methods from the economic, safety and effectiveness standpoints, it will be at least as good as current locust and grasshopper control technology. As more nonchemical control methods are integrated into the IMP system, it will become safer and less environmentally harmful while retaining its effectiveness.

USAID can consider IMP a long-term strategy, but entails beginning the process now. to do that, environmental monitoring, range management, economics, research, and components. These components will have to be maintained through training, institution building and strengthening, effective communication, and long-term operational support.

Whether or not USAID is willing to make that commitment will depend ultimately on AID's decision whether to continue its support of locust/grasshopper outbreak control. Development of the IPM approach through AID support will address not only a commitment to respond to outbreaks, but will address preventive strategies, monitoring training, and requisite technology toward maintaining insect pest populations at acceptable threshold levels.

By adopting this alternative, AID would expend additional resources but would (A) be in line with existing and developing U.S. technology, (B) would reduce criticism from groups concerned about overuse of unproven pesticides and (C) would be throwing less money and fewer resources down the drain than application approach to locust/grasshopper control.

F.2 Economic Analysis of Technical Alternatives

The most remarkable economic fact that arises from an examination of locust and grasshopper control is the paucity of meaningful data on either the benefits of the control in terms of crops saved or the overall costs of the control.

In order to calculate benefits it is necessary to know crop acreages and yields: output by country. We then need to know the crops that are lost to locusts and grasshoppers in a "normal" year, together with the loss under plague conditions. We then have to calculate the crops saved from locusts by control measures. The data for this does not exist. Then we have to calculate the costs. In order to do this we need to know local costs in the form of manpower and equipment, as well as donor costs. What we generally have is a figure for donor costs but no local costs. This tends to lead to an underestimate of the costs

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of locust control.

Given the many years in which locust control has been organized on a regional and international basis, it might seem unlikely that data has not been collected. However, the various organizations involved with locust control have concentrated their efforts on the actual control and research into more effective control methods. Whether locust control was economically worthwhile is not something that appears to have been questioned. During outbreaks the resources available to locust control organizations have been mobilized to deal with the outbreak and not to collect data on crop losses and costs.

It might be argued that economic analysis is not an appropriate tool for use in emergency situations; that we would not normally utilize it when examining earthquake or flood relief efforts. However, this assumes both that locusts are an emergency of a similar type and that they can be dealt with on an emergency, rather than a continuing, basis. Both assumptions are questionable.

The lack of data outlined above poses clear limitations on any economic analysis of the technical alternatives.

F.2.1 No control measures

Lacking good data for the maximum damage to crops that could result from a locust or grasshopper outbreak, one is thrown back on the figures collected for 1986 (FEWS, 1987a). In that year, during the grasshopper outbreak, it is estimated that some 241,000 metric tons of grain were lost in the nine African countries worst affected and that 350,200 tons of grain were saved by control measures. At an estimated value of $131 per ton this gives a value for the crop affected of $77.5 million, of which $31.5 million was lost in spite of control measures, and $45.5 million was saved. Without the control measures this $45.5 million worth of crops would have been lost. In order to save these $45.5 million worth of crops, donors expended some $40 million, on top of which local agencies also expended money that, in all probability, led to a total expenditure greater than the value of the crop saved. Therefore, doing nothing, i.e., taking no control measures, would have probably saved money in strictly economic terms. However, it would have led to the $45.5 million crop loss, and it is not obvious that the donor countries would have made $40 million available to compensate for the loss. Nor is it obvious that the farmer, who would have suffered the loss, would have been compensated at all. The problem here, of course, is that the cost of control and the cost of the loss are not borne by the same population. Normally in cost-benefit analysis we would assume that money not put into one use, in this case locust control, would <u>necessarily</u> be available to the country to

use for other purposes.

Under this Alternative no direct costs would be involved for control efforts. Indirect costs, however, might well exceed the cost of control, which for AID amounted to $9,332,014 in 1986. Indirect costs could include the provision of food and feed grains if the grasshoppers are allowed to destroy crops and pastureland. Transportation and distribution of these foodstuffs would also be included. Costs of damage to other agricultural projects in which AID is a participant would also have to be considered.

The advantage of no control measures from the environmental standpoint is that there is no impact from pesticides and no mitigation necessary. There is greater impact from the larger population of grasshoppers or locusts but, damaging as this may be economically, there is little or no evidence that such outbreaks have any lasting adverse impact on the natural environment.

F.2.2 Non-chemical control

The most important economic factor with regard to non-chemical control is that there is no evidence that non-chemical methods can control locust and grasshopper outbreaks. There are therefore few or no benefits although costs are clearly incurred. Non-chemical controls include the mechanical destruction of locusts and grasshoppers, the use of antifeedants and the planting of resistant varieties of crops. Each of these are dealt with in turn.

The mechanical destruction of locusts and grasshoppers and their eggs is a labor-intensive approach to control. In countries with underemployment and unemployment it is superficially attractive from an economic point of view. Indeed, if such methods could actually control locust and grasshopper populations they would have much to commend them. Unfortunately, there is little evidence that they do have an effect on populations. So we incur costs, albeit mainly labor costs (at a low wage rate), but show no measurable benefits.

Antifeedants, neem in particular, are often touted as a possible solution to locust and grasshopper control, and there is certainly evidence that neem is a fairly effective repellant. It has the further advantage that it can be produced locally, often by the farmers themselves. At a farm by farm level, the use of neem may be a very cost effective means of protecting standing crops. However, it is an antifeedant, or repellant. It is only sending the locusts and grasshoppers on to the next farmer. At a national level, protecting all crops would appear to involve a nationwide spraying program and this could be costly. Indeed, it

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could prove to be more costly than spraying locust and grasshopper swarms with pesticides as a means of control.

The planting of resistant crop varieties is a possibility that seems appealing, involving, as it does, no control costs beyond the normal cost of planting. However, resistant crop varieties are not yet deployed in any organized and deliberate manner and the cost of new ones could be considerable. Moreover, the antifeedant effects of resistant strains break down in situations where grasshoppers have no alternative food source.

Although the future possibilities of non-chemical controls should not be ignored, it seems clear that economically and technically viable means of non-chemical control of locusts and grasshoppers are not available at present.

F.2.3 Chemical control

Among the technical alternatives, chemical control is the only one that has proven effectiveness as a means of locust and grasshopper control. As such, it is the only alternative considered here to show immediate economic benefits. Unfortunately, as detailed above, the data that would enable the measurement of these benefits has never been collected. There is also a need for mitigative measures in order to minimize the environmental hazard of its use. So far these necessary mitigative have been largely ignored. Indeed, the measures needed to handle pesticides safely have been given very little attention by either donors or the recipient countries, so that today there are stores of obsolete, and frequently leaking, pesticides in many countries of Africa with no measures in place to ensure safe disposal.

Although the lack of hard data limits the usefulness of cost-benefit analysis as a tool to analyze chemical control, it is quite clear that the problem in the recent past has been with costs. Spraying which is costing $5-6 per hectare in the U.S., and should be costing between $8-10 in Africa, has actually been costing something on the order of $15-$30 per ha in Africa. These costs are too high and can be brought down.

A large part of the cost of spraying in recent years has resulted from the emergency airlifting of formulated chemicals to African countries. Pre-positioning of chemicals and local formulation can do much to bring this cost down. The other obvious means of bringing down the cost of chemical control is to spray fewer hectares. There is evidence of considerable overkill in terms of total areas sprayed in 1986. This drives costs up.

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The approach must be one of getting the most cost-effective control possible, and this is achieved by using the best technical solution for control, that of timely and accurate spraying of geographically limited outbreak areas. In this context, it is worth noting that the Red Locust Control Organization has been very successful for a large number of years and has operated on a budget of only $250,000 a year, of which probably no more than 25% was actually spent on spraying. With limited but effective spraying, the cost of the chemical used becomes less of a consideration. The choice of a more expensive chemical due to environmental considerations will have less impact on costs than if one was following a strategy of massive and widespread spraying.

F.2.4 Biological control

The one biological control that shows some promise at present is Nosema. However, there is no evidence to date that Nosema is capable of controlling locust and grasshopper populations. Until such time as its effectiveness can be shown, there can be no economic justification for its use, which would involve costs with no evidence of benefits.

A case can be made for funding more research in order to determine its efficacy under African conditions. However, any possible benefits of such research are likely to be far in the future and this will need to be borne in mind when allocating resources.

F.2.5 Integrated pest management

Given the fact that the only presently available and effective locust and grasshopper control method is the use of pesticides, the possibility of moving much beyond chemical control lies in the future. An IPM strategy at this time, therefore, would appear to involve judicious application of the chemical control measures outlined above plus research into non-chemical and biological measures. This research can be expanded to fill almost any budget made available and is not usefully tackled in terms of economic cost-benefit analysis. Basically it boils down to a policy decision as to how much AID or any other organization wishes to spend on this research.

G. OPTIONS FOR USAID LOCUST GRASSHOPPER POLICY

The policy options for USAID would seem to boil down to, in essence, three. These are:

1. to take no action, leaving locust control to other organizations,
2. to take no action on locust control but to intervene with food aid to replace the crops lost to locusts and grasshoppers; or
3. to continue to play an active role in locust control.

G.1 No Action

The advantage in AID not taking any part in locust and grasshopper control would appear to be two-fold. By moving out of the grasshopper and locust control field funds are made available to be used in other programs which, in many cases, are going to show much higher rates of return. Also, AID moves out of an area that, because it involves the application of pesticides, has adverse environmental effects.

The disadvantages are that this would involve AID turning its back on a situation which, from time to time, is an emergency. The political and public relations consequences of such an attitude are obvious. From the environmental point of view, a decision by AID not to remain involved with locust control would be unfortunate. AID has, for many years, been one of the most responsible voices with regard to the environmental impact of pesticides. If it was to withdraw from the program that voice would carry considerably less weight and the leadership role that AID has played in seeking to curtail the use of the most toxic pesticides would be lost. Thus, non-involvement by AID would be a setback for responsible environmental policy.

G.2 Provision of Food Assistance

This would appear to suffer from most of the disadvantages outlined above with the further difficulty of having to try to determine crop losses due to locusts and then handling the problems of food distribution. The advantages are that, from the US point of view, food aid can be thought of as fairly cost-effective. From the host country point of view, however, it can be seen as encouragement to not deal with the locust problem but to depend on US food assistance.

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In cases where locusts are not sufficiently controlled and there is a food deficit in a country, existing food assistance programs would appear to be sufficient to deal with the situation without having to institute an additional "Locust Food Assistance Program".

G.3 Intervention in Locust and Grasshopper Control

The present strategy followed by AID is to intervene in locust and grasshopper control. This would appear to have the disadvantage of involvement in a program that frequently does not look cost-effective, and one that has some possible adverse impact on the environment.

On the plus side, AID has been actively involved in a situation that has required prompt and adequate emergency response. This has been good for the Agency's image and for that of the US. The Agency has also been able to exercise a leadership role in the area of responsible use of pesticides while the US has taken the lead in trying to reduce the use of the more toxic chemicals.

The whole area of pest control and the environmental consequences of pesticide use is one in which, in many ways, the United States is ahead of most of the world. In operational terms this means that AID has at its disposal, both within the Agency and through its consultants, some of the best expertise available in these areas. This is a valuable resource that AID has been able to bring to locust and grasshopper control programs. It is a resource that can continue to be made available for the benefit of host countries by AID's continued involvement in such programs.

However, if AID is to remain involved in locust and grasshopper control some changes in approach are required. The present situation, that of dealing with locusts on an intermittent, emergency basis is the worst of all worlds. There is little or no structure in place in many of the African countries, so that when an emergency situation occurs there is very limited ability to mobilize local support. Problems include:

i. lack of effective monitoring of outbreaks because there are not enough scouts,
ii. insufficient storage facilities for pesticides,

iii. a shortage of application equipment, from hand sprayers to pumps to planes,
iv. insufficient local manpower with experience in handling chemicals,
v. few plants able to formulate chemicals.

Therefore; formulated chemicals, equipment, and technical personnel all have to be brought in. This makes the operations very high cost because of the imported and expatriate content, and limited in effect because the time required for mobilization means that frequently the application occurs too late in the locust cycle. The lack of local knowledge and first-hand on-the-ground observation can also lead to inappropriate or wrongly targetted spraying.

Regardless of the effectiveness or otherwise of the emergency operation, the lack of a local pest control infrastructure leads to a set of problems related to the use of pesticides, including:

i. improper chemical storage with consequent adverse environmental effects,
ii. no monitoring of the environmental consequences of the spraying,
iii. no disposal methods of chemicals or chemical containers,
iv. poor management of recording and accounting for chemicals.

Clearly, a better situation would be one in which there was, on the ground:

i. scouts to carry out egg counts and to monitor populations -- to relay information up through country to forecasting units,
ii. existing pesticide stocks -- properly stored and handled,
iii. a system of accounting for chemicals,
iv. a system for the safe disposal of out-of-date chemicals and chemical containers,
v. equipment available for spraying,
vi. trained personnel -- pilots, spray operators, etc.,
vii. the ability to formulate chemicals,
viii. trained chemists to manage and monitor storage, handling, spraying and disposal,
ix. a system to monitor the environmental impact of locust spraying,

x. trained ecologists to manage the monitoring system.

To work towards this situation would seem to be a reasonable long term aim. A couple of alternative ways of doing it are a "top down" approach through FAO and regional organizations, or a "bottom up" approach through the individual governments of the African countries.

An approach that makes each African country more responsible for its own locust problem would appear to be both more desirable and more likely to succeed in the long run. Such a "bottom up" approach would not preclude eventual regional or international cooperation, at the instigation of the involved countries themselves; but keeping regional organizations in place with only tepid support from the involved countries is not likely to be productive.

The problem with trying to achieve this is that locusts are an intermittent problem, therefore, the cost of the effort, relative to the benefits is unfavorable. An organization that sits waiting -- maybe 5 or 10 years -- for a locust plague to surface is likely to become bureaucratic and operationally ineffective. Plus, pesticides have a limited shelf life and will need to be destroyed and replaced every couple of years.

In addition, from an environmental point of view, we are addressing only part of a much broader problem -- the use of pesticides on a whole range of pests other than locusts -- the effect is cumulative.

All this argues that if, in order to achieve the objective, the best approach is within the context of a broad <u>pest</u> control program within each country rather than a specific <u>locust</u> control program. Within the pest control program there would be a locust office. The advantages of making the program broadly based are:

i. The cost/benefit equation immediately looks a lot better. Instead of keeping an organization in place to deal with an intermittent pest, we have an organization that is controlling pests -- with consequent benefits -- every single year.

ii. The organizations is in the operational mode constantly with no difficulty in adapting to deal with locust, armyworms, stemborers or whatever other pests need control.

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iii. Pesticides (not specific to locusts) get turned over and replenished constantly so there is little or no wastage.

From the AID point of view, such a strategy involves a long-term programmatic approach to the problems of locust and grasshopper control with the two-fold objective of eventually controlling locust and grasshopper outbreaks before they ever approach plague proportion and leaving this control in the hands of the host countries themselves with little or no need for donor assistance.

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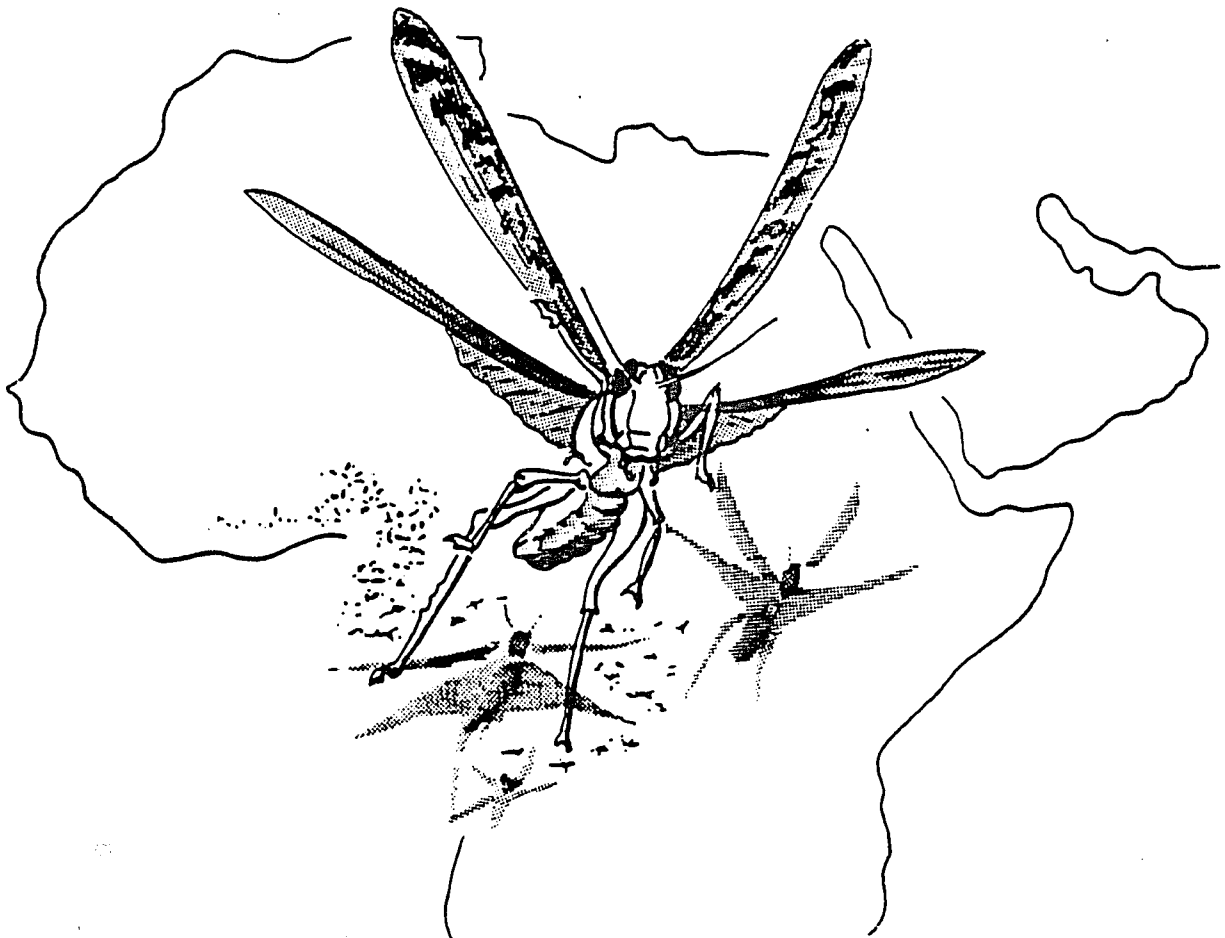
US AGENCY FOR INTERNATIONAL DEVELOPMENT

LOCUST AND GRASSHOPPER CONTROL IN AFRICA / ASIA

A PROGRAMMATIC ENVIRONMENTAL ASSESSMENT



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APPENDIXES

March, 1989

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APPENDIX 1.
LIST OF PREPARERS

This appendix identifies the individuals responsible for analysis and preparation of specific sections of the assessment. The appendix lists in alphabetical order the name, most advanced degree, institutional affiliation, and technical discipline of each contributor to the programmatic environmental assessment.

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The three volume PEA for Locust and Grasshopper Control was prepared by the following persons:

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APPENDIX 2.
USAID STAFF CONCERNED

This appendix lists the names, departmental affiliation and responsibilities of USAID staff closely connected to the Programmatic Environmental Assessment Project.

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USAID STAFF CONCERNED WITH
PROGRAMMATIC ENVIRONMENTAL ASSESSMENT

NAME	DEPARTMENT	RESPONSIBILITY
	PEA Design Committee	
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Stephen Lintner	ANE/PD/ENV	Environmental Coordinator
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APPENDIX 3. BIBLIOGRAPHY

Ref. Codes: L = Literature Cited
S = Significant Source
P = Personal Contact
O = Other

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WORLD ENVIRONMENT CENTER	1987	Pesticide Disposal in East Africa		New York, NY	L
WORTHING, C.R. and S.B. WALKER	1983	The Pesticide Manual	British Crop Protection Council	Lavenham, England	L
YATES and ACKERSON	1984	Measurement of Drop Size Frequency from Nozzles and Atomizers Used for Aerial Applications	USDA - Forest Service	Missoula, MT	L
YULE, V.H. and J.B. LLOYD	1959	Observations on Migration of Hopper Bands of the Red Locust (Nomadacris septemfasciata Serv.) in an Outbreak Area	J. Ent Soc. S. Afr. 22, pp. 233-244		L
ZAHIC, D.J. and L.O. HILO	1981	Factors Effecting Pesticide Photodecomposition Studies	Test Protocols for Environmental Fate and Movement of Toxicants. Proc. Sym. Assoc. of Off. Anal. Chem.	Arlington, VA	L
ZERAMOV, G.	1934	The Moroccan Locust in the Stavropol Province (N. Caucasus) in "Grasshoppers and Locusts", G.P. Uvarov, vol. 2, 1977			L
ZERIN, L.N.	1939	Les pontes des Acridiens. Morphologie, classification et ecologie.	Tabl. Anal. Faune URSS no. 23:33 pp.		B
ZOLESKI, L.C.	1968	Biocecologia y autogenesis de Scotussa ellisa (Stal) Lieb. (Acrididae, Catantopidae) en el Uruguay	Uvarov, 1977		B
ZOLOTAREVSKY, B.N.	1959	Les problemes acridiens	Phytistrie, Phytopharmacie, 8:173-179		B
ZOLOTAREVSKY, B.N.	1959	Organisation Internationale de la lutte anti-acridienne	Chimie et Industrie 81:303-309		B
ZOLOTAREVSKY, B.N.	1938 b.	Recherches sur les foyers grégarigènes du Criquet migrateur africain (Locusta migratoria migratorioides REF)	Bull. Soc. Hist. Nat. Af. Nord, 29:233-246		L
ZOLOTAREVSKY, B.N.	1940 a.	Les subdivisions des aires grégagènes et leur role dans la transformation des phases. (Essai de classification)	5th Int. Locust Conf.	Brussels, Belgium	B
ZOLOTAREVSKY, B.N.	1936	Compte rendu sommaire sur les recherches de la Mission d'Etudes de la Biologie des Acridiens dans la region du Tchad en 1935	Bull. Soc. Hist. Nat. Nord, 27:189-124		B
ZOLOTAREVSKY, B.N.	1934	Invasions des Acridiens en Guinee Francaise. Travaux du Comite d'Etudes de la Biologie des Acridiens	Bull. Soc. Hist. Nat. Afr. Nord. 25:216-231		B

AUTHOR	DATE	TITLE	PUBLISHER	CITY	REF. CODE
ZOLOTAREWSKI, B.N.	1933	Contribution a l'etude biologique de Criquet migrateur dans ses foyers permanents	Ann. Epiphyt. 19: 97-142		S
ZOLOTAREWSKI, B.N.	1939 a.	Note preliminaire sur les vols de sauterelles a Madagascar	Rev. Path. Veg. Ent. Agric. avril-mai 1939:4 pp.		S
ZOLOTAREWSKI, B.N.	1939 b.	Le riz et les sauterelles a Madagascar	Riz et rizicultures 4: 1-8		S
ZOLOTAREWSKI, B.N.	1939 c.	Le Criquet migrateur a Madagascar. Locusta migratoria capito Sauss.	Ann. Epiphyt. 15: 183-216		S
ZOLOTAREWSKI, B.N.	1940	Notice sur la destruction des sauterelles a Madagascar	Tananarive, Bureau Central de la Lutte Contre les Sauterelles:22 pp.		S
ZOLOTAREWSKI, B.N.	1947	Notes sur les Acridiens a Madagascar	Bull. Economique de Madagascar et Dependances:1-8		S
ZOOLOGICAL NOMENCLATURE	1964	International Code of Zoological Nomenclature Adopted by the 17 International Congress of Zoology	International Trust for Zoological Nomenclature:176 pp.	London, England	S

APPENDIX 4. LIST OF PERSONS CONTACTED

This appendix lists the name and title of all persons contacted by institutional affiliation as well as the phone, date and method of contact.

A separate list provides postal addresses.

LIST OF PERSONS CONTACTED
OUTSIDE TAMS/CICP

NAME	TITLE	INST/ORG AFFILIATION	DEPT	PHONE	DATE CONTACTED 1987-88	METHOD OF CONTACT
		AID	DIHL	202/951-7191	9/4	mtg
	Director	OTH	Amer.Cyanamid/Wayne,NJ		11/3	ltr
	Director	OTH	Amer.Hoechst Corp./NJ		11/3	ltr
	Director	OTH	Bayer AG/FRG		11/3	ltr
	Director	OTH	Aktiengasellschaft/FRG		11/3	ltr
	Director	OTH	Celamerck/FRG		11/3	ltr
	Director	OTH	Cheminova/Denmark		11/3	ltr
	Director	OTH	Ciba-Geigy/Basel		11/3	ltr
	Director	OTH	Dow Co./Midland,MI		11/3	ltr
	Director	OTH	FBC Ltd./England		11/3	ltr
	Director	OTH	FMC Ag/Ch Group/Phil.PA		11/3	ltr
	Director	OTH	ICI/England		11/3	ltr
	Director	OTH	Mobay Corp/KC,MO		11/3	ltr
	Director	OTH	NOR-AM/Wilmington,DE		11/3	ltr
	Director	OTH	Pennwalt/Phil.PA		11/3	ltr
	Director	OTH	Rhone-Poulenc Ag/France		11/3	ltr
	Director	OTH	Shell Chem./Houston,TX		11/3	ltr
	Director	OTH	Sumitomo Co./Japan		11/3	ltr
	Director	OTH	WR Grace Co./Memphis,TN		11/3	ltr
	Director	OTH	Union Carb/Res.Tr.Prk,NC		11/3	ltr
Abebe, Teshale	Acting Director	DEL	DLCOEA/Ethiopia	181475	10/5-15	
Abebe, Teshale	Offr in Charge	DEL	DLCOEA/Nairobi		10/5-15	mtg
Adama, Diarra	Spray Pilot	OTH	GOMali/Dept of Agric		10/5-15	
Adams, Carla	Service Rep	IND	EOSAT			
Ahmed Soueid, Abdallahi	Dir general	OTH	OCLALAV/Senegal		12/8-9	mtg
Ainan, A. E.	Ag Chief Engineer	DEL	DLCOEA/Kenya	501719	10/5-15	
Ainen, Abdullahi	Sr Aircraft Eng	DEL	DLCOEA/Nairobi		10/5-15	mtg
Akerman, James	Asst. Director	EPA	Pesticide Reg		10/5-15	mtg
Akesson, Norman	Prof Emeritus	UNIV	Agric Engr/UC, Davis	916/758-1472	10/5-15	
Akinnigbagbe, Julius	Chief Agric Offcr	OTH	Resource Rur Dev/Nigeria		12/8-9	mtg
Alloum, Djaffar	Dir, Prod Facteurs	OTH	Agric Ministry/Algiers			mtg
Amisi, Joram		DEL	DLCOEA		10/15	mtg
Anastasiadis, Basil	FMC Int'l Dev Mgr	OTH	FMC Int'l/Athens		12/8-9	mtg
Arao, Leo A.		AID	REDSO/ESA		10/15	mtg
Arifi, Dr.	Director	OTH	Crop Prot Serv/Morocco		10/5-15	mtg
Arraleh, A. S.	Agricl Pilot	DEL	DLCOEA/Ethiopia	181475	10/5-15	
Atchue III, J. A.	Staff Scientist	IND	Dynamac	310/468-2590		mtg
Ayoub, Ali Taha	Sr. Programme Ofr.	UN	UNEP/Nairobi	565885		
Ba, Moussa Bathily	Dir de Formation	CILSS	Institut de Sahel	222148	8/14	mtg
Ba, Moussa Bathily	Dir de Formation	CILSS	Institut du Sahel	2221482178	10/5-15	mtg
Ba Diallo, Daoule	Coordonnateur PI	CILSS	UCTR/PV		12/8-9	mtg

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Baldwin, Lori		OTH	World Wildlife Fund		9/10	
Ballentine, Janet	Dpty Director	AID	USAID/Rabat		10/5-15	mtg
Balmat, Maurice	Consultant	IND	FAO/AGPP		12/8-9	mtg
Bals, Edward	Owner	IND	Micron Sprayers/Bromyard		10/5-15	mtg
Barberham, Carl		EPA	OPTS	202/	9/2	mtg
Barbosa, Sebastiao	IPM Specl	FAO	FAO/Rome	57973551	10/5-15	mtg
Barchechat, George	Asst Director	OTH	CIDA/Africa Branch	9944186	10/5-15	
Batti, Renato	Admin principal	OTH	D.G. Dev/Belgique		12/8-9	mtg
Beatle, Jack	Spray Pilot	AID	TEG Aircraft Co/Mali		10/5-15	
Bellows, Scott	Contract Negotr	AID	M/SER/OP/OS/AFR	202/875-1009		mtg
Ben Halima, Dr.	Dir, Locust Contr	OTH	Crop Prot Serv/Morocco		10/5-15	mtg
Benharrosh, Gilbert	Dir des vegetaux	OTH	ACDI		12/8-9	mtg
Benjamin, Roger	Spec en agric	OTH	Agence Dev Int's/Canada		12/8-9	mtg
Bergman, J. M.	Contracting Offcr	AID	SER/AAM/OS			pho
Bernaki, Abdekabir	Lt Chef de la Iere	OTH	Royal Air Force/Morocco		10/5-15	mtg
Birante, Soumare	Dir adj de l'agric	OTH	Min dev rur/Mauritania		12/8-9	mtg
Bisegna, Gino	Expert, DGCS	OTH	Min des affrs/Italie		12/8-9	mtg
Blondin, Patrick		OTH	Ecole Normale Superier		10/21	ltr
Blondin, Patrick		OTH	Ecole Normale Superier		8/13	mtg
Blumberg, Andrea	AAAS Fellow	AID	ST/AGR/AP	703/235-1498	12/22	pho
Boange, Clive James	Sr Sc Offr Ent	UN	Research Stat/Essex		12/8-9	mtg
Bonou, Alphonse	Agric Dir	OTH	Agric Min/Burkina Faso		12/8-9	mtg
Booth, Gregory		AID	AFR/TR/ARD	202/647-8764	8/11	mtg
Bottrell, Dale		UNIV	U of Maryland	301/		
Bourgeois, Francois	Res Entomologist	OTH	Ciba-Geigy Ltd/Basle		12/8-9	mtg
Boyd, Bessie L.	Environmental Ofr	AID	ARF/TR/ARD	202/647-8750	12/8-9	mtg
Boyd, Bessie L.	Environmental Ofr	AID	ARF/TR/ARD	202/647-8750	12/1-14	mtg
Boyd, Bessie L.	Environmental Ofr	AID	ARF/TR/ARD	202/647-8750	12/8-9	mtg
Boyd, Bessie L.	Environmental Ofr	AID	ARF/TR/ARD	202/647-8750		pho
Boyd, Bessie L.	Environmental Ofr	AID	ARF/TR/ARD	202/647-8750	12/22	mtg
Boyd, Bessie L.	Environmental Ofr	AID	ARF/TR/ARD	202/647-8750	12/1-14	mtg
Brader, Lukas	Director	FAO	Plant Prod & Prot Div		12/8-9	mtg
Brahami, M.	Ast Dir/County Afr	IND	Air Algeria, Algiers			mtg
Bran, Noel		UN	UNEP	212/		
Brandstrup, Anders	Head of Division	OTH	Min Foreign Affr/Denmark		12/8-9	mtg
Brinkman, R.	Chief	FAO	AGLS/SRMCS	57973068	9/29	mtg
Brown, David	AID Liason	USDA	Forest Service		11/9	
Brown, Greg	Forester	UNIV	UMaine/Research	207/581-1504	9/24	mtg
Bruge, Georges	Dir du Dev Int'l	OTH			12/8-9	mtg
Bruggers, Richard	Chief Int'l Prog	OTH	Denver Res Center	303/236-7878	12/15	pho
Brumby, Peter J.	Livestock Specl	WB	Agric & Rural Dev	202/473-7577	11/13	mtg
Burnett, David	Econ Counsellor	USA	Algerian Embassy			mtg
Butler, Cal		IND		503/382-6886	1/11/88	ltr
Butrous, Munir Gabra	Researcher	OTH	Plant Prot Dept/Sudan		10/18	mtg
Cassana, Mustafa	Dir du servic PV	OTH	MDRP/Guinea-Bissau		12/8-9	mtg
Castel, Jean-Marie	Consultant	IND	FAO/AGPP		12/8-9	mtg
Castleton, Carl		AID	AFR/TR	202/647-8742	11/24	mtg
Castleton, Carl		AID	AFR/TR	202/647-8742	12/16	mtg
Castleton, Carl		AID	AFR/TR	202/647-8742	9/3	mtg
Castleton, Carl		AID	AFR/TR	202/647-8742	10/5-15	mtg

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Castleton, Carl	Entomologist	AID	AFR/TR/ARD		12/8-9	mtg
Castleton, Carl	Entomologist	AID	AFR/TR/ARD		12/8-9	mtg
Caudron, Louis	Sous-dir/dev rural	OTH	Min de la coop/France		12/8-9	mtg
Cavin, George	Entomologist	AID	USAID/Washington		12/8-9	mtg
Chadd, Elizabeth	Research	OTH	ICAP	(0234)750851	10/5-15	ltr/pho
Chalmette, Jean Pierre	Dir Affrs Int'l	OTH			12/8-9	mtg
Chalmette, Jean Pierre	Dir Affaires Int'l	IND	Rhone Poulenc Agrochimie		12/3/87	mtg
Chiavaroli, Eugene	Director	AID	USAID/Bamako		10/5-15	mtg
Chiavaroli, Eugene R.	Director	AID		225139		mtg
Chiavaroli, Eugene R.	Director	AID	Mali	223602		mtg
Coates, Marva	Librarian	FAO	North Amer Liaison Offc	202/653-2402	12/8	mtg
Coble, John R.	Sales Rep	OTH	Lockheed Aero Sys Co	404/424-2128	12/2	pho
Cohen, Mora	RA Coordinator	AID	C/AID	202/647-9662	8/31	mtg
Cohen, Norman	RA Coordinator	AID	C/AID	202/647-9662	11/24	mtg
Cohen, Norman	RA Coordinator	AID	C/AID	202/647-9662	8/11	mtg
Collier, Carroll	Pest Mgt Advisor	AID	ST/AGR/AP	703/235-2318	8/11	mtg
Collier, Carroll	Pest Mgt Advisor	AID	ST/AGR/AP	703/235-2318	12/16	pho
Collier, Carroll	Pest Mgt Advisor	AID	ST/AGR/AP	703/235-2318	10/28	pho
Collier, Carroll	Pest Mgt Advr	AID	ST/AGR/AP	703/235-2318	1/7/88	mtg
Collier, Carroll	Pest Mgt Advisor	AID	ST/AGR/AP	703/235-2318	9/3	mtg
Collier, Carroll	Pest Mgt Advisor	AID	ST/AGR/AP	703/235-2318	12/8	ltr
Collier, Carroll	Pest Mgt Advr	AID	ST/AGR/AP	703/235-2318	8/31	mtg
Collins, Richard		IND	Price Williams	301/	11/24	pho
Conze, Egbert	Senior Officer	FAO	AGL/Land and Water Div	57974084	9/29	mtg
Cummins, Ken		WHO	Frostburg State U/Oncho	301/	9/3	pho
Cummins, Ken		UNIV	U of Maryland	301/		
Dane, Charles	Program Offcr	USDI	IWS	202/653-5948	11/5	pho
David, Laszlo	Sr. Progr. Offr.	UN	UNEP/Nairobi	(254-2)49112		mtg
de B. Lyon, David J.	Hd Pest Mgmt Dept	UN	ODNRI		12/8-9	mtg
Dean, Stephen	Contracting Offcr	AID	SER/AAM/OS			pho
Di Saba, Fareed	Tech Manager	OTH	Agrochemical Div		12/8-9	mtg
Di Vecchia, Andrea	Res de la cooper	OTH	Min des affrs/Italie		12/8-9	mtg
Diallo, Abdul	Agricultural Asst	AID	USAID/Bamako		10/5-15	mtg
Dieterle, Gerhard	Alt Perm Repres	OTH	Emb Feb Repub of Germany		12/8-9	mtg
Dimond, John	Professor	UNIV	UMaine/Entomology Dept	207/581-2691	9/29	mtg
Dine, Joel	Charge de mission	OTH	Min de la coop/France		12/8-9	mtg
Dine, Joel		OTH	Res antiacridienne/Paris		12/8-9	mtg
Djimilia, Col.	Commander	OTH	Moroccan Army/South. Zn.		10/5-15	mtg
Dliou, Mr.	Ofr in Charge/Loc	OTH	Crop Prot Serv/Morocco		10/5-15	mtg
Dorsey, Learthen	Africana Biblgr.	UNIV	Africana Library	517/355-2366	9/10	pho
Doumbia, Yacouba O.	Dir. du Project	OTH	Lutte Integree/CILSS	226166		mtg
Doumbia, Yacoubia	IPM Director	OTH	Govt of Mali		10/5-15	mtg
Duvall, Leroy		USDI	National Park Service		11/9	
Ehlinger, T. Eric	Vice Pres	IND	Micronair Sales & Serv	305/592-9250	10/5-15	
Eilerts, Gary		IND	Price Williams	301/	11/24	mtg
Ekbom, Barbara	Scientific Offr	UNIV	Min du dev rural/Sweden		12/8-9	mtg
Ekbom, Barbara	Scientific Offr	UNIV	Swedish Univ Agric Sc		12/8-9	mtg
Elliott, Clive	Chief Tech. Advr.	UN	UNDP Crop Prot. Proj.	48202 ext. 6		mtg
El-Habib Ly, Mohamadou	Dir de la PV	OTH	Min du Dev Rural/Senegal		12/8-9	mtg
Eswaran, Hari	Project Ldr, SMSS	USDA	Soil Conservation Serv	202/447-6370	11/16	mtg

Evans, Jeffrey		IND	Dynamac	301/468-2500	11/24	mtg
Farnsworth, Kate	Program Officer	AID	USAID/Khartoum			mtg
Feliu, Edwin	Phytosanitary Spec	FAO	FAO/Rome	57976803	10/5-15	mtg
Ferguson, Dave	Program Offcr	USDI	FWS	202/343-5188	9/8	mtg
Frascatani, Giulio	Sales Mgr Afr	EPA	Dow Chemical/Italy		12/8-9	mtg
Friedline, Robert		AID	AFR/ORO			pho
Fujita, Takao	Director	EPA	Plant Protection		12/8-9	mtg
Gassert, Werner	Project Desk Offcr	IND	GTZ/Fel Rep of Germany		12/8-9	mtg
Gaudet, John	Env Offcr	AID	AFR/TR	202/647-8269	12/22	mtg
Gaudet, John	Ag Dev Offr	AID	REDSO/Nairobi		11/24	mtg
Gaudet, John	Ag Dev Offr	AID	REDSO/Nairobi		10/15	mtg
Gaudet, John	Ag Dev Offr	AID	REDSO/Nairobi		10/5-15	mtg
Gaudreault, Louise	Charge de Prgm.	UN	UNDP/Bamako	224380		mtg
Ghannan, Mr.	Asst Dir/Loc Contr	OTH	Crop Prot Serv/Morocco		10/5-15	mtg
Gritzner, Jeffrey	Associate	USA	WAS/S&T Intl Devlpt	202/334-3393	12/8	pho
Groom, Cyril	Sr Programme Offr	FAO	Agricultural Servs Div	57974711	10/2	mtg
Gueltling, Robert H.	Mgr Egypt/Sudan	OTH	Agric Division/Basle		12/8-9	mtg
Guerin, Jean Pierre	Consultant	OTH	Min de la Coop/Vidame		12/8-9	mtg
Guillon, Michel	Director	OTH	Plant Protection		12/8-9	mtg
Hadid, Rabah	Asst Dir, Plng	OTH	Forgn Affrs Min/Algiers			mtg
Hadley, Malcolm		UN	Man and Biosphere Prog			mtg
Hafraoui, A.	Agric Officer	FAO	Plant Prod & Prot Div		12/8-9	mtg
Haynes, Dean L.		OTH	ICIPE		10/15	mtg
Henderson, H. Francis	Chief	FAO	FIRI	57976654	10/1	mtg
Henderson, H. Francis	Chief	FAO	FIRI	57976654	8/19	mtg
Henry, John E.	Res Entomologist	USDA	ARS/Rangeland Inst Lab	404/994-3344	10/19-20	mtg
Hewitt, George B.	Res Entomologist	USDA	ARS/Rangeland Inst Lab	404/994-3344	10/19-20	mtg
Hielkema, Jelle	Remote Sensing Ofr	FAO	Remote Sensing Centre	57975589	12/13	mtg
Hielkema, Jelle	Remote Sensing Ofr	FAO	Remote Sensing Centre	57975589	9/30	mtg
Higgins, G. M.	Director	FAO	AGL/Land and Water Div	57973964	9/29	mtg
Hirsch, Allan	Vice President	IND	Dynamac/Health Res Div	301/468-2500	11/4	mtg
Hirsch, Allan	Vice President	EPA	Health Env Research		12/8-9	mtg
Hofseth, Paul	Minister of Env.	IND	Norway		8/87	mtg
Holland, Joe	Mali/Popov Tests	IND	Imperial Chem/England	(0428)4061	10/5-15	
Huden, Gudrun	Environmental Ofr	AID	OFDA/AFR	202/647-7554	12/14	mtg
Huden, Gudrun	Environmental Ofr	AID	OFDA/AFR	202/647-7554	12/8-9	mtg
Huden, Gudrun	Environmental Ofr	AID	OFDA/AFR	202/647-7554	11/24	mtg
Huden, Gudrun	Environmental Ofr	AID	OFDA/AFR	202/647-7554	12/8-9	mtg
Huden, Gudrun	Environmental Ofr	AID	OFDA/AFR	202/647-7554	10/28	mtg
Huden, Gudrun	Environmental Ofr	AID	OFDA/AFR	202/647-7554	10/28	mtg
Hudson, Stewart		OTH	Natl Wildlife Federation	202/547-9009	11/24	mtg
Jackowski, Richard	Biologist	USDI	FWS	202/343-4955	11/5	pho
Jackson, John	Owner	IND	Helicrop Air/Deddington		12/8-9	mtg
Jackson, John	Owner	IND	Helicrop Air/Deddington		10/5-15	mtg
Jago, Nicholas	Taxonomist	OTH	ODA/TDRI		10/5-15	mtg
James, Philippe	Reg Devel Mgr	AID	USAID/Africa		12/8-9	mtg
Johnson, D. L.	Res Entomologist	IND	Agriculture Canada		11/16	ltr
Johnson, Roger	Tech Advisor	UN	Agrochem Div/London		12/8-9	mtg
Johnstone, Craig	Ambassador	USA	Algerian Embassy			mtg
Kassvag, Nils Ragnar	Alt Perm Rep	FAO	Royal Norwegian Embassy		12/8-9	mtg

Kandiah, Arumugam	Technical Offr	FAO	WRDMS	57974033	10/2	mtg
Katary, Andre	Chef, vegtx serv	OTH	Rural Dev Ministry/Benin		12/8-9	mtg
Kemp, William P.	Res Entomologist	USDA	ARS/Rangeland Inst Lab	404/994-3344	10/19-20	mtg
Kessecker, Bob		AID	OFDA/OS	202/647-5716	10/5-15	mtg
Kessela, Tadesse	Pest Control Offcr	DEL	DLCOEA/Ethiopia	181475	10/5-15	
Kieta, Moussa	Asst to Director	OTH	Crop Prot Serv/Mali		10/5-15	mtg
Kiss, A.	Pesticide Speclt	WB		202/473-4837	1/11/88	pho
Klassen, Waldemere	Dir/Beltsville	USDA	Agricl Research Serv	301/344-3078	12/3	pho
Kohati, Madi	Dir de Admin	CILLS	Institut du Sahel		10/5-15	mtg
Kolodny-Hirsch, Doug		OTH	Envtl Resource Assoc	301/732-8698	11/24	mtg
Kreslins, Dagnija	Project Officer	AID	AFR/OEO	202/647-8827	8/11	mtg
Kreslins, Dagnija	Project Officer	AID	AFR/OEO	202/647-8827	9/28	mtg
Kreslins, Dagnija	Project Officer	AID	AFR/OEO	202/647-8827	9/16	mtg
Kreslins, Dagnija	Project Officer	AID	AFR/OEO	202/647-8827	9/3	mtg
Kreslins, Dagnija	Project Officer	AID	AFR/OEO	202/647-8827	10/5-15	mtg
Kurten, Gunilla	Couns Devel Coop	OTH	Min Foreign Affr/Italy		12/8-9	mtg
Kutzner, Ed	President	OTH		215/721-1712	1/11/88	ltr
Lux, Molly	ENV Offcr	AID	SAT/INR	703/235-2827	9/1	pho
Larew, Hiram	AAAS Fellow	AID	ST/AGR/AP	703/235-1497	12/10	pho
Launois, Michel	Res PRIFAS/CIRAD	PRIFAS	PRIFAS/CIRAD/Cedex		12/8-9	mtg
Launois, Michel		PRIFAS	PRIFAS/CIRAD/France		12/8-9	mtg
LeCompte, Douglas		NOAA	Natl Climatic Anlys Ctr	202/673-5381	11/24	mtg
LeSieur, Harold		AID	AFR/OEO	202/647-8742		mtg
Libby, Ron	Logistician	USDA	US Forest Service		10/5-15	mtg
Lintner, Stephen	Env Coordinator	AID	ANE/PD/ENV	202/657-8226	10/5-15	mtg
Lintner, Stephen	Env Coordinator	AID	ANE/PD/ENV	202/647-8226	8/11	mtg
Lintner, Stephen	Env Coordinator	AID	ANE/PD/ENV	202/657-8226	11/24	mtg
Lintner, Stephen	Env Coordinator	AID	ANE/PD/ENV	202/657-8226	9/16	mtg
Lintner, Steve	Env Coordinator	AID	ANE/PD/ENV	202/647-8226	9/1	mtg
Longcore, Jerry	Biologist	USDI	FWS	207/581-2680	10/6	mtg
Luscombe, B. Wayne	Rem Sensing Specl	WB		202/473-3456	12/7	pho
MacCuaig, Rod	Agric Consultant	FAO	FAO/Addis Ababa		12/4-15	mtg
Magnaghi, Giuseppe	Chef du antiacrid	CILLS	Ambassade d'Italie		12/8-9	mtg
Mahjoud, Nezil	Locust Offcr	FAO	Plant Prot Div/Algiers		12/2-12	mtg
Maignan, Ferauld	Senior Officer	FAO	Plant Prod & Prot Div	57973598	9/30	mtg
Major, John	Biologist	OTH	NY State Dept of Conav	518/457-5410	10/8	pho
Manafi, Mr.	Agricultural Div	AID	USAID/Rabat		10/5-15	mtg
Marcil, Anthony	Director	OTH	World Env.Ctr./NY NY		11/87	ltr
Marr, John		WHO			9/87	mtg
Marshall, Rosella	Contract Negotr	AID	M/SER/OP/OS/AFR	202/875-1036		mtg
Martin, Cal	AGR Coordinator	AID	AFR/TR/ARD	202/647-8175	12/21	mtg
Mason, Lawrence	Chief, Intl Affrs	USDI	FWS	202/343-5188	9/8	mtg
McCormack, Heather	Service Rep	IND	SPOT Image	703/620-2200	12/3	pho
McCrea, Ed	Env Ed Offcr	USDI	FWS	202/343-3895	9/8	mtg
McEwen, Lowell	Sr Res Scientist	UNIV	Biology Dept	303/491-1819	12/22	pho
McIver, Don	Biologist	UNIV	UNew Brunswick/Forestry	506/543-3513	10/6	pho
McKenna, John R.	Sr Agricl Planner	WB		202/676-9266	12/7	pho
Meinzingen, Wolfgang	Regl Coord	FAO	FAO/Nairobi		10/5-15	mtg
Merio, Armid	Chief Pilot	OTH	Adnas Air Service/Eth		10-8-87	mtg
Merio, Armid	Chief Pilot	OTH	Adnas Air Srv. Addis Ababa		10/8/87	mtg

Merritt, Earl	Climatologist	IND	Earth Satellite Corp	301/951-0104	11/30	pho
Merritt, Earl	Climatologist	IND	Earth Satellite Corp	301/951-0104	12/1	pho
Michael, Asmerom	Sr Radio Engr	DEL	DLCOEA/Nairobi		10/5-15	mtg
Michaud, Phil	Locust Officer	AID	Locust Prog/Bamako		10/5-15	mtg
Mierzijewski, Karl	Computer Speclt	OTH	ICAP	(0234)750851	10/5-15	ltr/pho
Minikowksi, Stanislaw	Consultant	OTH	Agence Dev Int'l/Canada		12/8-9	mtg
Monard, Annie	Agroeconomist	PRIFAS	PRIFAS/FAC au Sahel		12/8-9	mtg
Moore, Don	Chief/Biosc Applsc	USGS	EROS Data Center	605/594-6511	11/30	pho
Moore, Don	Chief/Biosc Applsc	USGS	EROS Data Center	605/594-6511	12/7	ltr
Moore, Thomas	Econ Attache	USA	Algerian Embassy			mtg
Morgan, Glen		WB	Environmental Grp/GIS	202/473-3455	11/24	mtg
Mouddour, Ismael	Dir de l'agric env	OTH	Agric/Envir/Niger		12/8-9	mtg
Musa, I. A.	Dir, Admin & Finc	DEL	DLCOEA/Addis Ababa		12/3	mtg
Musa, K.J.	Research Offr	DEL	DLCOEA/Ethiopia		12/8-9	mtg
Naimeur, Abdelouahad	Lt Base Cmndr	OTH	Royal Air Force/Morocco		10/5-15	mtg
Nayland, Pat	Manager	IND	Airspray/Nukuru, Kenya	85304	10/5-15	mtg
Naylor, John	Helicopter Enginr	IND	Evergreen Helicopter Co	503/472-9361	10/5-15	
Nellyer, Robert	Agricultural Offr	AID	USAID/Rabat		10/5-15	mtg
Newburg, Richard	Agricultural Offr	AID	USAID/Bamako		10/5-15	mtg
Newby, John E.	Representative	OTH	World Wildlife Fund	227/733338	11/12 & 11/23	ltr
Newby, John E.	Representative	OTH	World Wildlife Fund	227/733338	11/2	ltr
Newby, John E.	Representative	OTH	World Wildlife Fund	227/733338	12/10	tgm
Ngaromillet, Michel	Dir de l'agric	OTH	Min de l'agric/Chad		12/8-9	mtg
Nicholson, Stephen	Marketing Dir	IND	Agric Air/Ontario	416-832-1519	10/5-15	
Niggemann, Hilde	Agric Offr Oper	FAO	Plant Prod & Prot Div		12/8-9	mtg
Njagi, S.	Agric Attache	USA	US Embassy/Nairobi		10/15	mtg
Njinyam, Steven	Subdir, Crop Prot	OTH	Agric Min/Cameroon		12/8-9	mtg
N'Diaye, Alioune	Regional l'Afrique	FAO	FAO/Senegal		12/8-9	mtg
Ochtman, L. H. J.	Sr Agric Res Offr	FAO			10/2	mtg
Oloo, G. W.		OTH	ICIPE		10/15	mtg
Olsson, Jonathan	FEWS Tech Rep	AID	Africa Bureau	202/647-8178	12/8	pho
Olsson, Jonathan	FEWS Tech Rep	AID	Africa Bureau	202/647-8178	12/9	pho
Onsager, Jerome A.	Res Entomologist	USDA	ARS/Rangeland Inst Lab	404/994-3344	10/19-20	mtg
Otter, James	Marketing Mgr	UN	ICI PLC/Haslemere		12/8-9	mtg
Ottesen, Preben	Asst Professor	UNIV	Biology/Univ of Oslo		12/8-9	mtg
Ottesen, Preben	Asst Professor	UNIV	Biology/Univ of Oslo		10/5-15	
Ottesen, Preben	EA Team/Mali	OTH	Sommes Foundation		10/5-15	mtg
Oudejans, Jan H.	Policy Advisor	EPA	Plant Protection/France		12/8-9	mtg
Ouedraogo,		OTH	Agric Min/Burkina Faso		12/8-9	mtg
Owen, Ray	Professor	UNIV	UMaine/Wildlife Dept	207/581-2362	9/28	mtg
Palmer, George		EPA	Office of Intl. Actvs.	202/		
Papa Paolo, Gian	EEC Represent	OTH	EEC Rep/Rome		12/8-9	mtg
Parker, John D.	Director	OTH	ICAP	(0234)750851	10/5-15	ltr/pho
Parkin, C. S.	Research Dir	OTH	ICAP	(0234)750851	10/5-15	ltr/pho
Perry, James	Prof of Forestry	UNIV	Univ of Minnesota	612/624-9798	11/9	pho
Petr, Tomislav	Fishery Res Offr	FAO	FIRI	57376637	10/1	mtg
Philippon, B.	Chief/Vector Cntrl	WHO	Oncho Control Prog/Mali		10/5-15	
Pinto, Larry	Entomologist	IND	Pinto & Associates	703/938-3299	9/10	mtg
Poirier, Guy	Development Dir	IND	Agric Air/Quebec	514/378-4124	10/5-15	
Poirier, Guy	Development Dir	IND	Agric Air/Quebec	514/378-4124	12/8-9	mtg

Pollin, Joe	L/G Speclt	FAO	Plant Prod & Prot Div		10/5-15	mtg
Popov, George	Consultant	IND	FAO/AGPP		12/8-9	mtg
Popov, George	L/G Control Spec	FAO	FAO/Rome		10/14	pho
Popov, George	L/G Control Spec	FAO	FAO/Rome		12/2-14	mtg
Priestly, Michael	Regional Rep	UN	UNDP			
Pryke, Ian	US Rep	OTH	European Space Agency	202/	11/1	
Purnell, M. F.	Senior Officer	FAO	AGLS/SRMCS	57973192	10/1	mtg
Quantick, H. R.	Writer	OTH	ICAP	(0234)750851	10/5-15	ltr/pho
Redford, Charles	Spray Pilot	AID	TEG Aircraft Co/Mali		10/5-15	
Riedler, Tim		AID	GC/CP	202/647-6381	8/11	mtg
Rivett, Paul	Regional Entom	OTH	ICI Agrochemicals		12/8-9	mtg
Roffey, Jeremy	Agric Offr, R&P	FAO	Plant Prod & Prot Div		10/5-15	mtg
Roffey, Jeremy	Agric Offr, R&P	FAO	Plant Prod & Prot Div		12/8-9	mtg
Rose, T. J. W.		DEL	DLCORA		10/15	mtg
Rowley, John	Director	OTH	Vegetaux Prot Project	222404/4028	10/5-15	mtg
Saidy, Deborah		AID	USAID/Addis Ababa		10/21	mtg
Sakimoto, Clarence	Branch Chief	NOAA	Climatic Appl Branch	314/875-5263	12/3	pho
Sanders, D. W.	Senior Officer	FAO	AGLS/SRMCS	57974461	9/29	mtg
Scherer, Rainer	Admiral	OTH	Dr rer nat GTZ/W Africa		12/8-9	mtg
Scirocchi, Augusto	Expert, DGCS	OTH	Min des affrs/Italie		12/8-9	mtg
Scott, Rodd	Survey/Spray Pilot	IND	Evergreen Helicopter Co	503/472-9361	10/5-15	
Sellelo, Manjura	Operations Dir	DEL	DLCORA/Kenya	501719	10/5-15	
Shiff, Clyde	Health Officer	UNIV	Johns Hopkins/Public Hth	301/		
Sidatt, Moustapha	Rep to Mali	WHO	WHO/Bamako	222335	10/5-15	mtg
Skaf, Rafik	Senior Officer	FAO	Plant Prot Serv, AGP	57974021	12/8-9	mtg
Skaf, Rafik	Senior Officer	FAO	Plant Prot Serv, AGP	57974021	9/28	mtg
Smolikowski, Serge	Ingenieur UCLAF	OTH			12/8-9	mtg
Somme, Lauritz	Prof of Biology	UNIV	Biology/Univ of Oslo		10/5-15	
Somme, Lauritz	Prof of Biology	OTH	Minis of Dev Coop/Norway		12/8-9	mtg
Somme, Lauritz	Prof of Biology	UNIV	Univ of Oslo		12/7-10	mtg
Sorenson, Roger A.	Director	FAO	North Amer Liaison Offc	202/653-2400	12/8	mtg
Sountera, Soumana	Dir du Srv PV	OTH	Min de l'agric/Mali		12/8-9	mtg
Sountera, Soumana	Dir du Srv PV	OTH	Min de l'agric/Mali		10/3-10	mtg
Southerland, Mark	Staff Scientist	IND	Dynamac	301/468-2590	11/24	mtg
Spivy-Weber, Frances		OTH	Natl Audubon Society	202/647-8226	11/24	mtg
Stannard, Clive	Liaison Rep Offr	FAO	Plant Prod & Prot Div		12/8-9	mtg
Staten, Robert		USDA	APHIS/PPQ		1/13/88	pho
Stoner, Kimberly		AID	AFR/TR/ARD	202/647-5567	8/11	mtg
Stryker, Ron	Agricultural Offr	AID	USAID/Rabat		10/5-15	mtg
Svensson, L. O. G.	Managing Dir	IND	Autair Helicopters/Kenya	501211	10/5-15	
Tantare, Rudy	Logistician	USDA	US Forest Service		10/5-15	mtg
Tappan, Gray	Remote Sensg Spec	USGS	EROS Data Center	605/594-6411	11/2	pho
Tetefort, Jean	Insptr Gen Resrch	PRIPAS	ORSTOM	(65)997811	9/30	mtg
That, T. Ton	Rice Specl	FAO	FAO/Rome		10/5-15	mtg
Thelwell, Norman	Product Appl	IND	Imperial Chem/England	(0428)4061	10/5-15	
Thewys, George	Ingenieur Agronome	OTH	Afrique Centre/Cedex		12/3/87	mtg
Thibeault, Robert	Coord G/L Control	AID	OFDA/AFR	202/647-7558	10/5-15	mtg
Thibeault, Robert	Coord G/L Control	AID	OFDA/AFR	202/647-7558	12/7-15	mtg
Thomas, Wilbur	Dpty Mission Dir	AID	USAID/Bamako		10/5-15	mtg
Traboulsi, R.	Coordinator	FAO	Plant Prod & Prot Div		12/8-9	mtg

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Traore, Gaoussou	Econ. Poltcl. Asst	USA	US Embassy, Bamako	223747		mtg
Trawally, Bakary	Natl Coordinator	OTH	Crop Prot Serv/Gambia		12/8-9	mtg
Tucker, Richard	Group VP	IND	Dynamac	301/468-2500		mtg
Turner, Larry		EPA	OPTS	202/	9/2	mtg
UNKNOWN	Director	OTH	Crop Prot Serv/Ethiopia		10/5-15	mtg
van der Graaff, N.A.	Chief	FAO	Plant Prod & Prot Div		12/8-9	mtg
van Veldhuizen, Harvey	Env Advr/Ecolgt	IND	Jones & Stokes	206/641-3982	8/11	mtg
van Vugt, Chris	Sr Adv/Rural Dev	OTH	For Affr Min/Netherlands		12/8-9	mtg
Videau, Bernard	Product Dev Mgr	OTH	Pennwalt Agchem/PA		12/8-9	mtg
Visscher, S. N.	Professor	UNIV	Entomology Dpt/Mont St		10/20	mtg
Waite, Benjamin	Plant Patholgt	AID	ST/AGR/AP	703/235-2318	10/5-15	mtg
Waiyaki, B. G.		UN	UNEP		10/15	mtg
Waiyaui, J. N.		OTH	Natl Envir Sectrt/Kenya		10/15	mtg
Wakuno, Satoshi	First Secretary	FAO	Japanese Embassy		12/8-9	mtg
Walgenbach, D	Professor	UNIV	Plant Science Dept	605/688-4593	12/22	pho
Walter-Echols, Gerd	Biologist/Proj Mgr	OTH	GTZ	43631	9/3	ltr
Walter-Echols, Gerd	Biologist/Proj Mgr	OTH	GTZ	43631	10/18	mtg
Wannop, W. Bryan	Resident Rep.	UN	UNDP/Dar-es-Salaam	73121	10/18	mtg
Waters, Lewis	ENV Speclt	USDI	BLM/FOR	202/653-8864	10/4	mtg
Webb, Jerry L.	Operations Mgr	IND	Liftair Ltd/Addis Ababa	158400	10/5-15	mtg
Wederfort, Don	Manager	IND	Liftair Ltd/Addis Ababa	158400	10/5-15	mtg
Welcomme, Robin		FAO		5797	10/1	mtg
Weller, Dennis		AID	AFR/TR/ARD	202/647-4073	8/11	mtg
Werlin, Louise	Ofr in Charge/Mali	AID	AFR/SWA	202/647-8125	10/5-15	mtg
Wettstein, Klaus	Tech Manager	OTH	Cyanamid Int/Adliswil		12/8-9	mtg
Wiesmann, Peter A.	Alt Perm Rep	FAO	Swiss Embassy/Italy		12/8-9	mtg
Winer, Nicholas	Field Dir.	OTH	OXFAM/Addis Ababa	151256		mtg
Wirth, David		USA	HEDC	202/		
Wold, Berhanu Habte	Col General Mgr	OTH	Adman Air Service/ETH	158971	1/1/88	ltr
Wood, Diane	Project Offcr	OTH	World Wildlife Fund	202/723-2383	11/12	mtg
Worthley, P. J.	Librarian/PR Head	OTH	Ovrseas Dev Ntl Resr In		12/4/87	ltr
Worthley, P. J.	Librarian/PR Head	OTH	Ovrseas Dev Ntl Resr In		10/5-15	mtg
Worthley, P. J.	Librarian/PR Head	OTH	Ovrseas Dev Ntl Resr In		1/4/88	pho
Yost, David L.	Soil Scientist	USDA	Soil Conservation Serv	202/447-6370	11/16	mtg
Yucer, Onder	Dpty/Resident Rep	UN	UNDP/Nairobi	28776	10/5-15	mtg
Zosi, Richard	Curator	USA	Birds Div/Smithsonian	202/357-2335	11/24	mtg

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ADDRESSES OF ORGANIZATIONS/FIRMS ON CONTACTS LIST

CODE	ORGANIZATION	ADD1	ADD2	CITY/ST/ZIP
AID	AFR/TR/AB9	Rm. 2941 NS	Dept. of State	Washington, DC 20523
AID	Contracting Office	1100 Wilson Blvd.	Ste. 1500	Arlington, VA 22200
AID	Document Info. Handling Fac.	7222 47th St., #100		Chevy Chase, MD 20815
AID	OFDA	320 21st St., NW	Rm. 1262-A	Washington, DC 20523
AID	Office of S&T	1601 N. Kent		Arlington, VA 22200
AID	REDSO/ESA	REDSO/EA/Nairobi	USAID/State Dept	Washington, DC 20523
AID	SANAA	Dept. of State	2101 C St., NW	Washington, DC 20523
AID	ST/AGR/AP	SA18, Rm. 413	Dept. of State	Washington, DC 20523
AID	ST/AGR/AP	SA18/Room 413		Washington, DC 20523
AID	USAID/Mali	BP 34		Bamako, Mali
AID	USAID/Rabat			Rabat, Morocco
CILSS	CILSS			Dakar, Senegal
CILSS	CILSS Institut de Sahel	BP 1530		Bamako, Mali
DEL	Armyworm Control Project/EEC/ODA			
DEL	DLCOEA/Ethiopia	PO Box 4255		Addis Ababa, Ethiopia
DEL	DLCOEA/Kenya	PO Box 30023		Nairobi, Kenya
EPA	Dynamac Corp	11140 Rockville Pike		Rockville, MD 20852
EPA	EPA	401 M St., SW		Washington, DC 20460
EPA	Min Agric Water Res & Rur Dev	P.M.B. 2005		Kaduna, Nigeria
EPA	Min of agric et de environ	BP 323		Niamey, Niger
EPA	Mins du rural dev	BP 58		Porto Novo, Benin
EPA	Office of Intl Activities	401 M St., SW		Washington, DC 20460
EPA	Plant Protection	15 rue de Berri 75008		Paris, France
EPA	Plant Protection	PO Box 20401		Den Haag
FAO	AGRT Division	Via delle Terme	di Caracalla	00100 Rome, Italy
FAO	ECLO			Rome, Italy
FAO	FAO	BP 154		Dakar, Senegal
FAO	FAO/UNDP Crop Protection Project	PO Box 24607		Nairobi, Kenya
FAO	Inland Water Res/Aquacult Serv	Fishery Resrcs and Env Div	Viale Terme de Caracalla	00100 Rome, Italy
FAO	Japanese Embassy	Via Quintino Sella 60		Rome, Italy
FAO	Land and Water Development Div	Agriculture Dept	Viale Terme de Caracalla	00100 Rome, Italy
FAO	Liaison Offc for North America	1001 22nd St., NW	Suite 300	Washington, DC 20437
FAO	Locust Emergency Operations Grp	Plant Protection Serv/AGP	Viale Terme de Caracalla	00100 Rome, Italy
FAO	Northwest Africa	Plant Prot and Production		Algiers, Algeria
FAO	Plant Protection Service			
FAO	Plant Protection Service/AGP	Viale Terme de Caracalla		00100 Rome, Italy
FAO	Remote Sensing Centre	Research and Tech Dev Div	Viale Terme de Caracalla	00100 Rome, Italy
FAO	Soil Resources, Mgt & Consv Serv	Land and Water Devlp Div	Viale Terme de Caracalla	00100 Rome, Italy
FAO	Swiss Embassy	Via Barnaba Oriani 61		Rome, Italy
IND	Africa Branch/CIDA	220 Parliament St.	10th Floor	Ottawa, Canada
IND	Agric Air/Ontario		King City, ON	L0G 1E0 Canada
IND	Agric Air/Quebec		Ste-Cecile de Milton, QC	J0E 2C0 Canada
IND	Agri-line Aviation Consultants	20189 Firerock Road		Bend, OR 97701
IND	Air Algeria			Algiers, Algeria
IND	Airspray Ltd			Nukuru, Kenya
IND	Autair Helicopters Ltd	PO Box 41951		Nairobi, Kenya

IND	Dynamac International, Inc.	The Dynamac Bldg	11140 Rockville Pk	Rockville, MD 20852
IND	Earth Observation Satellite Co	4300 Forbes Blvd		Lanham, MD 20706
IND	Earth Satellite Corp.	7222 47th St.		Chevy Chase, MD 20815
IND	Environmental Resrc Associates	1729 Lancaster St.		Baltimore, MD 21231
IND	Evergreen Helicopter Co. Inc.	Box 359		McMinnville, OR 97128
IND	Helicrop Air Ltd	Healthfield House/High St	Deddington Oxon OX5455	Oxfordshire, England
IND	ICAP	Cranbrook Institute	Cranford-Bedford	England MK430AL
IND	Imperial Chemical Industries	Plant Protection Division	Fernhurst, Haslemere	Surrey, England GU273JE
IND	Liftair Intl Ltd	Hilton Hotel		Addis Ababa, Ethiopia
IND	Micron Sprayers Ltd	3 Mills St	Bromyard Herefordshire	England
IND	Micronair Sales and Service	7792 NW 54th St.		Miami, FL 33166
IND	Pinto & Associates	914 Hillcrest Dr.		Vienna, VA 22180
IND	Price Williams and Assoc. Inc.	8484 Georgia Ave.	Suite 400	Silver Spring, MD 20910
IND	Shell Int. Chem Co	Waterloo		London SE1 7NA England
IND	SPOT Image	1897 Preston White Dr		Reston, VA 22091
IND	S-G Servs for Veg/Fruit Farmers	PO Box 8192		El Amarat, Khartoum
IND	TEG Aircraft Co (Graham)	c/o USAID/Bamako		Bamako, Mali
NOAA	Natl Climatic Assessment Branch	1825 Connecticut Ave		Washington, DC 20235
OTH	ACDI	BP 548		Ouagadougou, Burkina Faso
OTH	Admas Air Service	PO Box 159		Addis Ababa, Ethiopia
OTH	Afrique de l'Quest du Centre	BP 1 St Marcel		13367 Marseille Cedex FR
OTH	Agric Canada Research Station		Lethbridge, AB T1J 4B1	Canada
OTH	Bayer A.G.			D5090 Leverkusen
OTH	Beeconist Systems Inc	31 Meetinghouse Road		Telford, PA 18969
OTH	Boissy les Perches	28340 la Ferte		Vidame, France
OTH	Cambridge Animal Pub Health	Saffron Walden		Essex CB 10 1XL
OTH	Canada de Dev Int'l	200 promenade du Portage		Hull, K1A-0G4, Canada
OTH	Ciba-Geigy Ltd. Basle			CH-4000 Basle Switzerland
OTH	Crop Protection Service	Ministry of Agriculture		Rabat, Morocco
OTH	Crop Protection Service			The Gambia
OTH	Crop Protection Service	Ministry of Agriculture		Addis Ababa, Ethiopia
OTH	Cyanamid Int. Corp	PO Box CH-8134		Adliswil
OTH	Denver Wildlife Research Center			
OTH	Dept of Agriculture	Government of Mali		Bamako, Mali
OTH	DOW Chemical	Viale Castello Hagliana 30		Roma, Italy
OTH	Dow Chemical Mid East/Afr	P.O. Box 196	1211 Geneva 20	Switzerland
OTH	D.G. Development	200, rue de la Loi		1040 Bruxelles, Belgique
OTH	Ecole Normale Superieure			Paris, France
OTH	Embassy of Tech Rep of Germany	Via paisielle 24		Roma, Italy
OTH	European Space Agency	955 L'Enfant Plz		Washington, DC 20024
OTH	FMC Int'l	Kifisias 10-12		Marouss, Athens Greece
OTH	Force Royale Aerienne/Morocco			Goulamine, Morocco
OTH	GTZ	6236 Eschborn 1		Fed Republic of Germany
OTH	GTZ	6503 Mainz		Kastel
OTH	Heathfield House	Deddington		Oxon, England
OTH	ICI Agrochemical			
OTH	ICI PLC Agrochemicals			Fernhurst, Haslemere
OTH	ICIP			
OTH	ICIPE/Kenya			
OTH	Institut du Sahel/CILSS	BP 1530		Bamako, Mali

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OTH	Lockheed Aeronautical Systems	Cobb Drive		Marietta, GA 30063
OTH	Locust Control	Crop Protection Service	Ministry of Agriculture	Goulamine, Morocco
OTH	Locust Control	Crop Protection Service	Ministry of Agriculture	Ait Melloul, Morocco
OTH	Lutte Integree/CILSS	BP 438		Bamako, Mali
OTH	MDRP	CP 71		Guinea-Bissau
OTH	Min de l'agriculture	BP 7028		Ouagadougou, Burkina Faso
OTH	Min des affrs entrangeres	Via Contarini 25		Rome, Italy
OTH	Min du Dev rural	BP 180		Nouakchott, Mauritania
OTH	Min du Dev Rural	BP 154		Dakar, Senegal
OTH	Min of rural dev	20, rue Monsieur		Paris, France
OTH	Ministere de l'agric	BP 441		N'Djamena, Chad
OTH	Ministere de l'agriculture	BP 1560		Bamako, Mali
OTH	Ministere de mission	20, rue Monsieur		Paris, France
OTH	Ministry of Agriculture			Algeria
OTH	Ministry of Agriculture	Govt of Mali		Bamako, Mali
OTH	Ministry of Agriculture	BP 1621		Yaounde, Cameroon
OTH	Ministry of Foreign Affairs			Algeria
OTH	Ministry of Foreign Affairs			Copenhagen, Denmark
OTH	Ministry of Foreign Affairs	Bezwidenhoutseweg 67		Hague, The Netherlands
OTH	Ministry of Foreign Affairs	Viale Cioacchino Rossini 18		Rome, Italy
OTH	National Audubon Society	801 Pennsylvania Ave., SE		Washington, DC 20003
OTH	National Environment Secretariat			Nairobi, Kenya
OTH	National Wildlife Federation			
OTH	OCLALAV	BP 1066		Dakar, Senegal
OTH	ODA			
OTH	ODA/TDRI			London, England
OTH	CPSR/Mali	BP 1560		Bamako, Mali
OTH	ORSTOM			Paris, France
OTH	Overseas Dev Natural Res Inst	College House/Wright's Ln		London W8 5SJ England
OTH	OXFAM/Ethiopia	PO Box 2333		Addis Ababa, Ethiopia
OTH	Penwalt Agchem Corp			Philadelphia, PA 19000
OTH	Plant Protection	11.b rue Miciotti		Beziers
OTH	Rhone Poulenc Agrochimie			
OTH	Royal Norwegian Embassy	Via delle Terme Deciane 7		Rome, Italy
OTH	Societe Agric Air Inc	185 route 137		Quebec, Canada
OTH	Sonnes Foundation/Mali			
OTH	S&T for Intl Development Board	National Research Council	2101 Constitution, NW	Washington, DC 20418
OTH	TDRI			London, England
OTH	UCLAF	163 Avenue Gambetta		Paris, France
OTH	World Wildlife Fund	BP 10933		Niamey, Niger
OTH	World Wildlife Fund	1250 24th St., NW		Washington, DC 20037
PRIFAS	CIRAD/PRIFAS	BP 5035		Montpellier, Cedex, FR
PRIFAS	PRIFAS/CIRAD	BP 5035	34032 Montpellier cedex	France
PRIFAS	PRIFAS/FAC au Sahel	BP 11285		Niamey, Niger
UN	UN Secretariat/Ethiopia	UNDP	PO Box 5580	Addis Ababa, Ethiopia
UN	UNDP/Kenya	PO Box 30218		Nairobi, Kenya
UN	UNDP/Khartoum	PO Box 913		Dar-es-Salaam, Khartoum
UN	UNDP/Mali	BP 120		Bamako, Mali
UN	UNEP	Liasion Offc Rm. DC2-803	2 UN Plz.	New York, NY 10017
UN	UNEP/Kenya	PO Box 30552		Nairobi, Kenya

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UN	UNESCO	7 place de Fontenoy		75700 Paris, France
UNIV	Biology Dept	University of Oslo	Blinden 0316	Oslo, Norway
UNIV	Colorado State University			Fort Collins, CO 80523
UNIV	Dept of Agricl Engineering	Univ of California/Davis	748 Elmwood Dr	Davis, CA 95616
UNIV	Dept of Entomology	Montana State Univ		Bozeman, MT 59717
UNIV	Dept of Entomology	University of Maryland		
UNIV	Dept of Forestry Resources	Univ of Minnesota		St. Paul, MN 55108
UNIV	Dept of Zoology	Univ of Oslo Biology Inst	PO Box 1050 Blindern	N-0316, Oslo 3, Norway
UNIV	Johns Hopkins Univ			Baltimore, MD 21200
UNIV	Sahel Documentation Center	Africana Library/MSU	W-316 Univ Libraries	East Lansing, MI 48824
UNIV	South Dakota State University			Brookings, SD 57007
UNIV	Swedish Univ of Agric Sc	Box 7044 S-75007		S-75007 Uppsala, Sweden
UNIV	University of Oslo	P.O. Box 1050	Blindern N-0315	Oslo 3, Norway
USA	Nat'l Research Dev. Council			Washington, DC
USA	Smithsonian Institution	Birds Division		Washington, DC 20560
USA	US Embassy/Algiers	4 Chemin Ch Bachir Brahimi		Algiers, Algeria
USA	US Embassy/Nairobi			
USDA	Agricultural Research Center	Beltsville Research Ctr		Beltsville, MD 20705
USDA	APHIS	Fedl. Bldg., Rm. 663	6505 Belcrest Rd.	Hyattsville, MD 20782
USDA	APHIS/PPQ	Boll Worm Station	4125 E Broadway	Phoenix, AZ 85040
USDA	ARS Rangeland Insect Lab	Montana State Univ		Bozeman, MT 59717
USDA	CSRS/CRIS	5th Fl. NAL Bldg.	10301 Baltimore Blvd.	Beltsville, MD 20705
USDA	Soil Conservation Service	PO Box 2890		Washington, DC 20523
USDA	US Forest Service			
USDI	National Park Service			
USGS	EROS Data Center	Bioscience Appls Offc		Sioux Falls, SD 57198
WB	The World Bank	1818 H St., NW		Washington, DC 20433
WHO	Onchocerciasis Control Program			Bamako, Mali
WHO	WHO/Geneva			
WHO	WHO/Mali	BP 99		Bamako, Mali

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APPENDIX 5.
SCOPING SESSIONS AND IN-COUNTRY CONVERSATIONS

This appendix contains the reports on two scoping sessions and in-country conversations. The attendance lists, showing names and institutional affiliations of attendees, for each meeting and other contacts made in-country are also listed.

The scoping sessions for this Programmatic Environmental Assessment were held in West Africa and in East Africa. In Mali a scoping session was held on 8 October 1987; in Kenya a scoping session was held 15 October 1987. Since many of the local experts for each country were working in field operations, we were able to record their comments in separate interviews during the week of October 5 in Mali and the week of October 12 in Kenya. To aid in obtaining impartial and pertinent comments, we have provided comments in the text without attribution.

Also included in this appendix are two reports of trips made to Morocco and Algeria in late 1987.

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Record of Mali Scoping Session

Scoping Session was convened at 9:30 a.m. on 8 October 1987 at the Nara camp of Dynamac, Mali. The site was chosen by pre-arrangement with AID and other interested agencies in order to bring together the many researchers who were working in northern Mali. As noted earlier we have also recorded comments from those who could not attend this session, but were interviewed that week.

The session was attended by and conversations were held with the following:

Ron Libby	U.S. Forest Service
Jeff Evans	Dynamac
Mark Sutherland	Dynamac
Andrew Stancioff	Dynamac
Ian Mackay	USAID/Mali
Buck Radcliffe	TeG (helicopter contractor)
Jack Beadle	TeG (helicopter contractor)
Carroll Voss	CICP
George Cavin	CICP
Jon Cooper	TAMS
John Rowley	Project Britanica, British ODA
Gaoussou Traore	US Embassy/Mali
Y. Santarra	Crop Protection Service, Mali
Y. Doumbia	IPM Program, Mali
George Popoff	FAO Consultant, Mali
Moustapha Sidett	WHO

The session was co-chaired by Jon Cooper, TAMS and George Cavin, CICP. We also incorporated comments made by others in a separate briefing after the scoping session.

Dynamac personnel described their research project, which was designed to look at the efficacy and environmental effects of 8 pesticides. They reported that all chemicals tested appeared to be of similar effectiveness against O. Senegalensis. There were, however, marked differences in mortality for non-target species. Malathion was the least selective and killed all species. Their draft report will be available in December; later reports will describe residue analyses from plants and animals in these studies.

Many topics were discussed in the next two hours

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including: assessment of program success, and funding of programs of locust control, need for monitoring and other pest control programs, and education and training needs.

Many participants complained that there have been numerous assessments -- particularly one by FAO -- and were not convinced they were all needed or were properly conducted. The EA team expressed the hope that our report would be shared with all those interested. Rather than a locust program per se, they felt that there was 1) a need to support local crop protection programs, 2) a need for smaller programs which are of an "appropriate" scale for countries and 3) coordination with other pest control programs. Other pests are enormous problems most years, while locusts are only a problem in one out of every 10 years. All present reported that no good crop damage estimates are available. ("How do you tell drought-caused damage from insect-caused damage?") There was little economic incentive for farmers to grow more food than their family needs. Others noted that AID needs to emphasize agricultural development -- less than 8% of arable land on Mali is farmed, and only 30% in Ghana and Senegal.

The timing of locust/grasshopper control programs was discussed. There is a continuing debate over whether it is more effective to treat adults, or juveniles (hoppers). Presently, participants felt that there was no good correlation between treatment one year and adult populations the next. For instance, lack of late season treatment does not necessarily mean high locust population the next year. There is a need to monitor life stages of locusts in the field and treat to "knock-back the first generation". Control programs need to be closely tied to monitory progress. USAID needs to develop a program that looks at populations in wild areas where there are usually no people to make reports. If that were achieved, locusts could be controlled at low densities and limited area.

IPM programs were tried in Mali over the last several years, but have been abandoned because of lack of funds. Nosema needs to be tested in Africa. An ideal would be to use pesticides to reduce grasshoppers to a lower density, and then maintain that density with biological-control agents. Participants were quick to point out that general threshold levels for pests in Africa have not yet been worked out.

In monitoring programs one needs to look at rainfall, kinds of soil, vegetation type and condition over a 5-10 year period. Better maps of breeding (outbreak) areas are needed. A program to coordinate on-going efforts needs to be achieved -- in particular between NERMS (USAID), FEWS (USAID), FAO, AGRHYMET

(CILLS) and, in the long-term, GEMS and INFOTERRA (UNEP).

Participants felt that there was a need to educate farmers in the safe use of pesticides. The training needs to have good follow-up in a repetitive way. The problems are compounded by a low literacy rate. The lack of a good agricultural infra-structure in West Africa meant that non-pesticide control measures were not tried, and that only pesticides were preferred. There needs to be some return to traditional control measures.

Finally land-use practices need to be revised. Local botanists report that the Nara region was blooming with trees and other vegetation 20 years ago. These areas are now mostly semi-arid savanna. Local people feel that new crops such as mangoes should be grown in this area.

In separate conversations, it was noted by other experts that there is a need for good monitoring programs for locusts and grasshoppers in desert areas. Factors important in monitoring locusts are: winds, rain, ripening of vegetation, and timing of egg hatch. In general, spraying programs are over 40-50,000 ha. In 1986, 1,000,000 ha were sprayed. There is a need to maintain a long-term operating fund and retain experienced people.

They noted that old stocks of pesticides have deteriorated and need to be destroyed. Dieldrin and DDT stocks should be used up in desert areas. It was cheaper and safer than transporting them and they may do some good since they act as a persistent barrier to stop the hopper stage of locusts.

On the subject of non-target species effects of pesticides, they noted that there is a society in Germany for the preservation of the white stork. This species is in decline and may have been dependent on locusts for a food source. Other aquatic birds may also be affected.

They would like to test Nosema, but none was available for the test programs over the past two years.

Starting in 1984, British researchers began conducting studies on locusts in Mali. They found that stemborer and header miner (rhaguva) were the real pests. Thus, other species control might be more cost-effective than the grasshopper program. Blister beetles cause major millet loss in Gambia. (They are predators on locusts). By 1984, drought had occurred for 10-20 years. They tried to find ways to stabilize yields in marginal

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areas through Project Pilot Britannica, which will finish in 1990. British disaster relief of £220,000 and 500 tons of pesticides were previously provided. This year they provided 10 landrovers (£285,000).

There was a discussion of the types of millet grown. In short-cycle millet there is usually only leaf damage by locusts and the grain can be harvested. For the long-cycle varieties, which survive drought well, there is a need for rain to finish maturation at end of season. This variety is more productive. Also rhaguva are not always present. But, if there are locusts, they eat grain and one loses crop. Therefore, short-cycle might be preferable.

The experts had the impression that pesticide use is predominantly on cotton crops (99%+); some are used on rice crops in the delta. The major use is in health programs. Therefore, locust programs are not major users of certain pesticides.

In discussing the alternative strategy of paying farmers for crop loss, they dismissed the idea. They asked how one would administer the program and that there are not enough people to determine who is to receive money (or grain). In southern Mali there is a surplus of millet which is held by the Grain Marketing Board.

Due to the isolation of the Nara site and since the control program was still in progress, several persons who could not attend the scoping session were interviewed individually and their comments have been included.

Dr. George Popov, FAO Consultant, interviewed at Dilli, Mali, was concerned that control efforts were still continuing as of October 8, 1987 when O. senegalensis were adults, had already laid eggs, and were migrating south. Little savings could result from continued treatment as the millet harvest in northwest Mali and southeastern Mauritania was 90% complete.

Dr. Yacouba O. Doumbia, Director, IPM, Mali, interviewed in Bamako, October 6, 1987, was concerned that all the pesticide tests conducted by AID (Dynamac contract), FAO, and Norway (Stromme Foundation), were solely in cooperation with the Mali Crop Protection Service while the Mali Government Research Organizations seemed to have been ignored. He made reference to the 1986 tests conducted by AID in which both the CPS and IPM provided personnel and a coordinating committee of Research, IPM, CPS, FAO and AID was formed which met frequently to establish the test protocol and review progress.

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Director of Crop Protection, S. Sountera, interviewed in Bamako, was of the opinion that the program in 1987 was operating on a sounder base than the 1986 control effort since equipment and material had arrived on a more timely basis and that lessons learned in 1986 enabled better management and smoother operations.

John Rowley, Assistant Director, U.K. Pilot Project, Mourdiah, interviewed in Bamako, expressed concern because the FAO insecticide tests were disrupted twice when Dr. Popov was dispatched, first to Chad and later to northern Mali to evaluate the Desert Locust problem. Although, recognizing the seriousness of both the locust and grasshopper problems in Mali, he felt that more attention in the future should be placed on integrating these control efforts with controls of other pest problems such as head miners and blister beetles which on a year-in, year-out basis caused greater losses to millet.

Record of Kenya Scoping Session

Subject scoping session was convened at 8:30 a.m., Thursday, October 15 at the ICIPE offices on the University of Nairobi campus.

Attendance consisted of:

Joram Amisi	DLCOEA
T. J. W. Rose	DLCOEA, Armyworm Control Project/EEC/ODA
B. G. Waiyaki	UNEP
G. W. Oloo	ICIPE
Dean L. Hayes	ICIPE
S. Njagi	U.S. Embassy, Ag Attache
J. N. Waiyaui	National Environment Secretariat
Clive Elliott	FAO Crop Protection Project
John Gaudet	USAID/REDSO/ESA
Leo A. Arao	USAID/REDSO/ESA
Jon Cooper	TAMS
George Cavin	CICP
Carroll Voss	CICP

Since he could not be present for the scoping session the FAO Coordinator for Migrant Pest Control, Dr. Wolfgang Meinzingen, was interviewed separately. His comments have been included as part of the record for this scoping session.

The session was chaired by Jon Cooper, TAMS, and George Cavin, CICP, since a prior committment delayed the arrival of John Gaudet.

Kenya being outside the normal breeding area of both the Red and Desert Locust has not suffered invasions since the mid 1950's. Kenya continues to maintain its membership in both IRLCO and DLCOEA. These organizations have responsibility for keeping Kenya free of locusts and their control if they do arise. Mr. Waiyaui explained that Kenya was satisfied that Kenya could only remain free of locusts as long as these two organizations remain functional. Kenya has its own small Crop Protection Service that is responsible for normal grasshopper problems but would be incapable of controlling a large locust invasion.

Most participants being unfamiliar with the present locust/grasshopper problem, the discussions turned to general crop protection problems and DLCOEA's participation in control programs in Kenya in other migratory pest problems, including armyworms and grain-eating birds.

Considerable interest was expressed as to the problems of widespread pesticide use by ill-trained agriculturalists, particularly women who do much of the pesticide application in Kenya. Until now most training programs conducted were focused on the male population. In many aerial spraying programs, the program is known as "death moving around" and people are told that feeling dizzy after spraying is normal.

The need for far more stringent controls on pesticide imports and the activities of commercial applicators was stressed. The comment was made that pesticide application in eastern Africa was horrendous. Whatever pesticide is available is used.

A Pesticide Control Board has been established in Kenya and they are in the process of developing regulations. However, there are only two inspectors nationwide to enforce these regulations.

Returning to the question of training, the participants expressed the opinion that training should focus more closely on the small farmers needs and should be on the job type training conducted in the field in the farmers' familiar environment. Training should take into account the farmers own knowledge of the ecology of his environment. An example, pointed out by Rose, was that for armyworm control farmers often utilize the polyhedral virus in their control efforts. They collect infected caterpillars, grind them up and incorporate this with bran to make a bait. This is an effective control for the first and second instars but the dosage must be increased 1,000 fold for the later instars. Training should take into account these local techniques and improve upon them by impressing upon the farmer the need for proper timing of application and what constitutes a threshold level population.

Compensation for the farmer for crop losses in lieu of control was passed but rejected by most participants as not a viable approach to the pesticide problem. It was pointed out that in general the small farmer is reluctant to give up the security of his own crop to feed his family to the insecurity of reliance that the government will provide for them in time of need.

There are problems of getting to breeding areas, due to "freedom fighters". There is political unrest in Uganda and in Sudan. Somalia's program needs to be better developed to prevent

outbreaks elsewhere. Persistence of pesticides is an issue. Dieldrin is banned and they want to use it. Alphacypermethrin is also good, but expensive.

Ecological effects of spraying was observed in some applications near Lake Victoria. They had also heard that the central bird migrations for Tanzania might be affected. In order to avoid problems, the spraying companies needed better maps showing adequate resources and human settlements. They noted that Denver wildlife has information on non-target bird species and on phytotoxicity of fenitrothion.

In an individual interview, Dr. Meinzingen expressed his hope that eventually Nairobi would become the headquarters for DLCOEA and that with the support of FAO, DLCOEA would become a research-oriented as well as control-oriented organization and a center for the development of application techniques for eastern Africa, for all migratory pests rather than just locusts. Such a center should also conduct research on the ecology and biology of migrant pests. He was quite critical of some of DLCOEA's present locust control procedures with their known detrimental effects on the environment and their lack of proper survey techniques.

Record of Conversations in Ethiopia and Sudan

This is a summary of conversations with the following people:

Ethiopia

Deborah Saidy	USAID
Nicholas Winer	OXFAM/Ethiopia
R. D. MacQuaig	FAO, pesticide chemist
Michael Priestly	UNDP

Sudan

Kate Farnsworth	USAID
Brian Wannop	USAID
Wendy Fenton	USAID
Paul Russell	USAID
Dr. Munir Gabra Butrous	Plant Protection Department
Gerd Walter-Echols	GTZ

There is a large excess of pesticides in storage depots in Sudan -- much of it stolen from bigger programs. In one program -- the temmex repurchase program -- they recovered 1.2 tons in two weeks. Much of the pesticides from locust programs shows up in the black market. Often, wrong or inappropriate formulation is provided and excess is used inappropriately -- e.g., ULV formulations given or stolen by the private sector which does not have aerial spray equipment. There needs also to be an emphasis on smaller packaging so that excess materials from large campaigns can be used elsewhere.

We made a trip to the central pesticide storage depot in Sudan. Immense numbers of open or leaking cans, bottles and barrels of pesticides lay exposed to the sun. There was a strong smell of organic chemicals in the air, and small lakes of sticky liquids surrounding the stores. A new shipment of gas cylinders (phostoxin) lay in a jumble on top of one of the pies, exposed to temperatures far in excess of 45 C. A WEC report of work on May 19 on pesticide storage should be forthcoming.

Ironically, rats and lizards swarmed around the small buildings (guardsheds and old chemical stone) adjacent, as well as large numbers of flies and mosquitos. On a preliminary view this confirmed the contention of my guide that the active

ingredients in the pesticides had deteriorated and only organic solvents remained.

We were told that the area is guarded 24 hours/day by three shifts. Generally, the guard sits in a shack next to the pesticide store and undoubtedly is exposed persistently to the fumes. There is a WEC report on pesticide storage that discusses some of these issues.

Apparently, in many irrigated areas there were stores of old stocks of pesticides. These need to be inventoried and disposed of properly.

The farmers have strong opinions about useful pesticides. This is a strong "pesticide" culture, where chemical controls are seen as the major response to agricultural problems. However, there is scorching of sorghum due to spraying -- and farmers did not want further spraying of fenitrothion -- even when there are strong predictions that large locust invasions are expected. In most cases, pesticides are overused. Farmers do not understand the relationship between pesticide consumption and economics of crop. Men do most of the work in the fields; women are in homes.

Locusts have not returned in the west of the country. There is no good advance notice because few people live in breeding areas for locusts and there are no early warning reports. There is a need for groups that do daily rounds -- using motor bikes, etc., to follow up with small farmers. They must make use of radio reports, since telephones do not work well.

Some people wanted to try bacillus cultures for biological control, but poor supplies made it hard to register, or test. Much money was needed for this large-scale "experimental" program.

Farmers are not expected to use biological controls even if they become available. There is not tradition of caring for animals -- animals protect themselves (e.g., let chickens find their own food). There is a tradition of leaving (migrating out) of areas and leaving wastes behind.

As in West Africa, there is the feeling that there are many other pest problems besides locusts. Jassid, white fly, aphids are a problem on cotton, where 70 pesticides are used. Birds and rats are a problem; as well as water hyacinths and birds (especially quelea).

Dinder Wildlife Park is not near spray areas; it is the

only main wildlife preserve. Many of the animals (lions, gazelles), and vegetation (forest) is gone due to poaching and wood collection. In nearby areas, the 1960's bone-hole drilling (for water) lead to overgrazing and loss of vegetation.

Finally, there were strong feelings that in Sudan, "too much aid is chasing needs," and that programs need to be better coordinated. Again (as is West Africa), programs need to be on a smaller scale -- the GTZ vegetable program was seen as an effective and efficient use of fuels.

THE DESERT LOCUST PROBLEM IN MOROCCO - 1987

George E. Cavin - Consultant Entomologist

After a somewhat rocky start, which is usual for most programs of this type, the program quickly reached a fairly high level of efficiency. The military and civilian personnel were young andd therefore inexperienced in Desert Locust control, but quickly grasped the needs for guidance, the techniques of application which are considerably different from normal grasshopper control or crop protection practices, and the aircraft spray capabilities.

The apparent pronouncement by top Morocco government officials that no locusts were allowed to reach the Souss Valley provoked an anxiety response toward overkill on the part of the Moroccan control personnel even to the end of my assignment. The USAID aircraft contractor augmented the problem by attempting to influence the policy makers as to the need for multi-engine aircraft, particularly his DC-7s. The pressure to bring these aircraft in was only alleviated after the contractor's pilots had sprayed two or three small swarms and pronounced that it would be impossible to use the DC-7s for the type of work necessary to control the locust swarms.

The swarms while flying were of low to moderate density (no more than 1 to 2 locusts per cubic meter) stratiform, no more than 30 meters thick (bottom to top) and varied from a few square kilometers in size to as much as 30 to 50 kilometers square. When settled and concentrated, the period when control was normally attempted, the size of the areas occupied by the locusts was generally no more than a few hundred hectares, with 3,000 hectares as maximum.

Even the highest density swarms could not be identified on the ground by the pilots, so marking of the area to be sprayed was necessary, or else spraying had to await the time when the locusts began to rise and mill around their settled location and the pilots could see the sun's reflection on their wings. Most swarms were sprayed in the completely settled condition. However, some locations where swarms settled were inaccessible by vehicle, and so could not be marked. Some swarms after settling would get up and move again for several kilometers on moonlit nights. For those swarms military helicopters were utilized to relocate them in the early morning.

By generally recognized classification standards, these were small, low to moderate density stratiform swarms of immature

gregarious and transiform Desert Locust adults.

By the time the swarms had reached the Goulamine area they had lost their bright pink coloration, having turned to a dull reddish brown. As this coloration was similar to the surrounding soil, they were not visible from the air while settled. A few males had reached the mature yellow coloration, yet only a very few females showed any yellowing, evidence of maturation. One dissected partially yellow female showed evidence of egg development, but the eggs had not yet been fertilized. By mid-November any breeding and egg laying by undetected and untreated swarms was still a couple of weeks away.

At the time of my departure from Morocco, November 19, more than forty swarms had been eliminated. The treatment area extended from southwest to northeast approximately 1,000 kilometers and was approximately 200 kilometers in depth. Within this area, 72,000 hectares had been treated.

The control area was divided into four work zones: (1) Southwestern zone with operations centered at Goulamine; (2) Central zone with operations centered at Zagora; (3) Eastern zone with operations centered at El Rachidia; and (4) the Northern zone with its base at Derkan, though not yet operational.

ALGERIA TRIP REPORT:
LOCUSTS
DECEMBER 11-14, 1987

George Cavin, Entomologist, AID/OFDA
George Popov, Entomolcgies, FAO
Robert Thibeault, Disaster Specialist, AID/OFDA

ALGERIAN SITUATION:

Algeria received no locust invasions until early October, when two swarms entered the country: One at Tinzaoatene, the other at Guezzame. Once in Algeria, the swarms split; some spread northwards, carried by strong southerly winds. On October 25, a swarm was reported as far north as Sidi bel Abbes.

One month later, two swarms entered the Tindouf area. One continued to Morocco; the other, measuring 500 hectares, was sprayed and destroyed November 26 to December 3.

As of December 12, the only locusts known to exist are low density hopper infestations in the Ahnet and Tassili Des Ajjer area, some of which have been controlled. However, historically only about 10% of hopper bands in desert areas are ever detected. It is likely, therefore, that additional undetected populations exist in southern and central Algeria that can form swarms and migrate north.

Algeria has been very active with its neighbors (Mali, Niger) in controlling locusts. Algeria has had a control team in both northern Mali and northern Niger for the first few months. Each team consists of 4 vehicles - 2 for survey and 2 for control operations. Algerian teams have sprayed (in cooperation with Niger, Mali and OCLALAV) the following hectares:

Niger	52,000
Mali	34,000
Algeria	2,080

OUTLOOK FOR ALGERIA:

Algeria faces a serious threat of invasion from two areas:

Chad/Mali/Niger and Mauritania/W. Morocco.

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Chad/Mali/Niger: Large residual populations exist in Mali/Niger and are suspected to be present in Chad. These (especially gregarious populations) may invade Algeria at any time given warm southerly winds, such as those which occasionally arise during passage of Mediterranean cyclones.

Mauritania/W. Sahara: Algeria's greatest threat is from widespread infestations in northern Mauritania and possibly Western Sahara. The swarms resulting from current breeding will reach flying stage during late January/February. While they may remain where they are (should favorable conditions continue), it is also possible that they may, once flying, move north into Morocco and/or northeast into Algeria. If they reach Morocco, they will most probably be dealt with by the Government of Morocco's effective locust control services. However, Algeria would be vulnerable to an invasion: the swarms may invade over a wide front and will need to be intercepted before they reach cultivated areas.

Invading swarms not effectively controlled in Algeria are likely to break up into smaller swarms in the Atlas Piedmont and establish a breeding cycle. Such a cycle would create an extreme and difficult-to-control risk for Algeria's northern agricultural regions.

Until our visit, the Algerians had not established a donor coordinating committee. Both the teams and Embassy personnel stressed the importance of such a committee to the Algerian locust control effort. The Algerians agreed to establish a donor committee and made a commitment that it would meet within a week of our departure. The donor committee held its first meeting on December 16, 1987.

- The Plant Protection Institute (INPV) has taken locust control efforts to neighboring countries (Mali/Mauritania) at its own expense.

- It was very obvious that the INPV has maintained its equipment over the years since vehicles of 10 years old were still in operation as well as radios purchased over 20 years ago.

- Because Algeria has been spared a locust plague for the last 25 years, the INPV lacks the hands on experience of running a major emergency locust control effort.

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- The military has supplied 2 helicopters to the INPV which are being used for survey work.

- Algerian officials understood the need to expedite customs clearance and waive taxes and fees for donated material.

- Thibeault told GOA officials that two turbo-thrushes currently in Morrocco are due to be decommissioned and will not be available for use in Algeria.

- Embassy understood that, if USG were to supply equipment and/or pesticides, Embassy would have to obtain waiver of A.I.D. Regulation 16.

- Equipment: OFDA/FAO officials were favorably impressed by the Algerian locust control efforts, run by the Plant Protection Institute (INPV).

- The Algerians were very open and forthcoming with information on the locust control effort.

- If they did not possess the technical expertise they were prepared to request it.

- The personnel we met were very dedicated and hardworking.

- We mentioned that no one donor would be in a position to supply all of the items they had requested. Additionally, we talked about what items donors had contributed to other countries for control campaigns.

- It was suggested that if they needed additional vehicles that they may wish to request them from the military.

- It took 10 days to preposition the spray planes (2 Grumman AG Cats) they had in Algiers to southern Algeria.

ATTACHMENT A

The following are key U.S. Embassy contacts:

L. Craig Johnstone, U.S. Ambassador
David Burnett, Economic Counsellor
Thomas Moore, Economic Staff

The following are the key Algerian officials who met with OFDA/FAO representatives:

Djaffar Alloum, Director of Production Factors, Ministry of Foreign Affairs
Rabah Hadid, Assistant Director for Planning, International Cooperation and Synthesis, Ministry of Foreign Affairs
M. Brahimi, Assistant Director, Commercial Affairs, Air Algeria
Djamel Dib, Assistant Director, Air Operations, Air Algeria
Mohaved N. Bencheikh, Director General, National Institute for Plant Protection (INPV)
Bachir Chara, Locust Specialist, National Institute for Plant Protection (INPV)
Nazil Mahjoub, FAO of North West Africa Locust Control Commission

APPENDIX 6. ACRONYMS

ADMIT	= Agricultural Drought Monitoring Integrative Technique
AETFAT	= Association pour l'Etude Taxonomique de la Flore d'Afrique Tropicale
AFR/OEO	= Africa Bureau/Office of Emergency Operations (AID)
AFSA	= Agricultural Research Service (USDA)
AGRHYMET	= Regional Center for Training and Application of Agrometeorology and Hydrology for the Sahel
AID	= Agency for International Development (U.S.)
AID/ST/AGR	= Science & Technology Bureau/Office of Agriculture
AISC	= Assessment and Information Services Center (NOAA)
ALRC	= Anti-Locust Research Centre (U.K.)
APHIS	= Animal and Plant Health Inspection Service (USDA)
APT	= automatic picture transmission
ARS	= Agricultural Research Service (USDA)
ARTEMIS	= Africa Real Time Environmental Monitoring using Imaging Satellites
ASECNA	= Agence pour la securite de la navigation aerienne en Afrique et a Madagascar
AVHRR	= advanced very high resolution radiometer
CIBC	= Commonwealth Institute for Biological Control
CIDA	= Canadian International Development Agency
CILSS	= Comite Interetat pour la Lutte contre la Secheresse au Sahel
CIRAD	= Centre de Cooperation Internationale en Recherche Agronomique pour le Developpement
CITES	= Convention on International Trade in Endangered Species
COPR	= Centre for Overseas Pest Research (U.K.)
CRIS	= Cooperative Research Information Service (USDA)
DCP	= Data Collection Platform
DLCOEA	= Desert Locust Control Org. for Eastern Africa
DLIS	= Desert Locust Information Service
EA	= environmental assessment
EC	= emulsifiable concentrate (insecticide)
ECLO	= Emergency Center for Locust Operations (FAO)
ECMWF	= European Centre for Medium Range Weather Forecasting
EEC	= estimated environmental concentration
ELT	= Emergency Location Transmitter
EMLD	= empirical minimum lethal dosage
EOSAT	= Earth Observation Satellite Co.
EPA	= Environmental Protection Agency (U.S.)
EROS	= Earth Resources Observation Satellite
ESA	= Endangered Species Act
ESA	= European Space Agency
FAO	= Food and Agriculture Organization (UN)
FEWS	= Famine Early Warning System (AID)
FIRI	= Inland Water Resource and Aquaculture Service (FAO)
GAC	= global area coverage
GEMS	= Global Environmental Monitoring System

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GERDAT	= Groupement d'Etudes et de Recherces pour le Development de l'Agronomie Tropicale (France)
GIEWS	= Global Information and Early Warning System (FAO)
GTS	= Global Transmission System
HRPT	= high resolution picture transmission
HRV	= high resolution visible
ICAP	= Intl. Centre for Application of Pesticides
ICIPE	= Intl. Centre of Insect Physiology and Ecology
IFOV	= instantaneous field of view
IPM	= Integrated Pest Management
IRLCO-CSA	= International Red Locust Control Organization for Central and Southern Africa
ITCZ	= Inter-Tropical Convergence Zone
IWLF	= International Wilderness Leadership Foundation
LAC	= local area coverage
LD50	= Insecticide dosage lethal to 50% of population
LGP	= length of growing periods
MSS	= multispectral scanner
NASA	= National Aeronautics and Space Administration (U.S.)
NERMS	= Natural Resources Management Support (AID)
NOAA	= National Oceanic and Atmospheric Administration (U.S.)
NRDC	= National Research Development Council
NVI	= normalized vegetation index
OC	= organochlorine (insecticides)
OCLALAV	= Organisation Commune de Lutte Antiacridienne et de Lutte Antiaviare
OCP	= Onchocerciasis Control Program
ODA	= Overseas Development Administration (U.K.)
ODNRI	= Overseas Development Natural Resources Institute
OECD	= Organisation for Econ Cooperation and Devlpt
OFDA	= Office of Foreign Disaster Assistance (AID)
OICMA	= Organization International contre le Criquet Migrateur Africain et de Lutte Antiaviare
OP	= organophosphorous (insecticides)
ORSTOM	= Office de la Recherce Scientifique et Technique d'Outre-Mer
PBAF	= potential breeding activity factor
PDUS	= primary data user station
PERMIT	= Polar-Orbiter Effective Rainfall Monitoring Integrative Technique
PRIFAS	= Programme de Recherches Interdisciplinaire Francaise sur les Acridiens du Sahel
SDUS	= secondary data user station
SEM	= Space Environmental Monitor
SMMR	= Scanning Multichannel Microwave Radiometer
SP	= synthetic pyrethroid (insecticides)
SPOT	= Systeme Probatoire d'Observation de la Terre
TAMSAT	= Tropical Agriculture Meteorology Satellite Project
TDR	= Program for Res and Training in Tropical Diseases
TDRI	= Tropical Development Research Institute (U.K.)

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TDRSS	= Tracking and Data Relay Satellite
TIR	= thermal infrared
TIROS	= television infrared observation satellite
TM	= thematic mapping
TOVS	= TIROS operation vertical sounder
TPRI	= Tropical Pest Research Institute (U.K.)
ULV	= Ultra low volume (spray application)
UNDP	= United Nations Development Programme
UNEP	= United Nations Environment Programme
UNESCO	= United Nations Educational Scientific and Cultural Organization
USEPA	= US Environmental Protection Agency
USFS	= US Forest Service (USDA)
USGS	= United States Geological Survey
UV	= Ultraviolet
VHF	= Very High Frequency
VI	= vegetation index
VIS	= visible
WEC	= World Environment Center
WMO	= World Meteorological Organization
WP	= wettable powder (insecticide formulation)

APPENDIX 7.
BIOLOGY OF LOCUSTS AND GRASSHOPPERS

Desert Locust (Shistocerca gregaria)

Habitat

Desert locust breeding is possible within very broad limits of annual rainfall, from under 50 mm to over 1,000 mm. Magor, 1963, determined that the areas where swarm breeding had occurred in not less than 50% of the years lie between 80 and 100 mm isohyets. The Sahelo-Saharan zone, with 50-200 mm of rain falling only during the hot summer period has the highest frequency of breeding.

The total area invaded during Desert Locust plagues extends over some 29 million km squared from the Atlantic shores of West Africa eastwards to Assam, India and from North Africa and the Middle East southwards to Tanzania, and involves 60 nations. Between plagues the Desert Locust occurs within its recession area, covering 14 million km squared of deserts and sub-deserts (Waloff, 1976).

In summer, the potential breeding area extends across Africa between 14 ^{o} and 20 ^{o} N. latitude, south into Ethiopia, across the southeastern edge of the Arabian peninsula and into Pakistan and northwestern India.

In winter, breeding is concentrated in the Somali peninsula and along the Red Sea. Breeding may also occur in Pakistan and northwest India, further south in east Africa, and in scattered areas across the summer breeding area of west Africa.

In spring, breeding takes place in northern and northwest Africa, Arabia and the Middle East, Iran and Pakistan.

Although female Desert Locusts may lay eggs in a wide range of soils, bare, moist sandy or silty soil is preferred. Saline soils are generally avoided. Once the female is ready to lay she must find a suitable site rather quickly. Fully mature females are able to delay laying for only three to five days (Popov, 1958).

Desert Locust eggs are generally laid in groups. Eggs do not go through a period of diapause. Egg survivability is dependent upon adequate soil moisture. They cannot survive a prolonged dry spell. The maximum period of viability is only about 2.5 to 3 months. The rate of egg development is related to soil moisture and temperature at 32 ^{o} C - 34 ^{o} C (air temperature). Egg development proceeds at the maximum rate and hatching takes place in 11 days. At 20 ^{o} C, hatching takes place in about 24 days.

Female Desert Locusts can lay eggs up to 3 times during their lifetime. The number of eggs in a pod can vary from about

20 to over 100. The average number of eggs in the first pod laid are about 95 for the solitarious phase and 70-80 eggs for the gregarious phase. If a third laying occurs the number of eggs average less than 50.

The young hoppers pass through five instars. Each instar extends from about 5 days for the first instar to 12 days for the fifth and final instar. The total hopper period averages 38 days, but can vary from a low of about 20 days at air temperatures of 38 °C to 66 days at 24° C. Solitarious populations may take 5 to 10 additional days to develop at the same temperature.

The final moult is from the fifth instar to adult. This change is called fledging and the young adult is called fledgling.

Observations on the behavior of hoppers showed that those hatched from scattered pods moved into the nearest vegetation and remained largely quiescent, while hoppers hatching in the areas of sparse vegetation formed marching bands at densities as low as 10-20 m squared. In contrast, hoppers hatching in areas of green annual vegetation covering at least 60% of the ground, at 30-40 m squared exhibited little spontaneous marching even in the later instars.

Crowding for more than one generation is required to produce fully gregarious characteristics. This happens either when a prolonged rainy season allows the production of several successive generations in the same area, or when a partially gregarized population moves to an alternative seasonal breeding area with conditions continuing to favor gregarization. Otherwise the population may revert to a partially or wholly solitarious type (Roffey, Popov & Hemming, 1970; Waloff, 1966).

When hoppers occur in large number they gather together in bands which move about as distinct units. They have a more or less regular pattern of behavior. At night and in the early morning hoppers will be found off the ground resting (roosting) on plants, bushes or stones. Roosting also occurs during the middle of the day when the temperature exceeds about 36 ° C.

Hoppers usually spend the greater part of the day marching. Under sunny conditions bands of first instar hoppers may march about 100 per day while large bands of fifth instar hoppers may march as much as 1-2 km per day. Direction of march is generally downwind. However, in rough or hilly terrain their direction of march may be channeled by watercourses and other impediments to a straight line movement.

The main feeding period for hoppers begin with their evening roost on plants, but they also feed briefly while marching. Just before moulting they feed very little or not at all. For the first three instars this non-feeding period lasts

about 1 day, but for the latter two instars it may last 2-4 days.

The length of life of an adult Desert Locust under favorable conditions varies between 2.5 and 5 months. It reaches sexual maturity about 45 days after fledging. Mature adults live about 30 days. In unfavorable conditions maturation may take as long as 6 months. In gregarious locusts the immature adults have a bright pink coloration while mature adults are yellow. These bright colorations make settled swarms readily visible for quite some distance.. In the solitarious form the adults are usually grey or dull brown and much more difficult to detect.

Desert Locusts begin flying soon after becoming adults. Solitarious forms fly at night and require a temperature of about 23 ^{o}C or more for takeoff. Some fly frequently, while others hardly at all. Low density solitarious forms are found throughout the Saharan and Sahelian areas of Africa and in the arid areas of the Near East and Asia. Gregarious locusts fly during the daylight hours. They can fly continuously up to 17 hours. The energy needed is derived from fat stored within its body. The longest flights are made by immature locusts, which do the most feeding and store the most fat. In sunshine long continuous flight is possible when all temperatures are above 14 ^{o}C but flight decreased when the air becomes hotter than 40 ^{o}C.

Most feeding occurs in the evening soon after settling has occurred. During swarming some feeding also occurs. Individual locusts leave the swarm for short periods to feed on the green vegetation that the swarm is passing over, then they rejoin the swarm.

The beginning of maturation can be recognized by the disappearance of the pink color of the hind bibia. Male locusts mature and then give off a phermone which causes maturation to start in the females.

Red Locust (Nomadacris septemfasciata)

Habitat

Red locust plagues start from a number of known locations in and along the Rift Valley in eastern Africa. The only recorded gregarization in the northern hemisphere was in 1957 in the Niger River delta of central Mali, which led to the formation of bands and swarms of sufficient intensity to warrant control operations (Popov, 1985). Outbreak areas are lowlands characterized by impeded or enclosed drainage. The main vegetation consists of grasses. These grasslands are subject to extremes of flood and drought. The floodplains are the important locust habitats. The recognized outbreak areas

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comprise about 7800 km squared, while the invasion area is about 7,800,000 km squared or about 1000 times as large.

Life History

The Red Locust has a long pre-reproductive period of 8-9 months, largely coinciding with the dry season (Robertson, 1958). It has only one generation a year. Eggs are laid in the soil in pods containing about 100 egg less in the gregarious phase and more in the solitarious phase, at about 10-15 day intervals. A single female may lay as many as 5 pods within a 38 day period under favorable conditions (Robertson, 1958). Adults begin to die soon after reaching sexual maturity so that on an average probably less than two pods are laid per female (Symmons, 1964). Egg laying begins following the start of the rainy season (October or early November in the southern hemisphere and June to August in the northern hemisphere). Eggs are deposited in bare soil or areas of sparse vegetation. Eggs hatch in about 30 days.

Newly hatched hoppers pass through 6 and often 7 instars during a period of 60-70 days (Burnett, 1951; Chapman, 1959). The young hoppers, which at first remain in dense family groups, soon disperse, but there is a distinct re-grouping in the second and third instars. This tendency to concentrate is greatest in dense vegetation. Grouping populations are mostly in the transient phase.

Hopper bands are normally formed in the outbreak areas when the third instar hoppers appear, during the third and fourth weeks after hatching. A partial dispersal occurs during the fifth and sixth instars (Dean, 1967). Hoppers pass the night in a torpid state low down in the grass and after dawn they slowly crawl up the grass stems and bask in the sun at the tips (Burnell, 1951). When air temperatures rise about about 23 ^{o}C the hoppers descend into the lower grass levels for migration and feeding (Yule and Lloyd, 1959). Densities decrease as they spread out and they become hidden from view by the tall grass. Hopper bands are visible from the air primarily in the early morning (0600-0900 hrs.) and to a lesser extent in the late afternoon (1500-1900 hrs.) coinciding with the peak roosting densities on the tips of the grass.

The adult stage occurs almost entirely within the dry season (June to August in the southern hemisphere and November to May in the northern hemisphere). Fledging begins near the end of the rainy season and adults remain sexually immature throughout the dry season. Sexual maturity is reached at the beginning of the rains.

Swarm migration cannot be ascribed to lack of food which is always abundant (in the outbreak areas) nor to the state of the vegetation, since some fresh growth is present even

at the height of the dry season (Callaway, 1948; Rainey, Waloff and Burnett, 1957).

The persistence of a plague has been shown by Symmons, 1977, to be due to a certain proportion of the swarming population being confined to retention areas where swarms are able to survive a dry season without undertaking hazardous migration. The main retention areas comprise eastern Zimbabwe, the lower Zambezi Valley and southern Malawi. The other retention area is in southwest Uganda and northernmost Tanzania. The reason for the comparative immobility of swarms in these retention areas is probably due to seasonal patterns of airflow.

The major factor in the decline of a Red Locust plague appears to be the open circuit pattern of its swarm migration, as this often results in swarms being brought to areas unfavorable for reproduction.

Brown Locust (Locustana pardalina)

Habitat

Outbreaks of the Brown Locust originate in the Karoo, a well defined area which includes parts of the Orange Free State and Cape Provinces of the Union of South Africa and the extreme southern portion of Botswana. It comprises country that ranges from semi arid to semi-desert.

Life Cycle

Female oviposition begins 15-20 days after the locusts become adults. Ovipostion occurs at about 7-8 day intervals. Each pod contains an average of 37 eggs in solitarious and 47 to 200 pods per m squared in areas of up to 2-3 ha. One female may lay as many as 11 egg pods during her lifetime (Smit, 1939) but the average is 4-5.

Eggs are normally deposited in dry soil, but the embryos can only develop after water has been absorbed (Matheo, 1951). Eggs can survive up to about 15 months without rain. Rainfall as low as 2.5 mm is sufficient for the eggs to continue survival.

The first rains generally fall in September-October. About 10 mm of rainfall and temperature of at least 14°C is sufficient to stimulate development. The young hoppers pass through 3 instars. Solitarious phase hoppers may complete their development in as few as 21 days while gregarious phase hoppers require about 40 days, with the transient phase taking an intermediate position (Smit, 1939).

Brown locusts normally produce at least 2 generations during the rainy season, quite often a third and sometimes a fourth before the onset of the dry season. Eggs of the second and later generations of gregarious females hatch in 8-18 days (average 11 days at mean air temperature of 19.5 °C). Solitarious populations may have fewer generations than gregarious as the eggs must go through a period of obligatory diapause or quiescence for a period of between 20-95 days, even under favorable conditions.

Incipient outbreaks have practically all arisen in areas with high solitarious population 2 seasons before. This indicates that many Brown Locust eggs may lie over the whole winter and the whole of the following dry summer and still emerge after summer rains some 18-20 months later (Lea, 1964).

African Migratory Locust (Locusta migratoria migratorioides)

The African Migratory Locust has a wide ranging environment. In the northern half of its range in the Sahel it consists largely of elevated dunes of permeable sandy soils and open tussock vegetation with bare patches. In the extreme north of its range it is restricted to low lying areas of runoff and heavy water retaining clay soils. In the central part of its range, in the southern Sahel, it is confined to man-made habitats. In the southern part of its range, in the Sudan, owing to the higher rainfall and very dense vegetation, it is restricted to recently fallowed land (Batten, 1967).

Solitary populations are largely restricted to between 13 °and 17° N in the middle Niger of Mali, but small numbers are found as far south as 8° N in winter and far north as 20° N in summer.

The outbreak areas from which swarms arise are associated with extensive and seasonally flooded grass plains along the middle Niger, the south and southeastern parts of the Lake Chad basin and the Blue Nile Region of Sudan. Rain in this outbreak area normally falls between June and September. The Niger River begins to rise because of the rain which falls in the highlands to the southwest and annually it overflows its banks and floods the surrounding country. The floods begin to recede in October at the southern end of the plains, but last until February or March in the north.

Life Cycle

The African Migratory Locust is one of nine closely-related species occuring in different parts of the world. One sub-species, Locusta migratoria capito is a major pest of agriculture in Madagascar.

Unlike some other species of locusts, the African

Migratory Locust does not have any stage which can tolerate a long period of unfavorable conditions. Populations must breed continuously or die out. Rapid development and frequent disposal give the species the capacity to multiply and spread rapidly when there are widespread rains of long duration (FAO).

The annual cycle consists of five overlapping periods of reproduction. There are normally 3 generations per year in the Middle Niger Delta and Lake Chad Basin that probably only live in the inland areas (Davey and Johnson, 1956). A fourth generation is possible in the Middle Niger when extensive flooding occurs during the normally dry season due to the arrival of water from the upper reaches of the river.

Eggs of the gregarious phase hatch in 10-20 days in the African lowlands (Batten, 1967), but can take up to 46 days when the mean minimum air temperature is less than 23 ^{o}C (Farrow, 1975). A serious deficiency of water can extend the incubation period to as long as 60-102 days (Descamps, 1960, Popov, 1969).

In the cool season females lay only 1-2 egg pods, but as many as 305 pods in the hot season. The mean number of eggs per pod is amount 65 for the solitarious form and less for the gregarious form.

There are normally 5 hopper instars in both the solitarious and gregarious phases, but under very dry condition the solitarious phase may be 6 to even 7 instars.

In the Middle Niger hopper bands occur more frequently during the cool, dry season as the floods recede, and are rarely found during the rainy season. Hopper bands produced on the retreating floods rarely give rise to swarms.

The adult life span varies from about 6 weeks in the hot season to 10 weeks in the cool season. Adults leave the fledging area regardless of whether condition are suitable for further breeding or not (Farrow, 1975).

Laying females appear in the central plains of the Middle Niger in April- May to produce the FIRST RAINS GENERATION. Eggs remain quiescent until the first heavy showers.

At the time of the high floods in August-September most adults leave the flood plain for the surrounding Sahelian areas where they produce the LAST RAINS GENERATION.

If the rains come early a MIDDLE RAINS GENERATIONS may also be produced.

Adults of the Last Rains Generation migrate back to the flood plains and produce the FIRST RETREATING FLOOD GENERATION (October to January). Adults of this generation, flying against

the wind, migrate to the northern plains and produce the LAST RETREATING FLOOD GENERATION (January to April).

Adults of the LAST RETREATING FLOOD GENERATION return to the Central Plains and the cycle begins again (Farrow, 1975).

The life cycle of the Migratory Locust of Madagascar, Locusta migratoria capito, is similarly complex. Solitary populations are characterized by their great mobility. Rainfall plays a fundamental role in displacement. With the approach of the warm season displacemnt is to the southern coastal regions (Lecoq, 1977).

Rainfall amounts suitable for growth and development range from 30 mm-150 mm per month. Deficient or excessive rainfall inhibits development. In southern and southeastern Madagascar optimum rainfall persists for 5 consecutive months in the warm season, whereas rainfall in the north and western regions is favorable only at the beginning and end of the rainy season.

No location can be designated as a consecutive reproduction site. Population exchanges between northwestern and southwestern regions are infrequent. These exchanges are not indispensable for starting of a generalized invasion (Launois, 1977).

Tree Locusts - Anacridium sp.

Three species of Tree Locusts occur in Africa and the Middle East. The habitat and life cycles of each species are similar.

Habitat

Anacridium aegyptium occurs principally around the Mediterranean and in the Middle East. A. melandorhodon is found throughout the Sahel and in Ethiopia, Somalia, northern Kenya, Yemen and the Tihama of Saudi Arabia, generally in areas of short grass and scattered trees, principally Acacia sp. A. wernerellum is found mainly to the south of A. melanorhodon where there are more trees, but the two species overlap considerably.

Tree locusts are often mistaken for the Desert Locust as they look somewhat alike, but Tree Locusts live mainly outside of agricultural areas and so they seldom cause any major agricultural damage.

Life Cycle

The best studied species of Tree Locust is A. melanorhodon on which this life cycle is based.

Eggs are laid in mostly sandy, clay, or silt soils in June or July in the Sahel at the onset of the rains. There are about 150 eggs per pod. Hatching occurs in about 26-53 days (Popov and Ratcliffe, 1968).

There is normally only one generation per year, but if conditions are favorable, such as elongation of the rainy season, 2 successive generation are possible (Duranton, Launois et al, 1982).

The hoppers pass through 5-6 instars, rarely 7-8. The greater number is generally in the females. The number of instars is also influenced by phase, being greater in solitarious. Hopper development may be completed in 2 months in males but requires considerably longer in females (Popov and Ratcliffe, 1968). Soon after hatching the hoppers climb the nearest plant or tree. By day they spend nearly all their time inactive while feeding usually occurs at night. Gregarious hoppers congregrate in groups or small bands. Marching is rare, particularly in the daytime.

Adult Tree Locusts fly at night and roost in trees during the day. Swarms are low flying, stratiform. Swarms are generally small, rarely more than 1 m squared. Adults remain immature throughout the dry season. Until the onset of maturation with the start of the rainy season, swarms spend the day roosting on the topmost branches of the taller trees, feeding mainly at night or early morning.

Moroccan Locust - Dociosstaurus maroccanus

The Moroccan Locust for many years has been considered no more than a minor pest, but political problems in the Middle East leading to shifts in human populations from the agricultural sector are currently leading to renewal of its status as a serious pest. Skaf (FAO) reports severe infestations of this locust throughout Morocco and in Iran in 1987.

Habitat

The Moroccan Locust is found in semi-arid steppe and semi-arid desert with abundant spring grasses and sedges, particularly, Poa bulbosa. Its range includes Soviet Middle Asia, Afghanistan, Iran, Iraq, Syria, Turkey and westward along both sides of the Mediterranean to Morocco and the Canary Islands. Its distribution is discontinuous with many localized populations clearly isolated. Studies by Herton, 1959 in Cyprus and 1961 in Iran, Uvarov, 1932 in Turkey and Pasquier, 1934 in Algeria provide evidence that vegetative changes through the destruction of forests and loss of vegetation through

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overgrazing has provided additional habitat for this migratory pest.

Life Cycle

There is only one generation per year. It passes through approximately 9 months of the dry season in the egg stage (Launois, 1982). Oviposition takes place only in undisturbed, moderately compact and almost dry soil. Cultivated areas are unsuitable for oviposition (Dempster, 1957). Solitarious phase locusts lay about 20 eggs per pod and the gregarious phase 30 eggs per pod (Jannone, 1938). Solitarious phase females lay no more than 2 pods (Bodenheimer, 1944). Gregarious phase females may lay as many as 5 times (Dempster, 1957). Egg pods are grouped forming clusters of 5-6 pods with several such clusters per m squared.

The hoppers pass through 5 instars, taking 30-45 days from hatch to fledging. Gregarious hoppers march in bands which are only about 2 meters deep but may extend for several miles (COPR, 1982). Marching occurs only during the hot hours of the day, but bands marching in the afternoon may continue on into the night (La Baume, 1918).

Adult flight activity increases in length during the day as temperatures rise. Although the insects are unquestionably gregarious both morphometrically and behaviorally, this behavior has rarely been seen to result in migratory flight.

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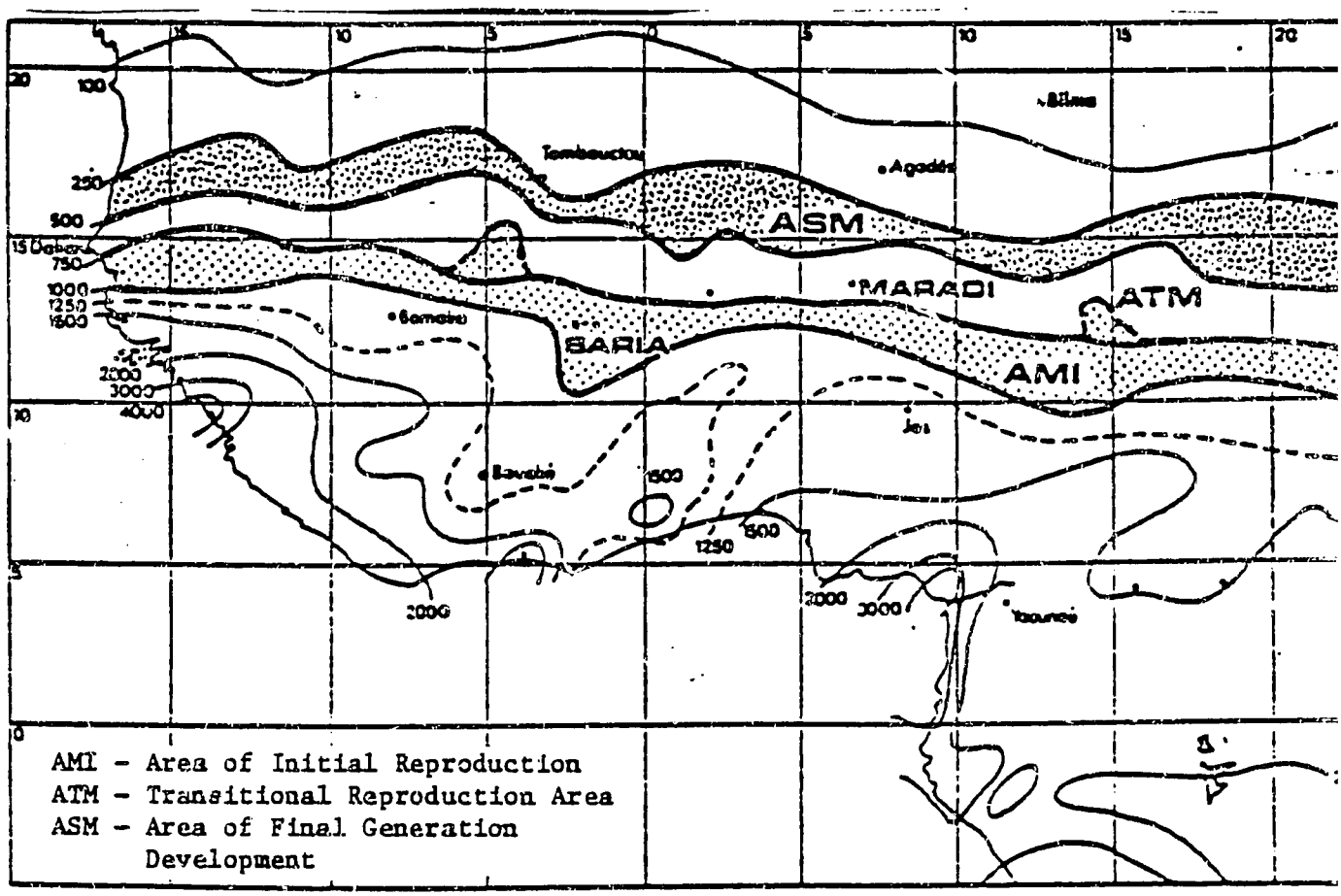
(ASM) in the northern part of the distribution area some 500 km southwards in the wake of the retreating intertropical convergence zone (ITCZ) depositing their eggs en route but principally in the southern area (AMI).



These eggs survive the dry season largely in a state of obligatory diapause lasting 5-6 months and hatch with the first rains. The resulting adults of GI leave the AMI zone, which progressively becomes humid, and emigrate following the advancing ITCZ to reach the intermediate ATM zone at roughly the time of the first rains. There they breed to produce the G2 generation which becomes mixed with the local GI. The resulting adult progeny of both then advances further north into ASM where the third generation, G3, is formed.

The adults of G3 appear towards the end of the rains when ASM begins to dry out and they soon begin to leave it, moving southwards in the wake of the retreating ITCZ.

Senegalese Grasshopper - Oedaleus senegalensis

The species manifests notable phase attributes but at a lower level of gregariousness than in true locust. At higher densities, nymphs may aggregate in groups when roosting and occasionally form marching hands. Adults form loose swarms which may fly by day, but more frequently by night (Riley and Reynolds, 1983).

Habitat

O. senegalensis affects all the Sahelian countries including the Cape Verde Islands, but also extends beyond them to parts of north Africa and southwest Asia (Batten, 1969). This area comprises the dry tropical belt south of the Sahara delimited approximately by 200-1,000 mm mean annual rainfall. In western Africa the distribution belt is relatively narrow. It occurs principally in open or lightly wooded savanna, steppe or ephermeral prairies with sandy soil. The tussock grass, Aristida pallida, is characteristic of the perennial and Cenchrus biflorus of the annual communities. (Popov, 1985). In eastern Africa the distribution belt widens southward to central Tanzania. It is not found in the Sahara. Outside Africa it occurs in southwest Asia with a mean annual rainfall between 150-800 mm.

Life Cycle

Laying takes place preferentially in moist sandy soil. Eggs are very resistant to dry conditions. In the Sahel, eggs laid during the earlier part of the rainy season until about mid-August to early September develop directly without interruption unless dry conditions occur, upon which they may enter a state of quiescence. Development is resumed if the eggs receive moisture.

Eggs laid after late August to early September enter a state of obligatory diapause. This is controlled photo-periodically. This diapause condition extends throughout the dry season and may continue for even 2 or more years if adequate moisture is not received.

Launois' biomodel of O. senegalenis divides the area of anticipated infestation into 3 units. The biomodel, while recognizing that variation does occur from year to year, projects that some diapausing eggs will be laid at the northern terminus of the ITCZ, an area of 200-500 mm rainfall annually, somewhat more in the 500-750 mm annual rainfall zone; but in total these should not exceed 25% of the diapausing eggs. The remaining 75% are projected to be laid in the 750-1,000 mm annual rainfall zone.

Generalized hatching occurs in May - July, 8-15 days following 25 mm or more of rainfall. In areas of lighter rain

hatching is partial and many eggs remain in a state of quiescence. These residual eggs complete their development and hatch following subsequent rains.

In the Sahel hopper development through 5 nymphal instars is completed in 17-20 days. The interval between hatch and first laying is about 35 days.

According to the Launois biomodel the resulting adults leave the AMI zone and emigrate following the advancing ITCZ to reach the intermediate ATM zone at roughly the time of the first rains within that zone. There they breed and produce the second or G2 generation. The G2 generation becomes mixed with the local G1. The adult progeny of both advance further north into the ASM where the third generation, G3 develops. The adults of G3 appear towards the end of the rains and when the ASM begins to dry out they begin to move south in the wake of the retreating ITCZ. A late retreat of the ITCZ with prolonged stagnation in the latitudes of ATM is likely to lead to an accumulation of G3 adults where a majority will lay and die with few surviving to reach AMI by the time the ITCZ resumes its southward retreat. Prolonged stagnations and oscillations of the ITCZ in northern latitudes may result in scattering, mortality of adults and laying under adverse conditions in ASM, ultimately leading to a decline in grasshopper numbers (Duranton, Launois et al, 1982).

Sudan Plague Locust - *Aiolopus simulator*

Habitat

Aiolopus simulator occurs throughout the Sahelian belt eastward to the Sudan, Egypt and to southwest Asia, where it extends north to Turkestan and east to Bangladesh. It is associated with black cracking hydromorphic clay soils which are found mainly in the major flood basins, the Senegal, Niger and Nile Rivers and Lake Chad basin.

Life Cycle

Breeding begins soon after the start of the rains. The egg incubation period lasts 18-28 days.

There are 5 nymphal instars. The duration from hatch and adult varies between 18-28 days.

There are generally 2 generations per year. First generation adults migrate north following the northward advance of the ITCZ. The second generation is produced in the northern area. These return south with the retreating ITCZ. Migrating adults fly individually or in thin scattered groups or swarms up to heights of 1500 meters. Like most grasshoppers flight is at night.

Adults of the second generation overwinter the dry season hidden deeply in the cracks in the soil. With rising temperatures and humidity, as a forerunner to the rainy season, they begin to emerge but return to the soil cracks during the heat of the day, re-emerging as temperatures decline in the afternoon (Popov, 1985).

Populations are generally greater in the Nile valley than in the Chad, Niger and Senegal basins. Popov speculates that this is because of the north-south orientation of the Nile valley, whereas the other basins are more limited in extent and do not have the appropriate north-south orientation. Thus, mortality occurs during migration when the adult grasshoppers fail to encounter suitable shelter and breeding habitats.

Variegated Grasshopper - Zonocerus variegatus

Habitat

This grasshopper is distributed throughout west Africa south of the Sahara, spreading eastwards as far as Uganda and northwards into Sudan. It occurs in many parts of the forest zone, but always in clearings and in cultivated, deforested areas. It penetrates the savanna principally along the drainage systems (Popov, 1985).

Life Cycle

Z. variegatus can be found throughout the year. There are two populations, the wet season and the dry season populations. The dry season population is by far the largest and most important. The wet season population, occuring between April-October is generally small and of no economic importance.

Egg laying of the dry season population takes place from mid-March until the end of April or early May. Egg laying occurs is groups of several hundred to several thousand pods. There is an average of 50-60 eggs per pod. Embryonic development, which includes diapause takes 6-7 months. Eggs hatch in October-November (Page, 1978).

There are generally 6 nymphal instars, though in a few cases only 5. Following hatching the young nymphs remain together and often form dense, rather ostentatious clusters. This behavior is probably because the repugnatorial effect is intensified en masse of an unpleasant smelling liquid produced in a gland on the back of the first abdominal segment. During the early instars the nymphs remain in the original habitat, but the older nymphs ar much more mobile (Popov, 1985). They are capable of short migrations of up to about 500 m total.

Adults, appearing in early February are dimorphic for

wing length. The long wing forms are capable of short flight in excess of 100 meters. Adult females can lay up to 3 egg pods, but normally there are only 2. (Page, 1978).

Z. variegatus feeds on a wide variety of plants, showing preference to various annual herbs and flowers and tender terminal shoots of citrus and coffee. Lesser food plants include cassava, banana and cotton.

APPENDIX 8. REMOTE SENSING

The overall advantages of using remote sensing are many:

- being able to see in one view a significant part of an environment, what is in that environment and where entities are in relation to each other,
- using the unique spectral or digital operating characteristics of a remote sensing system to learn something about objects in the environment by seeing them in a way in which they cannot ordinarily be seen,
- imaging or photographing observed features at different times in order to see change and monitor events.
- and saving time and money by exploiting these uses.

There are many types of sensors used in a wide range of remote sensing applications. The most frequently mentioned of the sensors used for resource analysis are cameras, multispectral scanners, thermal sensors, microwave sensors and radar. So far, digital multispectral scanners in the visible to infrared bands, and to some extent, aerial cameras, have been the sensors used the most for early warning projects.

The aerial camera is an analog sensor that, in a continuous mode, records what it senses in the environment. Once the shutter on the camera is operated, the light energy (and the scene) is instantaneously captured on the film and eventually processed as a photograph.

Digital scanner imagery, on the other hand, does not result from light being directly focused through a lens onto a film, but instead is the result of energy that is sensed and converted to an electronic signal before being revealed as a photographic-like image comprised of thousands of discrete (digital) picture elements (pixels). This digital image technology has ushered in new dimensions in using remote sensing for research, resource analysis and early warning.

Meteosat, the NOAA satellites, Landsat and SPOT all use this digital technology. The radiometers they carry sense reflected or emitted electromagnetic radiation and produce a photographic-like image by generating a number of rows of scan lines, each of the scan lines being made up of the many picture elements (pixels) that represent the scanner's instantaneous field of view (IFOV), or the minimum unit of area that the scanner can sense (Figure 1). This characteristic of the scanner defines its areal resolution.

These scanners each usually sense in a number of different "bands" of the electromagnetic spectrum, that we know as the various colors of visible light, reflected (near) infrared radiation, middle infrared and emitted (thermal) infrared radiation. Each of these spectral bands provide a

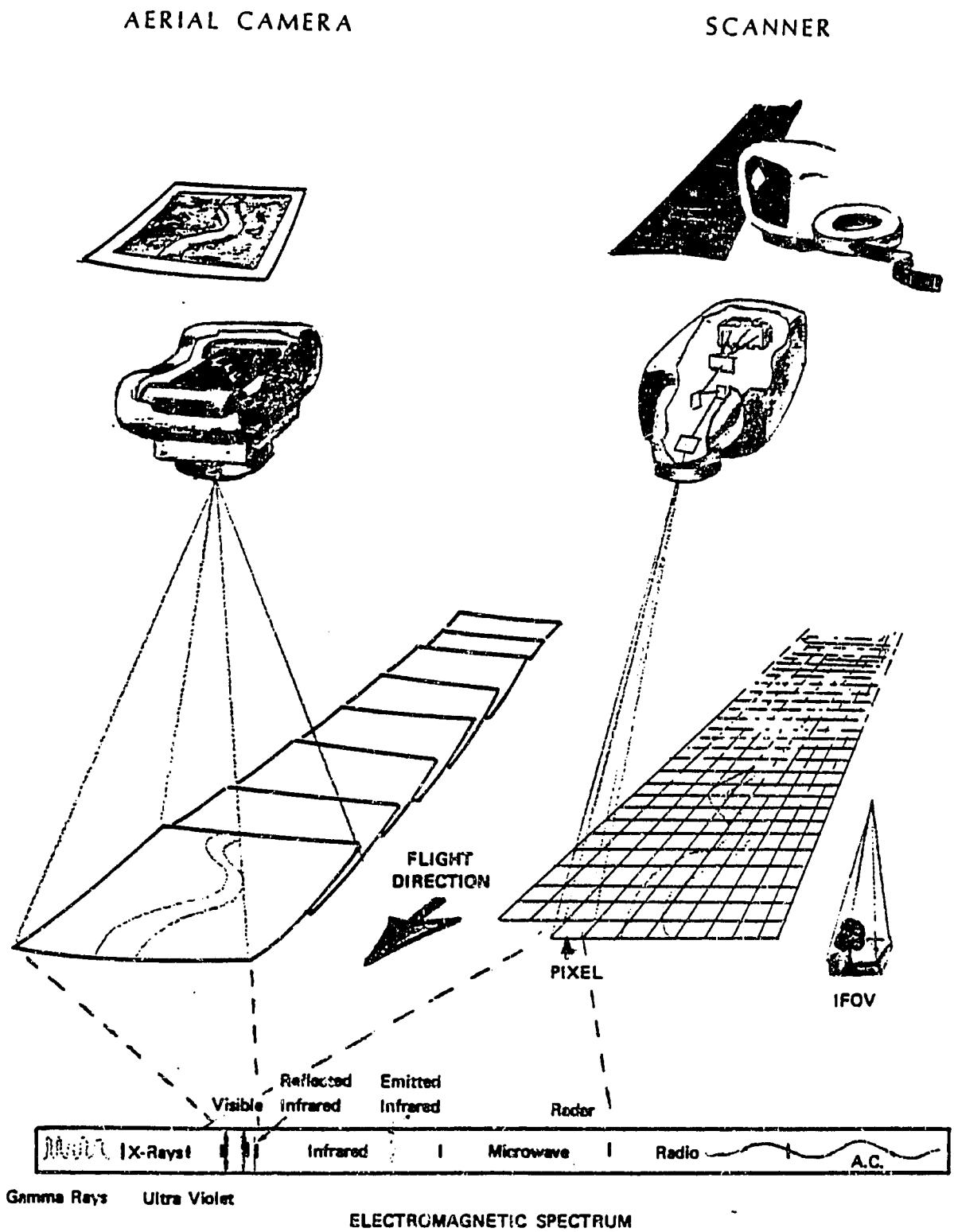


Figure 1. Cameras and Scanners. The photographic camera instantaneously captures a whole scene in one contiguous unit, the digital scanner captures a scene by recording it in a series of discrete digital units. Digital scanner information can be recorded on computer compatible tapes, shown on computer screens, prepared as images or presented as quantitative data.

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unique view of the environment depending on how the EM energy in any specific wavelength in which the sensor operates interacts with different kinds of matter and is eventually recorded by the sensor. The degree of brightness of each pixel in each of the individual bands corresponds to the amount of energy returned to the sensor from a particular environmental entity -- dark pixels meaning little energy is received, bright pixels meaning significant energy is received. These gradations of darkness or brightness from black to white and the shades of gray between them correspond to a range of discrete digital values. The greater the number of gradations between black and white in each band, the greater a sensor's ability to discriminate objects in the environment. This is the sensors radiometric resolution. Although most people see the color product, the images can be viewed in black and white tones for the individual bands, then the bands can be combined photographically or digitally on image analysis systems to make a color image (Figure 2). When a digital analysis of a color image is done, it is actually an analysis of each respective band making up that color scene. The more different bands a scanner has, the greater its spectral resolution. Being able to see how objects appear in each respective band and in a color image as well increases a user's capability to do environmental interpretation. It is this multispectral representation of information that alows the visual and digital analysis necessary for estimating vegetation biomass, rainfall and other environmental factors affecting acridid development.

The field of view of the sensor and the altitude and orbital path of the satellite determines how often a sensor views a particular location - the temporal resolution of the system. For the four satellites that have been used most for early warning, this frequency of observation of a location ranges from 30 minutes to 26 days.

Among the other advantages of digital sensors are their capabilities to

- add consistency to remote sensing data collection and interpretation
- store and quantify information
- enhance objects in a scene
- identify landscape and land use elements shown on an image and record the areas of identified elements
- correct for distortions in scenes caused by atmospheric conditions and sensor or vehicle movements
- fit the image projection to different map projections
- provide change detection information by digitally comparing images of the same locale taken at different times and generating a third image that shows where changes have taken place.

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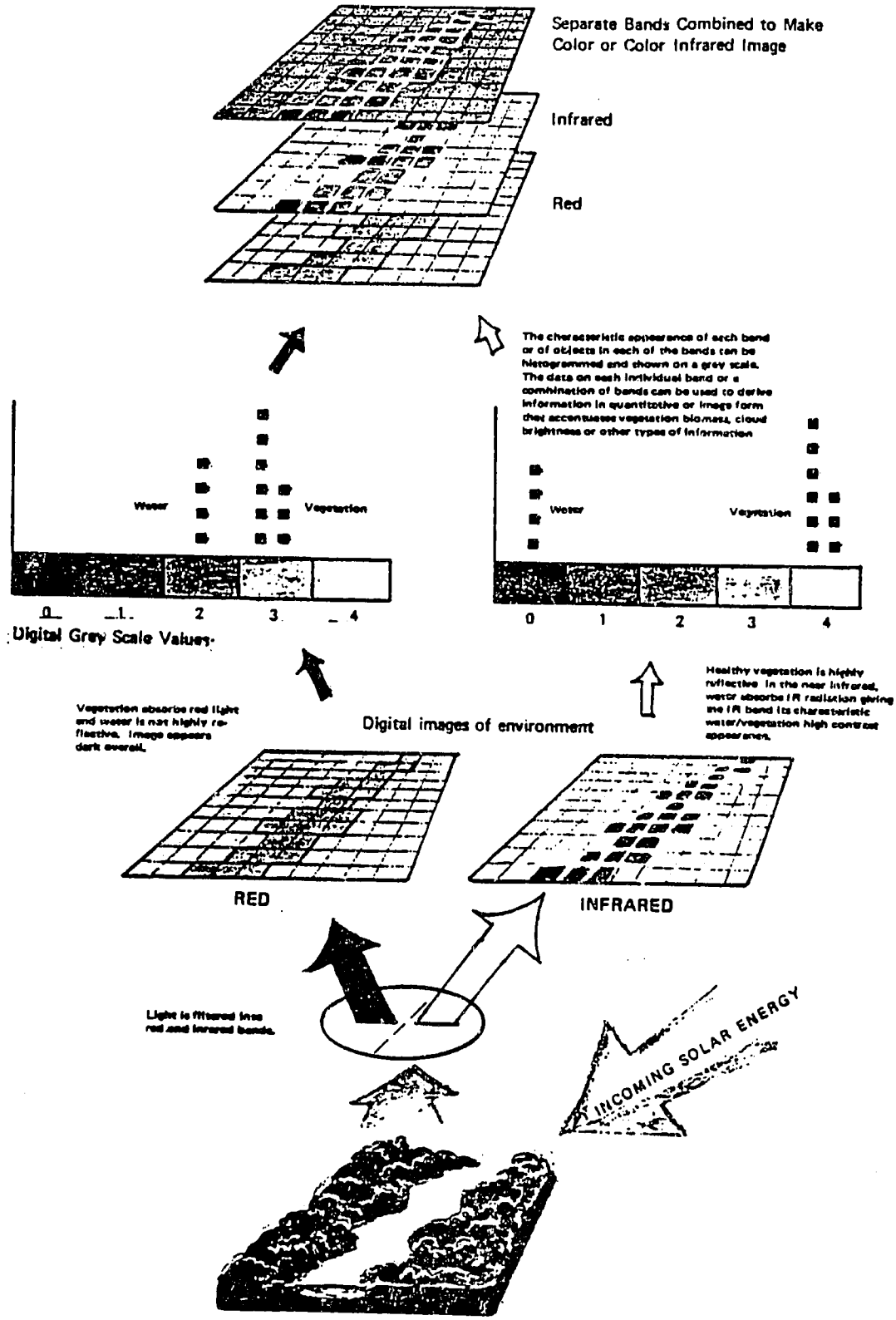

Figure 2. Multispectral digital images are composed of several bands of spectral information. Light reflected from vegetation and water is filtered into red and infrared bands that each depict the same environment in different tones. Each of these bands, by their digital nature, is quantified and information can be gained from each band itself or by combining the data from several bands.

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Digital information can be telemetered from satellites or aircraft to ground receiving stations, and relayed from one station to another via satellite or ground communication lines. This has enabled researchers at properly equipped locations to quickly gather and analyze world-wide satellite acquired data. As more receiving stations are established this capability will be more widely expanded.

After data reception from the satellites, initial data tape and image processing is done by larger computers, as are some of the more complex digital analysis programs. Images or parts of images are now being put on diskettes for use in microcomputer systems that can be installed in more dispersed field locations.

Table 1 summarizes some important features of the four satellite systems that are described below in this report.

METEOSAT - A GEOSTATIONARY SATELLITE

Meteosat II is a geostationary orbiting satellite that maintains its position 35,800 kilometers over a point south of the Bight of Benin, Africa. It imagery provides a full hemisphere view of Africa, Europe, the Arabian Peninsula and part of northeastern South America as often as every 30 minutes.

Meteosat's three channel radiometer (one visible and two infrared) provide continuous 24 hour monitoring of sea surface temperatures, cloud movement and atmospheric water vapor content. By being able to monitor the dynamics of the sea surface temperature and atmospheric phenomena, valuable information is gained that is used for estimating the rainfall amounts and determining wind field patterns that are important in locust forecasting. These satellites are also used as data and communications relay satellites.

Six basic climatological parameters are derived from the ground processing of Meteosat digital information:

- cloud wind vectors
- sea and cloud surface temperatures
- cloud top height maps
- cloud distribution maps
- maps of the distribution of water vapor in the upper troposphere
- a basic climatological data set.

These products are used to

- Determine cloud top temperatures as a means of estimating rainfall. Assessments are done several times a day over a period of ten or more days. Daily estimates of precipitation based on cloud top temperatures can be made, but with less accuracy.
- Monitor cloud masses and squall lines. Cloud masses movements in squall lines are easy to follow. Weather centers can make a daily information update by plotting actual rainfall into the satellite images.

	Meteosat	NOAA	Landsat	SPOT
Altitude (km)	36,000	833-879	704	832
Orbit	geosynchronous	polar, sun synchronous	polar, sun synchronous	polar, sun synchronous
Overpass time	(continuous observation)	daily, once by day, once by night	every 16 days, in morning, every 9 days when 2 satellites are up	every 26 days, in the morning, with "revisit" capability upon demand of at least twice a week
Swath width (km)	hemispheric	2700-3000	185	60-117
Single-frame coverage (sq. km.)	hemispheric	2,000,000	34,000	3,600
Time for global coverage	48 times/day information transmission possible	24 hrs	16 days	26 days
Sensor/ Spectral resolution	high-resolution radiometer sensing in 3 spectral channels: visible, water vapor absorption, thermal infrared	3 sensors: advanced very high resolution radiometer (AVHRR), visible, infrared and 3 thermal bands . TIROS operation vertical sounder (TOVS), a 3-sensor atmospheric sounding system, sensing invisible to microwave bands, and a space environmental monitor (SEM) that measures solar particle flux.	2 scanners: MSS imaging in 4 spectral bands: blue, green, red, near infrared; TM in 7 spectral bands: 3 visible, 2 near infrared 1 thermal	2 high-resolution visible scanners (HRV). Multispectral mode in green, red and near infrared bands, panchromatic broad green to red band.
Areal resolution	visible channel 2.5-5 km, water vapor absorption channel 5 km, thermal infrared channel 5 km	GAC global area coverage 4 km, LAC local area coverage 1.1 km	multispectral scanner (MSS) 80 m, thematic mapper (TM) 30 m, thermal infrared channel 120 m	multispectral mode 20 m, panchromatic mode 10 m
Radiometric resolution (quantizing levels)	256	1024	MSS=64-128 TM=256	256

Table 1. Operating Characteristics of Principal Satellites

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o Determine wind fields by analyzing time series images of cloud movement at various altitudes and combining the remotely sensed data with atmospheric pressures derived for selected altitudes.

Meteosat information is received by two kinds of data reception stations: Primary Data User Stations (PDUS) that receive the sensed information in digital form, and Secondary Data User Stations (SDUS), less expensive and simpler, that receive imagery and meteorological charts in an analog (continuous, non-digital) format. The principal difference between PDUS and SDUS in terms of product use is that PDUS information can be digitally processed in its original format for complex analysis purposes, or for the processing of imagery and tapes, whereas the SDUS products, transformed into the analog signal, simply present a facimile picture, display screen image or map of a situation as it was when it was originally derived from the digital information (Figure 3). The display screen data can be redigitized though not in the original digital format. The analog transmission does play an important role in quickly providing information to users who do not have digital processing facilities.

POLAR ORBITING SATELLITES

The TIROS-NOAA satellites, along with Landsat and SPOT, are near-polar orbiting sun-synchronous satellites. These satellites orbit at lower altitudes than do the geostationary satellites and continually image the area below them at the same time of day as they move along their flight paths. In general, these lower flight altitudes allow greater sensor resolution and the sun-synchronous aspect, providing a nearly constant sun angle view of the Earth from image to image, provides uniformity of sensed information. Depending on sensor scan width, full earth coverage can be obtained in one 24-hour period, or can take 26 days.

NOAA 9 AND 10

The NOAA 9 and 10 weather satellites themselves each orbit the Earth at 833 to 870 kilometers providing daily coverage of the Earth's surface. NOAA's timely, moderate-resolution imaging is good for low-cost (US$ 0.05/1000 km sq), multipurpose environmental monitoring over large areas. Its advanced very high resolution radiometer (AVHRR), through its earth and sea surface and cloud mapping funcitons, and the TIROS operation vertical sounder, through its atmospheric sensing functions, provide earth and atmospheric data important to locust forecasting and early warning activites. Its AVHRR sensor with its 2700 kilometer wide swath width is used to produce the vegetation greenness maps used to determine vegetation state in potential locust breeding sites and to image cloud patterns indicative of potential rainfall.

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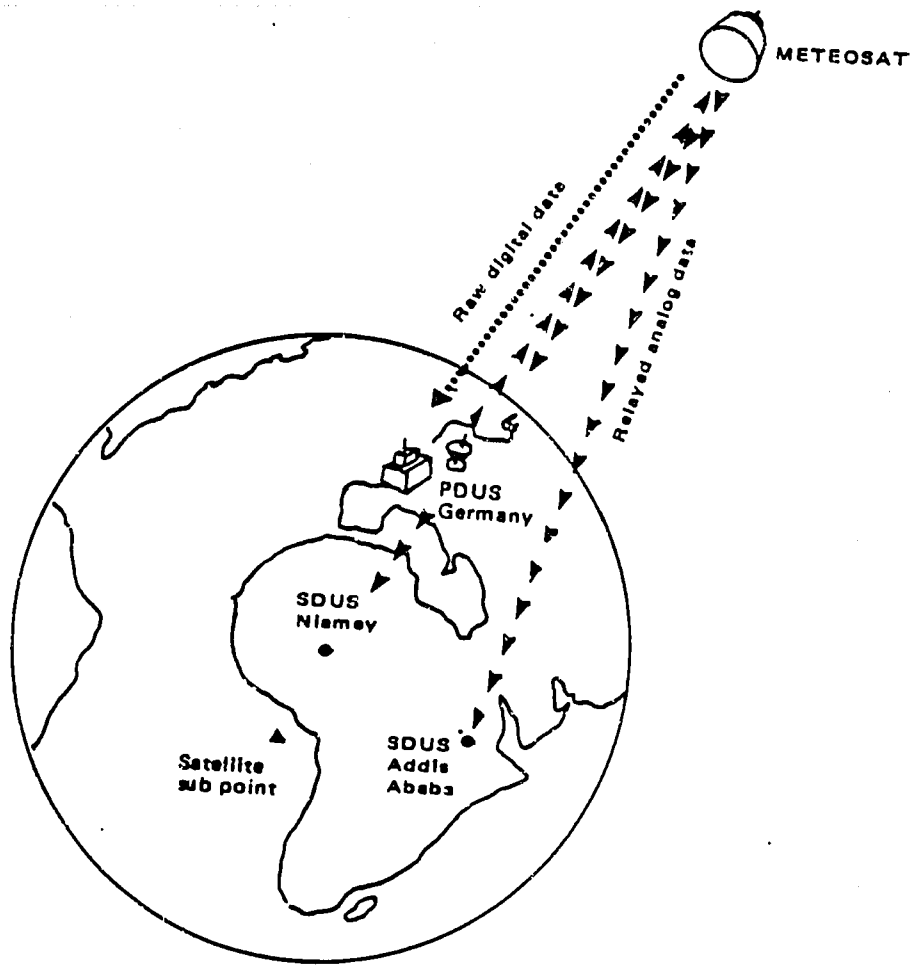

Figure 3.

Meteosat satellite continuously sends "raw" image data to a Primary Data User Station (PDUS). Imagery in three spectral bands can be produced every 30 minutes. Initial data group is formatted, often combined with other data, then, in some cases, relayed to SDUS stations like AGRHYMET in Niamey, or the International Livestock Centre for Africa (ILCA) in Addis Ababa in analog form.

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The AVHRR has a resolution of 1.1 km [Local Area Coverage (LAC)] and 4 km resolution [Global Area Coverage (GAC)]. The LAC data are telemetered to receiving stations as the satellite overflies them. When not in range of a receiving station, LAC data are stored on board the satellite for later data drops to a receiving station. Because there is so much LAC data and storage space on the recorders is limited, only ten minutes of LAC data are available on each of the satellite passes that occur out of station range. To obtain global coverage on a continual basis, the LAC data and "sampled down", (fewer of the pixels are recorded) to 4 km resolution so that the data can be stored on board and the global area coverage can be achieved.

Imagery at a scale of 1:1,000,000 (1 cm = 10 km) can be prepared from LAC data, and this is a convenient scale for comparing the imaged terrain and vegetation features with aeronautical charts and other country wide scale base maps. LAC data, however, is competed for by many users, and may not always be available to a bidder.

GAC data is readily available to users and is used for country wide as well as regional coverage. It is sometimes further sampled down to produce 7.9 km data for country or regional scales. The EROS Data Center pilot program used 1 km data for its maps, ARTEMIS proposes to use both 1 and 4 km data.

AVHRR channels sensing in the visible (green to red) and in the near infrared spectral regions are used to produce vegetation biomass index maps that show the state of vegetation, which is an indicator of rainfall, soil moisture and locust food source and cover in the region being mapped. The vegetation index (VI) maps are produced by subtracting the visible band digital values from the infrared digital values to get a better indication of biomass. A normalized vegetation index (NVI), [(Ch2 - Ch1)/(Ch2 + Ch1)], is used for observing vegetation biomass on a global scale. The NVI compensates for changing illumination conditions, surface slope and sensor viewing aspect. NVI is expressed as a ratio.

The vegetation index maps produced to date are actually derived from a series of images obtained over seven to fourteen day periods. Ten-day composites are often used because they correspond to ten-day (decadal) data analysis cycles used for weather assessment purposes. A vegetation index can be derived from a single day's imagery, however, on any given day, a location that is imaged may be obscured by clouds or have ground or atmospheric conditions or sensor "look angles" that would prevent the best biomass data from being obtained. Consequently, a series of images is analyzed over, for example, a ten-day period and the pixels with the highest VI (greenest vegetation) for each scene are used to make a ten-day composite image. Changes in vegetation biomass are detected by comparing these composites over time. Researchers at GIMMS further process the VI data to derive a "locust potential breeding activity factor" (PBAF) map - a ranking of different levels of

greeness with respect to their potential for locust development. High-value areas are conducive to breeding and gregarization and should be checked by ground survey teams.

The vegetation maps are shipped to the field via courier or some other rapid means. If they cannot be sent fast enough, important information such as locations of significant vegetation changes or suspected locust breeding areas is telexed to users. Theoretically, field officers can have the information within two and one half to three weeks of analysis of the first of the 10 or 14 day images. When information is needed urgently, and if observation conditions are good for the area in question, one day's image or a series of two or three might serve and be much more timely.

NOAA also provides high-resolution rainfall estimation data on a twice-daily (nighttime/daytime) basis. It also plays a part in monitoring thermal fronts by determining temperature gradients from ground surface radiation data obtained over several day periods. NOAA information is used in conjunction with Meteosat data in some climate assessment programs.

NOAA digital data is telemetered from the satellite to high resolution picture transmission (HRPT) stations in Alaska and Virginia, then sent to the National Environmental Satellite Service in Maryland for processing and archiving. There are also data receiving and processing stations in Lannion, France and analog data is sent to automatic picture transmission (APT) stations in Niamey, Niger and various locations around the world (Figure 4). The analog Meteosat SDUS and NOAA APT data can be received by the same stations, but the digital data reception capabilities are not interchangeable. HRPT receiving stations are planned for the FAO's Remote Sensing Center in Rome, for DLCOKA in Nairobi, Kenya and AGRHYMET in Niamey. Special data processing is done at Goddard Space Flight Center and other institutions with the appropriate equipment.

LANDSAT AND SPOT SATELLITES

Landsat and SPOT produce land cover and land use imagery with higher spatial resolution than Meteosat and NOAA satellites. However, their coverage is of smaller areas at less frequent intervals, and their products are relatively expensive. Costs for imaging 1000 sq km are US$ 44-129 for Landsat 5 and $400-1100 for SPOT, depending on the sensors used (USAID, 1986a).

Landsat's 80 meter resolution multispectral scanner (MSS) imagery is good for providing more detailed information in support of AVHRR imagery, where necessary. The early development of vegetation biomass imaging for the Desert Locust control program was done using Landsat visible red and near infrared spectral bands. The thematic mappers (TM) 30

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meter resolution increases Landsat's areal and spectral resolution capabilities. A TM image is about four times as expensive to produce as an MSS image.

Landsat data is telemetered directly to a number of receiving stations when the satellite is within a radius of 3000 km of them. Figure 5 is a map of the ground receiving stations as of Spring 1987, showing that parts of Africa are not covered by direct reception capability. Imagery of areas not within range of a ground receiving station is telemetered to the EOSAT receiving station in the U.S. via a Tracking and Data Relay Satellite (TDRSS).

SPOT has a 26 day return cycle, but can, upon command, point its scanner mirrors east and west of its flight track and "revisit" a flight line at least twice a week. This scanner tilting capability also allows SPOT to acquire imagery that can be stereoscopically viewed and used for topographic mapping. SPOT's radiometer produces 20 meter resolution color imagery and 10 meter resolution black and white (panchromatic) imagery.

SPOT telemeters its data to 6 different receiving stations around the world. When not in range of a station, it stores data on board until it arrives over one. Figure 6 shows the current and planned SPOT receiving station network. SPOT data is put on computer compatible tapes or photographic products.

GEOGRAPHIC INFORMATION SYSTEMS

More and more the maps and descriptive information used to support remote sensing are being put into data management systems called geographic information systems (GIS). GIS's combine data management with computer mapping. Computer mapping is digital mapping, entering discrete units of information that cause a pen, printer or digital display unit to mark points, lines and polygons that show the location or shapes of entities depicted on a map. These points (e.g. the location of a small village), lines (e.g. a road), and ploygons (e.g. a soils map unit), are defined by one or more pairs of coordinates, keyed to a specific mapping or plotting system. Whatever information is used to discribe each of the map units is also stored in the GIS so that it can be easily recalled, and specific units of interest (good habitat for locust development, for example) can be selected from the larger set of information describing a whole region.

Once all of the information has been entered into the program and sorted in the computer, the maps can be quickly recreated, modified, updated, the scale changed or other operations performed. Soils maps can be "merged" with vegetation maps, and in the case of locust early warning, these types of information can be digitally merged with the satellite imagery.

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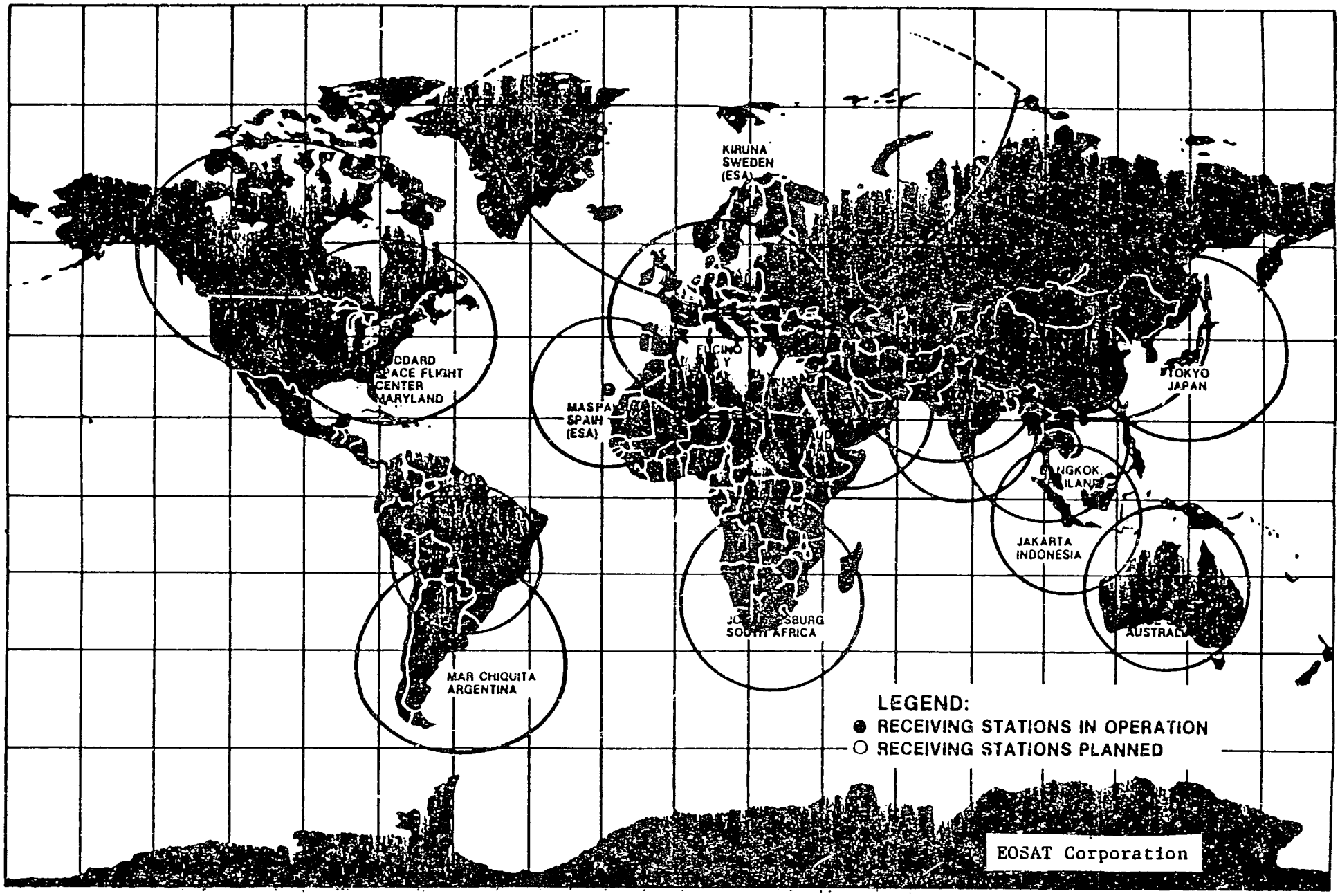
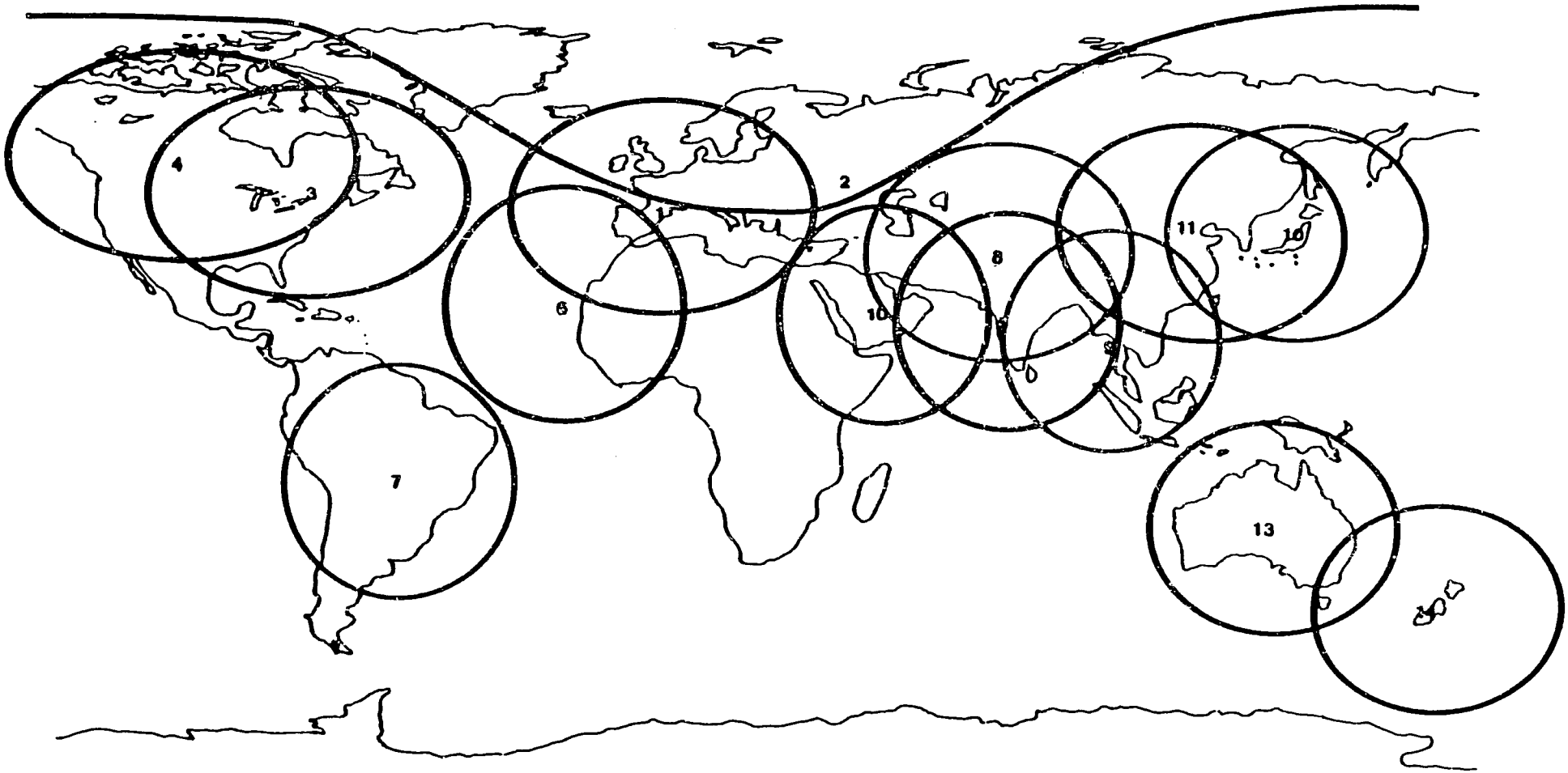


Figure 5. Landsat Receiving Stations



Stations Currently Operational
1 Toulouse, France
2 Kiruna, Sweden
3 Gatineau, Canada
4 Prince Albert, Canada
5 Hyderabad, India
6 Maspalomas, Canary Islands

Under Construction
7 Cuiaba, Brazil
8 Islamabad, Pakistan
9 Bangkok, Thailand
10 Hatoyama, Japan

Under Negotiation
11 Beijing, China
12 Riyadh, Saudi Arabia
13 Alice Springs, Australia
14 Auckland, New Zealand

Figure 6. SPOT Receiving Stations

As stated in section D.1.1.2.1. many remote sensing and GIS systems can be used in conjunction with each other in order to take advantage of each system's particular operational advantages.

FAO ARTEMIS PRODUCTS

The FAO's ARTEMIS system proposes to use the following remote sensing products in supporting its centralized Reporting and Forecasting Service of the International Desert Locust Plague prevention programme.

- Meteosat/Insat imagery for the recession area for general precipitation monitoring (early warning)

  -seasonal periods: May-October: summer breeding area. October-May: winter/spring breeding area 2 x daily: 1200 and 1800 GMT visible/thermal infrared scale 1:12,000,000 annotated coordinate references and country boundaries

  -maximum delay: 2-3 days

- NOAA/AVHRR vegetation index imagery:

  -seasonal periods: May-October summer breeding area
  October-May: winter/spring breeding areas

  -spatial resolution: 4 km (GAC data) for general monitoring of entire recession area
  1 km Large area coverage (LAC) data for specific high frequency breeding areas during key periods in the season

  -temporal resolution: 10-day composites of 4 km (GAC) VI data, complemented with incidental 1 km (LAC) coverage

  -formats: scale 1:10 000 000 (FAO HQ centralized assessments)
  1:5 000 000 (regional assessments)
  annotated coordinate references, country boundaries and seasonal breeding areas

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-maximum delay:	10 days
-data base development:	systematic processing of historical Locust/ecological records using Landsat and/or NOAA imagery for establishing baseline data.

RECOMMENDATIONS FOR PILOT MAPPING FOR GRASSHOPPER PROJECT - AFRICA BUREAU/USGS EROS DATA CENTER

The following are the recommendations listed in the executive summary of the evaluation of the Africa Bureau Pilot Testing of AVHRR Greenness Mapping for Grasshopper Control Programs in Senegal, Mauritania, Burkina Faso, Chad and Niger. The final report is in preparation.

- The consensus is that the greenness mapping programs should continue in the five countries involved in the Pilot Project. A number of users recommended that this activity should be expanded to include all of the Sahelian countries.
- The map delivery time should be shortened to a week or less following the production of each map cycle. Several options for accomplishing this need investigation.
- Minor deficiencies in map content should be remedied, including the addition of more locational information. Expansion of the greenness scale should be considered.
- The maps should be integrated with other resource data information, using geographic information system technologies.
- Host government agencies should be approached and defined for coordination of continued greenness mapping activities.
- Future project plans should be integrated with plans for NRMS, FEWS, and AGRHYMET.
- Follow-on activities should work toward technology transfer, providing continued in country technical advice during critical seasons, and in-country satellite data reception for improved data dissemination.
- Documentation of cost-savings as a result of decisions based upon greenness maps should be a major objective of follow-on activities.

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APPENDIX 9.
NATURAL ENEMIES OF LOCUSTS AND GRASSHOPPERS

Tables 1-3 give detailed information on insect predators, insect parasites, pathogens and bird predators of the grasshopper and locust pests covered in this Environmental Assessment. Citations refer to the bibliography found at the end of Appendix 9 and are given so that readers can go to the literature for more details.

Table 1. Predators, Prasites, and Antagonists of Grasshoppers and Locusts.

Predator/parasite/antagonist species	Life stage attacked	Location & citation
Desert Locust, Schistocerca gregaria, (Forskal)		
Orthoptera: Tettigoniidae		
Saga ephippigera F.-W.	Nym.	Palestine 36
Tettigonia viridissima (L.)	Nym.	Morocco 97
Mantidae		
Sphodromantis viridis (Forskal)	Nym.	Morocco 97
Diptera: Nemestrinidae		
Symmictus costatus Loew	Nym.	Ethiopia, Kenya, Sudan 126
Asilidae		
Scylaticus sp.	Egg	Ethiopia 354, Kenya, Somali R. (S. Region) A.L.R.C. 280
Stenopogon sp.	Egg	Somali R. (S. Region) A.L.E.C. Col. 280
Trichardis sp.	Egg	Ethiopia (Eritrea) A.L.R.C. Col. 354
Apoclea nr. femoralis Wied.	Egg	Pakistan 280
Machimus sp.	Egg	Morocco 282
Philodecus sp.	Egg	Pakistan 280
Bombyliidae		
Callostoma desertorum Macq.	Egg	Jordan, Palestine, Lebanon, Syria 8
Cytherea transcaspica Becker	Egg	U.S.S.R. (Turkestan) 391, 392
** Lomatia hamifera Becker	Egg	Morocco 282
Systoechus aurifacies Greathead	Egg	Ethiopia (Eritrea) 123
S. somali Oldroyd	Egg	Ethiopia (Ogadon) 6, Kenya, Somali R. (S. Region) 125, 153, Somali R. (N. Region) A.L.R.C. Col.
** Thyridanthrax circe (Klug)	Egg	Egypt 13
** T. griseola (Klug)	Egg	Egypt 13
** T. incana (Klug)	Egg	Egypt 13
** T. stigmulus (Klug)	Egg	Egypt 13
Dolichopodidae		
Sciopus euzonus (Loew)	Egg	Algeria (174)

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Predator/parasite/antagonist species	Life stage attacked	Location & citation
Conopidae		
** Myopa picta Panzer	Egg	Morocco (282)
Drosophilidae		
Cyrtonotum cuthbertsone	Egg	Ethiopia (Eritrea, Ogaden) Kenya 124, Mali A.L.R.C. Col.
Ephydridae		
Acocetor margaritatus (Wied.)	Egg	Ethiopia (Eritrea) 354
Calliphoridae		
Agria affinis	Nym.	Algeria 174
Blaesoxipha spp.	Nym.	Ethiopia (Eritrea, Ogaden), Somali R. (S. Region) 129
B. filipjevi	Nym.	Aden (W.Prot.) 272, Persia B.M. Col., U.S.S.R. (C. Asia, Transcaucasia) 268, Ethiopia (Eritrea) 353, Tanganyika 302
B. laticornis (Meigen) syn gryllocotona Loew	Nym.	U.S.S.R. (C. Asia) 303, (Transcaucasia) 268
B. lineata (Fallen)	Nym.	U.S.S.R. (C. Asia, Transcaucasia) 268, Algeria 174, Somali R. (N. Region) 129, Sudan 388
B. monticola Rohd.	Nym.	U.S.S.R. (C. Asia, Trancaucasia) 268, (Uzbekistan) 303, 359
B. subcochlearis Seguy	Nym.	Algeria 326
** Sarcophaga nodosa Engel	Nym.	Kenya B.M. Col.
Sarcophaga X 1	Nym.	Algeria 326
Sarcophaga X 3	Nym.	Algeria 326
** Wohlfahrtia bella Macq.	Nym.	Algeria 84
** W. (Disjuncto) balassogloi (Porch.)	Nym.	U.S.S.R. (C. Asia, Turkmenistan) 303, (C. Asia, Transcaucasia) 263, (Uzbekistan) 359
** W. euvittata Villen.	Nym.	S.W. Africa 103, 105
** W. nuba (Wied.)	Nym.	Pakistan 280
** W. trina (Wied.)	Nym.	Jordan B.M. Col., India 280, U.S.S.R. (Turkmenistan) 268

Predator/parasite/antagonist species	Life stage attacked	Location & citation
Dolichotachina nigeriensis Zumpt	Nym.	Ethiopia (Eritrea, Ogaden) A.L.R.C. Col.
Oophagomyia plotnikovi Rohd.	Nym.	U.S.S.R. (C. Asia, Transcaucasia) 268, (Turkmenistan) 303, (Turkestan) 391
Paraphylloteles hessei (Meigen)	Nym.	Ethiopia (Eritrea) A.L.R.C. Col.
Senotainia sp.	Nym.	Kenya, Ethiopia (Eritrea) 354, Senegal 293
Stomorhina lunata (F.)	Nym.	Palestine 33, 34, 36, Turkey 8, 357, U.S.S.R. (C. Asia) 303, (C. Asia, Transcaucasia) 268, (Turkmenistan) 391, Algeria 3, 72, 84, 174, Egypt 13, 97, Ethiopia (Eritrea) 6, 18, 128, 161, 162, 354, (Ogaden) 6, 128, Kenya 128, 381, Morocco 282, Somali R. 128, Sudan 169, Tanganyika 294, 381
Wohlfahrtia erythrocera	Nym.	Ethiopia (Eritrea) 354
Tachinidae		
** *Gymnosoma rotundatum* (L.)	Nym.	n.c. 122
Muscidae		
Hylemia cilicrura Rond.	Egg	Algeria 3, 72, 174, 84, Morocco 282, Tripolitania, B.M. Col.
Hymenoptera: Scelionidae		
Scelio sudanensis Ferriere	Egg	Ethiopia (Eritrea) 354
Formicoidea		
Aphaenogaster rufotestacea (Foerst.)	Egg-Nym.	Egypt 13
Camponotus sp.	Egg-Nym.	U.S.S.R. (Transcaucasia, C. Asia) 2[illegible]3
Monomorium salomonis indicum Ford	Egg	Pakistan 280
Myrmecocystis bombycinus	Egg	Egypt 13

Predator/parasite/antagonist species	Life stage attacked	Location & citation
M. viaticus (F.)	Egg	Egypt 13, 97, Pakistan 280
Paltothyreus tarsatus	Egg	Ethiopia (Ogaden) 6
Vespidae		
Vespa orientalis L.	Nym.	U.S.S.R. (Uzbekistan) 359
Vespula germanica (F.)	Nym..	U.S.S.R. (Uzbekistan) 359
Sphecidae		
Sphex spp.	Nym.	Somali R. (N. Region) 141
S. (Harpactopus) aegyptius Lep.	Nym.	Tanganyika 138, 381
S. luteipennis Mocs.	Nym.	Somali R. (S. Region) 245
S. (Calosphex) nigropectinatus Tasch.	Nym.	n.c. 24
S. (Chlorion) regalis (Smith)	Nym.	Pakistan 280
S. (Prionomyx) subfuscatus (Dahl.)	Nym.	Ethiopia (Eritrea) 18
Tachytes observabilis Kohl	Nym.	Ethiopia (Ogaden) 6
Coleoptera: Carabidae		
Chlaenius discopictus Fairm.	Egg	Somali R. (N. Region) A.L.R.C. Col.
C. obesus Laferte'	Egg	Nyasaland 337
C. (Chlaeniostenus) stellatus (Dej.)	Egg	Senegal 293
C. (Trichochlaenius) transversalis Dej.	Egg	Ethiopia (Eritrea) 354, Senegal 284
Harpeglossus laevigatus (Dej.)	Egg	Senegal 293
Pterostichus purpurascens Dej. (Adults)	Egg	Morocco 282
Siagona dejeani Ramb. (Adults)	Egg	Morocco 282
Acmostes haroldi Schaum	Nym.	Morocco 282
Anthia nimrod (F.)	Nym.	Senegal 293
Graphopterus cineraceus Fairm.	Nym.	Ethiopia (Ogaden) 6
Scarites cyclops Crotch.	Nym.	Morocco 282
S. sulcatus Oliv.	Nym.	Pakistan 280
Cicindelidae		
Megacephala euphratica Latr. and Dej.	Egg	Egypt 97
Histeridae		
Saprinus sp.	Egg	Senegal 293

Predator/parasite/antagonist species	Life stage attacked	Location & citation
S. elegans Paykull	Egg	Ethiopia (Eritrea) 128
S. ornatus Er.	Egg	Pakistan 280
Trogidae		
Trox gemmatus F. (Adults)	Egg	Senegal 293
T. procerus Harold (Adults & larva)	Egg	Ethiopia (Eritrea, Ogaden) 6, Kenya, Saudi Arabia 300, Somali R. (S. Region) 99
T. squalidus Oliv. (Adults)	Egg	Senegal 293
Scarabaeidae		
Adoretus sp.	Egg	Senegal 293
Pentodon sp.	Egg	Senegal 293
Cleridae		
Trichodes affinis Cherv.	Egg	Egypt 13
T. crabroniformis (F.)	Egg	Egypt 13
Tenebrionidae		
Pimelia rugosa (F.)	Egg	Algeria 174
Meloidae		
Epicauta erythrocephala (Pallas)	Egg	U.S.S.R. (Turkestan) 390
Mylabris spp.	Egg	Egypt 13, Ethiopia (Eritria) 18
M. nr. holosericea Klug	Egg	Somali R. (S. Region) A.L.R.C. Col.
M. schreibersi Reiche	Egg	Algeria 174
M. zonata Klug	Egg	Ethiopia (Eritrea) A.L.R.C. Col.

African Migratory Locust, Locusta migratoria (Reiche & Fairmaire)

Hemiptera: Reduviidae		
Harpactor albopunctata Stal.	Nym.	Uganda 167
Diptera: Therevidae		
? Thereva bipunctata Meigen	Egg	France 285, 296

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Predator/parasite/antagonist species	Life stage attacked	Location & citation
Bombyllidae		
Anastoechus biagakumensis Par.	Egg	U.S.S.R. (Turkestan) 391, 393
A. nitidulus (F.)	Egg	France 282, 296: U.S.S.R. 233, (Caucasus) 330, (Crimea, Transcaucasia) 263, (Georgia) 352, (Kazakhstan) 273, S. Russia 267,
Exoprosopa spp.	Egg	Madagascar 110
Phoridae		
Megascelia sp.	Egg	Mali (262)
M. aspera Schmitz	Egg	U.S.S.R. (Dagestan) 324
M. leucozona Schmitz	Egg	U.S.S.R. (Dagestan) 324
M. parvula Schmitz	Egg	U.S.S.R. (Dagestan) 324
Platystomatidae		
Elassogaster sepsoides	Egg	Philippines 119,120
Calliphoridae		
Blaesoxipha spp.	Nym.	N. Rhodesia 184, S. Africa 102, 104
B. anceps Villen.	Nym.	Uganda B.M. Col. 58
B. brevicornis Villen.	Nym.	U.S.S.R. (S. Russia) 267,
B. filipjevi Rohd.	Nym.	U.S.S.R. (Kazakhstan) 311, Ghana B.M. Col., Sudan 388, Tanganyika B.M. Col.
B. laticornis (Meigen) syn gryllocione Loew	Nym.	U.S.S.R. (Dagestan, Kazakhstan) 240, (Kazakhstan) 311,
B. lineata (Fallen)	Nym.	France 54,296, U.S.S.R. 308, (Astrakhan) 313, 314, (Caucasus) 260, (Dagestan, Kazakhstan) 240, 231, 232, 311, (S. Russia) 267, Ghana B.M. Col., Sudan 388
B. litoralis Villen.	Nym.	U.S.S.R. 301
B. (Locustaevora) migratoriae (Rohd.)	Nym	U.S.S.R. (Uzbekistan) 301, 304, Mali 286
** Sarcophaga furcadorsalis	Nym.	Sierra Leone 133
Oophagomyia plotnikovi Rohd.	Egg	U.S.S.R. (Kazakhstan)303, (Turkestan) 391

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Predator/parasite/antagonist species	Life stage attacked	Location & citation
Stomorhina lunata (F.)	Egg	France 285, 296, U.S.S.R. (Caucasus) 335, Congo 41, N. Rhodesia 184, Tanganyika 135, 294, Uganda 134, 147
Wohlfahrtia balassogloi (Porch.)	Nym.	U.S.S.R. 233
Tachinidae		
Ceracia aurifrons Aldrich	Nym.	Philippines 119, 121
Phorocerosoma pilipes (Villen.)	Nym.	Madagascar 86
** Winthemia quadrata (Wied.)	Nym.	Uganda 147
Zenilliana sp.	Nym.	Madagascar
Muscidae		
Acridomyia sacharovi Stack.	Egg	France 5,54,296, U.S.S.R. (Caucasus) 395, (Dagestan, Kazakhstan) 240, (Kazakhstan) 311
Hylemia sp.	Egg	France 285
H. cilicrura Rond.	Egg	U.S.S.R. (Russia) 95, (Ukraine) 351,
Hymenoptera: Scelionidae		
Scelio spp.	Egg	U.S.S.R. (Russia) 233, Mozambique 53, 210, Nyasaland, 336, S. Africa (Natal) 195,
S. bipartitus Kieffer	Egg	Australia (Qd) 118
S. facialis Kieffer	Egg	Philippines 119,121
S. remaudieri Ferriere	Egg	Mali 234, 262, 286
S. sudanensis Ferriere	Egg	Mali 234, 262, 286
S. uvarovi Ogloblin	Egg	U.S.S.R. (Ukraine) 237, (S. Russia) 267
S. vulgaris Kieffer	Egg	France 285
S. zolotarevskyi Ferriere	Egg	Madagascar 396
Formicoidea		
Camponotus sp.	Egg-Nym.	Malaya 266
Dorylus sp.	Egg	Uganda 167
Oecophylla smaragdina (F.)	Nym.	Malaya 266
Vespidae		
Polistes cavapyta Sauss.	Nym.	Malaya 266

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Predator/parasite/antagonist species	Life stage attacked	Location & citation
Vespa cincta F.	Nym.	Malaya 266
Sphecidae		
Sphex spp.	Nym.	France 296
S. (*Prionomyx*) *subfuscatus* (Dahl.)	Nym.	China 257
Tachytes sp.	Nym.	U.S.S.R. (Azerbaijan) 258
Coleoptera: Carabidae		
Abacetus afer Tschitsch.	Egg	Mali 262
A. dainelli popovi Straneo	Egg	Mali 262
Chlaenius spp.	Egg	Mali 262
C. quadrinotatus Dej.	Egg	Mali 262
C. (*Homalolachnus*) *sexmaculatus* Dej.	Egg	Mali 262
C. (*Chlaeniostenus*) *stellatus* (Dej.)	Egg	Mali 262
Platysma punctulatum (Schall.)	Egg	U.S.S.R. (Kazakhstan) 273
Pterostichus kuselenni (Panzer)	Egg	U.S.S.R. (S. Russia) 267
Anthia aequilatera Klug	Egg	Tanganyika 135
A. artemis Gerst.	Nym.	Tanganyika 135
A. striatopunctata Guer.	Nym.	Tanganyika 135
Staphylinidae		
Philonthus sp.	Egg	Mali 262
Byrrhidae		
Byrrhus nr. *pustulatus* Foerst.	Egg	France 285
Elateridae		
Aeolides sp.	Egg	Mali 262
Agriotes elongatus	Egg	U.S.S.R. (Kazakhstan) 273
Melyridae		
Henicopus pilosus (Scop.)	Egg	U.S.S.R. (Kazakhstan) 273
Tenebrionidae		
Pimelia subglobosa Pallas	Egg	U.S.S.R. (Kazakhstan) 273
Tentyria nomas (Pallas)	Egg	U.S.S.R. (Kazakhstan) 273

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Predator/parasite/antagonist species	Life stage attacked	Location & citation
Meloidae		
Coryna apicornis Guer.	Egg	Uganda 147
Epicauta erythrocephala (Pallas)	Egg	U.S.S.R. (Kazakhstan) 273, 274, 275, (N. Caucasus) 308, (Russia) 233, (S. Russia) 267, (Turkestan) 390, 391
Mylabris spp.	Egg	Nyasaland 336, N. Rhodesia 184
M. amplectus Gerst.	Egg	Uganda 166
M. frolovi Germ.	Egg	U.S.S.R. (Turkestan) 264
M. ledereri Mars.	Egg	U.S.S.R. (S. Russia) 264
M. quadripunctata Pallas	Egg	U.S.S.R. (E. Russia, C. Asia) 264
M. sexmaculata F.	Egg	U.S.S.R. (S. Russia) 122
M. tripunctata Thumb. (misidentified in literature)	Egg	U.S.S.R. (N. Caucasus) 308

Red Locust, Nomadacris septemfasciata (Serville)

Orthoptera: Tetigoniidae		
Acanthoplus armativentris Pering	Nym.	Mozambique 53,210
A. discoidalis Walk.	Nym.	Angola 16
A. Speiseri Granc.	Nym.	Nyasaland 337
Hemiptera: ReduviidaeN		
Rhinocoris violentus Germ.	Nym.	Nyasaland 337
Diptera: Asilidae		
Promachus scalaris Loew	Egg	S. Rhodesia 78
Bombyliidadd		
Exoprosopa rubicunda Hesse	Adult	N. Rhodesia 78
Phoridae		
Pulicophora rhodesiana Schmitz	Egg	S. Rhodesia 77, 159
Calliphoridae		
Blaesoxipha spp.	Nym.	N. Rhodesia 184, S. Africa 102, 104
** Sarcophaga nodosa Engel	Nym.	S. Rhodesia 158

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Predator/parasite/antagonist species	Life stage attacked	Location & citation
** W. euvittata Villen.	Nym.	S.W. Africa 102, 104
Stomorhina lunata (F.)	Nym.	Congo, Ruanda Urundi 41, Mauritius 165, Mozambique 53, 209, 210, 318, Nyasaland 337, N. Rhodesia 184, S. Rhodesia 75, 76, 158, 208, S. Africa 104, (Eastern) 93, (Natal) 195, Tanganyika 136,
Tachinidae		
Ceracia nomadacris van Emden	Nym.	N. Rhodesia, Tanganyika 100
Muscidae		
Anthomyia rubrofasciata	Egg	Reunion (38)
Hymenoptera: Scelionidae		
Scelio howardi Crawfd.	Egg	Angola 17, Nyasaland 337, N. Rhodesia 185, S. Rhodesia 159, Tanganyika 136
S. sudanensis Ferriere	Egg	Mali 387
Coleoptera: Tenebrionidae		
Psammodes carbonarius Gerst.	Egg	Mozambique 53
Meloidae		
Epicauta spp.	Egg	Mozambique 209
E. brevipennis Haag	Egg	Nyasaland 337
E. ruficollis	Egg	Mozambique 53, 210
E. velata Gerst.	Egg	Mozambique 210
Mylabris spp.	Egg	Angola 16, Nyasaland 336, N. Rhodesia 184
M. dicincta Bert.	Egg	Nyasaland 337
M. pertinax Per.	Egg	Nyasaland 337

Brown Locust, Locustana pardalina (Walker)

Diptera: Nemestrinidae		
Symmictus costatus Loew	Nym.	S. Africa 139

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Predator/parasite/antagonist species	Life stage attacked	Location & citation
Bombyliidae		
Systoechus acridiophagus Hesse	Nym.	S. Africa 265
S. weltoni Hesse	Nym.	S. Africa (Karoo) 144
S. xerophilus Hesse	Nym.	S. Africa 265
Calliphoridae		
** Rhyncomyia soyauxi Karsch syn Cynomyia pistifacies Bigot	Egg	S. Africa (Transvaal) 113
** Wohlfahrtia euvittata Villen.	Egg	S.W. Africa 94, 379, S. Africa 93, 265, 321

Moroccan Locust, Dociostaurus maroccanus (Thunberg)

Orthoptera: Tettigoniidae		
Decticus spp.	Nym.	Cyprus 87, U.S.S.R. 358
D. albifrons (F.)	Nym.	Turkey 175
D. verrucivorus (L.)	Nym.	Bulgaria 61
Platycleis sp.	Nym.	Cyprus 87
Saga natoliae Serv.	Nym.	Turkey 175
S. serrata F.-W.	Nym.	Mediterranean Coast 122
S. syriaca Lucas	Nym.	Iraq 35
Tettigonia sp.	Nym.	Cyprus 89
T. albifrons (F.)	Nym.	Algeria 174
Mantidae		
Empusa fasciata Brulle'	Nym.	Cyprus 87
Rivetina fasciata Thunb.	Nym.	Cyprus 87
Neuroptera: Myrmeleontidae		
Palpares libelluloides Ramb.	Nym.	Turkey 175
Diptera: Leptidae		
Chrysopilus nubeculus Fallen.	Nym.	Algeria 174
Asilidae		
Promachus leontochlaenus Loew.	Egg	U.S.S.R. (Kazakhstan) 183
Stenopogon poreus Loew.	Egg	U.S.S.R. (Kazakhstan) 182

Predator/parasite/antagonist species	Life stage attacked	Location & citation
Bombyliidae		
Anastoechus nitidulus (F.)	Egg	Italy 243, Morocco 181, 282, Portugal 325, Spain 85
A. oophagus Par.	Egg	U.S.S.R. (Turkestan) 391
** Bombylius canescens Mikan	Egg	Sardinia 200
Callostoma fascipennis Macq.	Egg	Turkey 175
Cytherea fenestratula (Loew.)	Egg	U.S.S.R. (Azerbaijan) 392
C. infuscata (Meigen)	Egg	Italy 160, Spain 19
C. obscura F.	Egg	Italy 243, 246, Sicily 350, Spain 241, U.S.S.R. (Crimea) 351, (Turkestan) 334
Exoprosopa spp.	Egg	U.S.S.R. (Turkestan) 391, 392
** Spogostylum isis (Meigen)	Egg	Turkey 175
Systoechus autumnalis Pallas	Egg	Cyprus 87, 201, 375, U.S.S.R. 263 (Crimea) 351,
S. gradatus Wied.	Egg	U.S.S.R. (Crimea) 351
S. sulphureus (Mikan)	Egg	Italy 160, 243, 244, 246, Spain 19, U.S.S.R. (W. Siberia) 26
** Thyridanthrax sp.	Egg	Iraq 306
T. fenestratus (Fallen)	Egg	Algeria 3, 174
T. pallidipennis Par.	Egg	U.S.S.R. (Uzbekistan) 391
Syrphidae		
** Volucella bombylans (L.)	Egg	Turkey 175
Calliphoridae		
Blaesoxipha filipjevi Rohd.	Egg	Cyprus 87,375, Israel B.M. Col.
B. grisea (Meigen)	Egg	Italy 243, 248
B. laticornis (Meigen) syn. gryllopsoma Loew.	Egg	Sardinia 200
B. lineata (Fallen)	Egg	Corsica 174, France 367, Italy 160, 243, 248, Sardinia 200,242, Spain 52, Turkey 320, U.S.S.R. 15, (Azerbaijan) 393, (Kazakhstan) 311, Yugoslavia 14, Algeria 174,
B. paoli Villen.	Egg	Italy 248
** B. ungulata Pand.	Egg	n.c. 11
Sarcophaga nr. offuscata Meigen	Egg	Cyprus 87

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Predator/parasite/antagonist species	Life stage attacked	Location & citation
Tachinidae		
Acemyia acuticornis Meigen	Nym.	Cyprus 375
** *Gymnosoma rotundatum* (L.)	Nym.	n.c. 122
** *Tachina larvarum* L.	Nym.	Sicily 350
Muscidae		
Hylemia cilicrura Rond.	Egg	Turkey 175, Algeria 3, 72, 174,
Hymenoptera: Formicoidea		
Myrmecocystis viaticus (F.)	Egg	Cyprus 87
Sphecidae		
Sphex spp.	Nym.	U.S.S.R. (Azerbaijan) 358
S. paludosa Rossi	Nym.	Spain 52, 227
S. (*Prionopyx*) *subfuscatus* (Dahl.)	Nym.	France 367, Turkey 175, Algeria 174, Morocco 122
Cleridae		
Trichodes sp.	Egg	Morocco 282
T. amnios	Egg	Portugal 325, Spain 19, 52, Sicily 350, Turkey 175, Algeria 3, 72, 174
T. flavocincta Spin.	Egg	Algeria 73
T. laminatus Cherv.	Egg	Iraq 35, 306
T. laminatus cyprius Reitt.	Egg	Cyprus 87, 201, 375
T. ? spectalilis Krauss	Egg	U.S.S.R. (Turkestan) 391
T. ? turkestanicus Krauss	Egg	U.S.S.R. (Turkestan) 391
T. umbellatarum (Oliv.)	Egg	Sicily 350, Algeria 73
Tenebrionidae		
Apontanodes globosus (Reiche)	Egg	Cyprus 87
Ocnera sp.	Egg	Iraq 35
Meloidae		
Epicauta erythrocephala (Pallas)	Egg	Italy 316
Mylabris spp.	Egg	Italy 316, Portugal 325, Sardinia 200, U.S.S.R. (Turkestan) 334
M. atrata Pallas	Egg	U.S.S.R. (Turkestan) 390, 391
M. beckeri (Esch.)	Egg	U.S.S.R. (Mid. Russia, Caucasus) 122

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Predator/parasite/antagonist species	Life stage attacked	Location & citation
M. cincta Oliv.	Egg	U.S.S.R. (Turkestan) 264
M. decimpunctata F.	Egg	Spain 52
M. deserti (Semen.)	Egg	U.S.S.R. (Turkestan) 390, 391
M. floralis Pallas	Egg	Bulgaria 61, U.S.S.R. 358, (Transcaucasia) 264
M. frolovi Germ.	Egg	U.S.S.R. (Turkestan) 264, 334, 390, 391
M. fusca Oliv.	Egg	U.S.S.R. (Azerbaijan) 393, (Turkestan) 264
M. hieracii Graells	Egg	France 122
M. madoni Mars.	Egg	Cyprus 87
M. magnoguttata Heyd.	Egg	U.S.S.R. (Russia, Turkestan) 264
M. scabiosae scabiosae Oliv.	Egg	U.S.S.R. (Turkestan) 390, 391
M. schreibersi Reiche	Egg	Algeria 3, 174
M. silbermanni Cherv.	Egg	Algeria 73
M. tekkensis Heyd.	Egg	U.S.S.R. (Turkestan) 390, 391
M. variabilis Pallas	Egg	Bulgaria 61, Italy 160, 243, 244, 246, Sardinia (Introd.) 39, Sicily 350
M. zebraea Mars.	Egg	U.S.S.R. (Azerbaijan) 393

Tree Locust Anacridium melanorhodon (Walker)
(This species is not listed, used two other Anacridium species)

Diptera: Calliphoridae		
Blaesoxipha filipjevi Rohd.	Egg	Sudan 388, Tanganyika 302
B. lineata (Fallen)	Egg	Algeria 174, Sudan 388
Tachinidae		
Acemyia acuticornis Meigen	Nym.	Europe 387, Tunisia 49, n.c. 327
Ceracia mucronifera Rohd. alloti (Seguy)	Nym.	France 180, Spain 255, syn. Tunisia 49

Predator/parasite/antagonist species	Life stage attacked	Location & citation
Senegalese Grasshopper, Oedaleus senegalensis (Krauss)		
Diptera: Bombyliidae		
Anthrax sp. nr. oophagus Pas.	Egg	Oman A L.R.C. Col.
Sudan Plague Locust, Aiolopus simulator (Walker) (Species other than this one were listed)		
Diptera: Calliphoridae		
Blaesoxipha aspinata (S.-W.)	Egg	India, B.M. Col., 26a, n.c. 172, U.S.S.R. (Dagestan, Kazakhstan) 240
Blaesoxipha lineata (Fallen)	Egg	U.S.S.R. (Dagestan, Kazakhstan) 240
Pachyophthalmus signatus (Meigen)	Egg	France 360
Hymenoptera: Scelionidae		
Scelio sudanensis Ferriere	Egg	Mali 234
Variegated Grasshopper Zonocerus variegatus (L.)		
Diptera: Calliphoridae		
Blaesoxipha filipjevi Rohd.	Egg	Sierra Leone 133

** Indicates entries about which there was some doubt of host relationships by the original author.

? Indicates entries about which there was some doubt of host relationships by Greathead (1963)

* The numbers following each country entry are citation numbers from the origanal document by Greathead 1963.

n.c. Indicates no country indicated.

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Table 2. Micro-organisms Infective of Grasshoppers and Locusts.

Species	Host species	Geographic occurance	Selected citations
		FUNGI	
Entomophthora grylli	various Acrididae & Pyrgomorphidae	So. Africa, U.S.A., Thailand	Edington 1898, Brunner 1901, Roffey 1968, Skaife 1925
Metarrhizium anisopliae	Many Insecta, Schistocerca gregaria Schistocerca paranensis Scapteriscus borellii Nomadacris septemfasciata	Worldwide, Argentina, Eritrea	Balfour-Browne 1960, Marchionatto 1944, Lewin 1936
Cunninghamella sp.	Eggs of Acrididae	Argentina	Daguerre 1937
		BACTERIA	
Coccobacillus acridiourm	Acrididae	Mexico, Africa, Argentina	D'herelle 1911, 1912, 1914a,b, Beguet 1915, Laines 1915
		PROTOZOA	
Nosema locustae	56 spp. in the Acrididae	England (lab.), U.S.A.	Canning 1953, Henry 1969, and many others
Nosema acridophagous	Schistocerca americana, Melanoplinae, Crytacanthacridinae	U.S.A.	Henry 1967, Henry & Oma 1974
Undescribed Nosema *nr* acridophagous	Acoryphaga glaucopsis Kraussaria augulifera Hieroglyphus daganensis Oedaleus senegalensis Oedaleus nigeriensis	Cape Verde, Mauritania, Senegal	Henry et al. 1985
Nosema cuneatum	Melanoplus confusus, M. sanguinipes, M. bivittatus, M. femurrubrum, M. differentialis,	Cape Verde, Mauritania, Senegal	Henry 1971, Henry & Oma 1974

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Species	Host species	Geographic occurance	Selected citations
	M. infantilis, Schistocerca americana		
Undescribed Nosema *nr* cuneatum	Oedaleus senegalensis, Acrida, bicolor	Cape Verde, Mauritania, Senegal	Henry et al. 1985
Undescribed Microsporidium	Aulocara elliotti Psoloessa delicatula	U.S.A.	Street & Henry 1984
Undescribed Eugregarine	Oedaleus senegalensis Pyrgomorpha cognata Pseudosphingonotus savignyi	Cape Verde	Henry et al. 1985
	VIRUSES 1/		
Grasshopper inclusion body virus (GIBV)	Melanoplinae, Cyrtacanthacridinae	U.S.A.	Henry et al. 1969 Langridge et al. 1983
Arphia pox virus (APV)	Oedipodinae	U.S.A.	Langridge & Henry 1981, Langridge et al. 1983
Crystalline-array virus (CAV)	Melanoplinae, Cyrtacanthacridinae, Oedipodinae, Gomphocerinae	U.S.A.	Jutila et al. 1970, Henry & Oma 1973 Henry 1972
Polyhedrosis virus (PV)	Melanoplus sanguinipes M. bivittatus M. differentialis Schistocerca americana	U.S.A.	Henry & Jutila 1966
Oedaleus group viruses (OEV)	Oedaleus senegalensis, O. nigeriensis, Kraussaria angulifera	Mauritania, Senegal, Gambia	Henry et al. 1985
Cataloipus group viruses (CEV)	Cataloipus fuscocoerulipes, C. cymbiferus	Mauritania, Senegal, Gambia	Henry et al. 1985

Species	Host species	Geographic occurance	Selected citations
Heteracris group viruses (HEV)	Hieroglyphus daganensis	Mauritania, Senegal, Gambia	Henry et al. 1985
	RICKETTSIA		
Rickettsiella grylli	Gryllus bimaculatus G. capitatus Schistocerca gregaria Locusta migratoria Zonocerus variegatus	Jordan Senegal	Vago & Martoja 1963, Martoja 1964, Henry et al. 1986, Henry et al. 1985
Rickettsiella schistocercae	Schistocerca gregaria Locusta migratoria	Jordan	Vargo & Meynadier 1965

1/ These records are preliminary to the findings of Oma and Henry 1986, which characterized them all as follows: 1) Melanoplus entomopoxvirus (MsEPV), 2) Arphia entomopoxvirus (AcEPV), 3) Phoetaliotes entomopoxvirus (PnEPV), 4) Oedaleus entomopoxvirus (OsEPV), 5) Cataloipus entomopoxvirus (CcEPV), and 6) Aeropedellus entomopoxvirus (AecEPV). The first three were collected in the U.S.A., the next two were collected from Western Africa and the last one was collected from Canada.

Table 3. Birds observed to feed on the Desert Locust (from Huddleston 1958 and Smith & Popov 1953).

Family	Common Name	Scientific Name
Coraciidae	Rufous-crowned roller	*Coracias naevia* Daud.
	European roller	*C. garrulus* L.
	lilac-breasted roller	*C. caudata lorti* Shelley
Bucerotidae	red-billed hornbill	*Torkus erythrorhynchus* Temm.
	yellow-billed hornbill	*T. flavirostris* Rupp.
	grey hornbill	*T. nasutus* L.
Upupidae	--	*Upupa epops senegalensis* Swains
Alaudidae	unidentified larks	
Motacillidae	African pied wagtail	*Motacilla aguimp* Dumont
	Yellow wagtail	*Budytes* sp.
Turdidae	Somali wheatear	*Oenanthe phippipsi* Shelley
	common wheatear	*O. oenanthe* L.
	an unidentified thrush	
Sylviidae	many unidentified warblers, some were *Eremomela* sp.	
Dicruridae	--	*Dicrurus adsimilis* (Bech.)
Laniidae	fiscal shrike	*Lanius collaris* L.
Corvidae	lesser brown-necked raven	*Corvus corvus edithae* Phill.
Sturnidae	superb starling	*Spreo superbus* Rupp.
Accipitridae	black kite	*Milvus migrans* Bodd.
	great spotted eagle	*Aquila clanga* pall.
	western steppe eagle	*Aquila nipalensis orientalis* Cab.
	tawny eagle	*Aquila rapax* Temm.
	kestrel	*Cerchneis* sp.

Family	Common Name	Scientific Name
Buteoninae	long-legged buzzard hawk	*Buteo ferox* Cretz.
Falconidae	Lanner falcon	*Falco biarmicus* Temm.
Ciconiidae	white stork black stork Marabou stork	*Ciconia ciconia ciconia* L. *C. nigra* L. *Leptopilos crumeniferus* Less.

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APPENDIX 10.
PROPERTIES OF INSECTICIDES

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Insecticide	LD50, microg/g Desert Locust adult dermal (g)	Formulations & effective dose (90% spray kill, 80% bait kill), grams active ingredient/ha	Action time (days)	Residual effect (days)	Use Patterns and remarks
dieldrin	3.7-6.9	ULV 10-35 (locusts)	3-10 (2)	10-40 (9)	Residual stomach poison good for barrier spraying and vegetation baiting
lindane (Gamma-BHC, Gamma-HCH) 160-200	5.5-14.5	dust 400 (grasshoppers) bait 13-40 (locusts) ULV160-200 (grasshoppers) 200-500 (locusts)	1-3	2-5	Good for hopper bands and settled swarms but too volatile to last over nonfeeding periods or in barriers; for cheapness against locusts, Lindane has generally been used in formulations containing 75% other isomers (9)

acephate	33	WP 60 (grasshoppers)	3-5	moderate residual systemic activity 10-15	Must be applied to green vegetation for systemic effect; low toxicity to locusts (9); needs further trials
chlorpyrifos	3-3.2	bait 100 (9) ULV/EC 150-200 (grasshoppers) 250 (locusts)	1-2(15) bait 6 (9)	medium; short on foliage, long in soil	Microencapsulated formulation gives good control; shows superior performance to carbaryl as bran bait (15); bait works better when evenly spread (4); less toxic to nymphs (9)
diazinon	3.4-6.5	ULV/EC 450 (grasshoppers) 500 (locusts)	1-2	low	Used on settling or settled swarms significantly less toxic to immatures (4); grasshopper sprays; microencapsulated product gives good control
fenitrothion	3.7-8.4	dust 250 (grasshoppers) ULV/EC 200-350 (grasshoppers) 400-500 (locusts)	<1-4 good knock-down (16)	2-3 under tropical conditions (4)	Used widely against acridids; good for swarm control; not

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					resistant to washoff; no bait possible (16); 3% dust considered good substitute for HCH dust; smaller ULV dosage maybe effective in large volume of codacide oil (12); microencapsulated product gives good control
malalathion	25-38	ULV/EC 560 (grasshoppers) 925 (locusts)	1 (6)	low	Locust swarm control and grasshopper sprays; primarily contact action; not resistant to washoff (14); not effective at <70 F (11)
bendiocarb	1-2.1	dust 50-100 (3) dust bait 25 (locusts) ULV/WP 30-100 (grasshoppers) 75-100 (locusts)	1-2	moderate	More bait testing needed (5)
carbaryl	25->100	dust 720 (grasshoppers) ULV Sevin-4-oil diluted with 4:1 diesel oil 240-280 (grasshoppers) 1000 (locusts)	2-5 bait 3-6 (9)	7-21 (5, 10,11)	Contact and stomach action; good for swarm control; resistant to washoff; unaffected by temperature; possible use

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					in barrier spraying; dust leaves 20-35% pests alive; residual effect may be largely repulsion; bait application rate rather than toxicant concentration important (15)
propoxur	1-2.6	dust 100 dust bait 100-150 (grasshoppers) WP 500 ULV 125 (grasshoppers) 100-120 (locusts) (9)	<1-2 good knock-down (4)	low	1-2% dust considered good substitute for HCH dust
cypermethrin	2.2	ULV 36 (grasshoppers)	<1 rapid knock-down(9)	moderate	Recovery may occur; needs further trials
lambdacyhalothrin		ULV 20 (grasshoppers and locusts)	<1-3 good knock-down	0-5	
tralomethrin		ULV 10-20	1	moderate	Needs further trials

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APPENDIX 11.
LIST OF BIRDS IN THE SPRAYING AREA

Bird List
(observed in region surrounding Nara, Mali, West Africa)

Ardeidae

Cattle Egret *Ardeola ibis*
Green-backed Heron *Butorides striatus*
Great White Egret *Egretta alba*
Goliath Heron *Ardea goliath*

Anatidae

Egyptian Goose *Alopochen aegyptiaca*
Spur-winged Goose *Plectropterus gambensis*

Accipitridae

Nubian Vulture *Aegypius tracheliotus*
Brown Harrier Eagle *Circaetus cinereus*
Gabar Goshawk *Melierax gabar*
Grasshopper Buzzard *Butastur rufipennis*
Red-tailed Buzzard *Buteo auguralis*
Black Kite *Milvus migrans*
Black-shouldered Kite *Elanus caeruleus*
Swallow-tailed Kite *Elanus riocourii*

Falconidae

Lanner Falcon *Falco biarmicus*

Phasianidae

Double-spurred Francolin *Francolinus bicalcaratus*

Otitidae

Black-bellied Bustard *Eupodotis melanogaster*

Burhinidae

Senegal Thick-knee *Burhinus senegalensis*
Spotted Thick-knee *Burhinus capensis*

Charadriidae

Black-headed Plover *Vanellus tectus*
Forbes'Banded Plover *Charadrius forbesi*
Black-winged Stilt *Himantopus himantopus*

Columbidae

Speckled Pigeon *Columba quinea*
Red-eyed Dove *Streptopelia semitorquata*
Mourning Dove *Streptopelia decipiens*
Vinaceous Dove *Streptopelia vinacea*
Long-tailed Dove *Oena capensis*
Red-billed Wood-dove *Turtur afer*

Cuculidae

Levaillant's Cuckoo *Clamator levaillantii*

Strigidae

Barn Owl *Tyto alba*

Caprimulgidae

Standard-wing Nightjar *Macrodipteryx longipennis*

Apodidae

European Swift *Apus apus*
White-rumped Swift *Apus caffer*
Little African Swift *Apus affinis*

Alcedinadae

Malachite Kingfisher *Alcedo cristata*
Senegal Kingfisher *Halcyon senegalensis*

Meropidae

White-throated Beeeater *Merops albicollis*

Coraciidae

Abyssinian Roller *Coracias abyssinica*
Blue-belted Roller *Coracius cyanogaster*

Upupidae

Hoopoe *Upupa epops*

Bucerotidae

Grey Hornbill *Tockus nasutus*
Red-beaked Hornbill *Tockus erythrorhynchus*

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Picidae

Cardinal Woodpecker *Dendropicos fuscescens*

Alaudidae

Singing Bush-Lark *Mirafra javanica*
Rufous-naped Lark *Mirafra africana*
Chestnut-backed Finch Lark *Eremopterix leucotis*

Hirundinidae

European Swallow *Hirundo rustica*
Fanti Rouch-winged Swallow *Psalidoprocne obscura*

Laniidae

Fiscal Shrike *Lanius collaris*
Woodchat Shrike *Lanius senator*

Sturnidae

Purple Glossy Starling *Lamprotornis purpureus*
Long-tailed Glossy Starling *Lamprotornis caudatus*
Chestnut-bellied Starling *Spreo pulcher*

Corvidae

Pied Crow *Corvus albus*
Brown-necked Raven *Corvus ruficollis*

Turdidae

Rufous Scrub-robin *Cercotrichas galactotes*

Sylviidae

Melodious Warbler *Hippolais polyglotta*
European Whitethroat *Sylvia communis*
Desert Fantail Warbler *Cisticola aridula*
Grey-backed Camaroptera *Camaroptera brachyura*

Emberizidae

Rock Bunting *Emberiza tahapisi*

Fringillidae

Grey Canary *Serinus leucopugius*

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Ploceidae

Slender-billed Weaver *Ploceus luteolus*
Vitelline Masked Weaver *Ploceus velatus*
Village Weaver *Ploceus cucullatus*
Black-faced Dioch *Quelea quelea*
Yellow-crowned Bishop *Euplectes afer*
Yellow-mantled Whydah *Euplectes macrourus*
Buffalo Weaver *Bubalornis albirostris*
Sparrow Weaver *Plocepasser superciliosus*
Grey-headed Sparrow *Passer griseus*
Bush-Sparrow *Petronis dentata*
Pin-tailed Whydah *Vidua macroura*
Broad-tailed Paradise Whydah *Vidua orientalis*

Estrildidae

Cut-throat Weaver *Amadina fasciata*
Black-rumped Waxbill *Estrilda troglodytes*

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APPENDIX 12.
LIST OF ENDANGERED SPECIES

This is a list of animal species as found in Appendixes I, II, and III of the Convention on International Trade in Endangered Species of Wild Fauna and Flora, (1984).

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ORDER	SPECIES	COMMON NAME	APPENDIX/ STATUS
Primates	Euoticus elegantulus	Needle-clawed bushbaby	?
Primates	Arctocebus calabarensis	Angwantibo	?
Primates	Colobus baduis rufomitratus	Tana River red colobus	II
Rodentia	Epexerus wilsomi	Wilson's palm squirrel	II
Carnivora	Hyaena hyaena barbara	Barbary hyaena	I
Perissodactyla	Equus asinus somalicus	Somali wild ass	I
Artiodactyla	Alcelaphus b. swaynec	Swayne's hartebeest	I
Artiodactyla	Alcelaphus b. tora	Tora hartebeest	I
Primates	Alouatta palliata (=villosa)	Mantled howler monkey	I
Primates	Ateles geoffroyi frontatus	Black-handed spider monkey	I
Primates	A.g. panamensis	Black-handed spider monkey	I
Primates	Cebus capucinus	White-throated capuchin	II
Primates	Cercocebus galeritus galeritus	Rana River mangabey, Agile mangabey	I
Primates	Cercopithecus diana	Diana monkey	I
Primates	Chiropotes albinasus	White-nosed saki	I
Primates	C. b. gordonorum	Uhehe red colobus	II
Primates	C. b rufomitratus	Tana River red colobus	I
Primates	C. verus	Olive colobus	II
Primates	Gorilla gorilla	Gorilla	I
Primates	Macaca silenus	Lion-tailed macaque	I
Primates	M. sylvanus	Barbary ape	II
Primates	Pan paniscus	Pygmy, Chimpanzee, Bonobo	I
Primates	P. troglodytes	Chimpanzee	I
Primates	Papio (=Mandrillus) leucophaeus	Drill	I
Primates	P. sphinx	Mandrill	I
Primates	Pongidae spp.	Chimpanzees, Gorillas	I
Insectivora	Erinaceus frontalis	African hedgehog	II
Pholidota	M. gigantea (all parts and derivatives)	Giant pangolin	III (Ghana)
Pholidota	M. longicaudata (all parts and derivatives)	Long-tailed pangolin	III (Ghana)
Pholidota	M. temmincki	Common African ground pangolin	I
Pholidota	M. tricuspis (all parts and derivatives)	African tree pangolin	III (Ghana)
Rodentia	Anomalurus spp.	Scaly-tailed flying squirrels	III (Ghana)
Rodentia	Epixerus ebii (all parts and drivatives)	African palm squirrel	III (Ghana)
Rodentia	Hystrix, spp. species native to Ghana	Crested porcupines	III (Ghana)

	(all parts and derivatives)		
Rodentia	Idiurus spp. species native to Ghana (all parts and derivatives)	Pygmy flying squirrels	III (Ghana)
Carnivora	Aonyx microdon	West African "clawless" otter	I
Carnivora	Acinonyx jubatus	Cheetah	I
Carnivora	Felidae spp. (all species)	Cats (not including house cats)	II
Carnivora	Hyaena brunnea	Brown hyaena	I
Carnivora	Mellivora capensis	Honey badger, Ratel	III
Carnivora	P. pardus	Leopard	I
Carnivora	Proteles cristatus	Aardwolf	III
Carnivora	Viverra civetts (all parts and derivatives)	African civet	III
Tubulidentata	Orycteropus ater	Aardvark	II
Proboscidea	Loxodonta africana	African elephant	II
Sirenia	Dugong dugon	Dugong	I
Sirenia	T. senegalensis	West African manatee	II
Perissodactyla	Equus africanus	African wild ass	I
Perissodactyla	E. grevyi	Grevy's zebra	I
Perissodactyla	E. zebra hartmannae	Hartman's mountain zebra	II
Perissodactyla	E. z. zebra	Cape mountain zebra	I
Perissodactyla	Ceratotherium simum cottoni	Northern white rhinocereos	I
Perissodactyla	Diceros bicornis	Black rhinoceros	I
Artiodactyla	Addax nasomaculatus	Addax	I
Artiodactyla	Boocerus (Taurotragus) euryceros	Bongo antelope	III (Ghana)
Artiodactyla	Cephalophus dorsalis	Bay duiker	II
Artiodactyla	C. jentinki	Jentink's duiker	II
Artiodactyla	C. monticola	Blue duiker	II
Artiodactyla	C. ogilbyi	Ogilby's duiker	II
Artiodactyla	C. sylvicultor	Yellow-backed duiker	II
Artiodactyla	C. zebra	Zebra-banded duiker	II
Artiodactyla	Choeropsis liberiensis	Pygmy hippopotamus	II
Artiodactyla	Damaliscus dorcas dorcas	Bontebok	II
Artiodactyla	D. lunatus (all parts and derivatives)	Sassaby antelope, Korrigum	III (Ghana)
Artiodactyla	Gazella dama	Dama gazelle	I
Artiodactyla	G. dorcus (all parts and derivatives)	Dorcas gazelle	III (Tunisia)
Artiodactyla	G. gazella cuvieri (all parts and derivatives)	Mountain gazelle	III (Tunisia)
Artiodactyla	G. leptoceros (all parts and derivatives)	Slender-horned gazelle	III (Tunisia)
Artiodactyla	Hippopotamus amphibius (all parts	Hippopotamus	III (Ghana)

	and derivatives)		
Artiodactyla	Hippotragus equinus	Roan antelope	II
Artiodactyla	H. niger variani	Giant sable antelope	I
Artiodactyla	Hyemoschus aquaticus (all parts and derivatives)	Water chevrotain	III (Ghana)
Artiodactyla	Kobus leche	Lechwe	II
Struthioniformes	Struthio camelus (populations of Algeria, Cameroon, Central African Republic, Chad, Mali, Mauritania, Morocco, Niger, Nigeria, Senegal, Sudan, and Upper Volta)	Ostriches: Ostrich	I
Ciconiiformes	Ardea goliath (all parts and derivatives)	Goliath heron	III (Ghana)
Ciconiiformes	Bubulcus (=Ardeola ibis (all parts and derivatives)	Cattle egret	III (Ghana)
Ciconiiformes	Casmerodius albus (all parts and derivatives)	Great white stork	I
Ciconiiformes	Ciconia ciconia boyciana	Oriental white stork	I
Ciconiiformes	C. nigra	Black stork	II
Ciconiiformes	Egretta garzetta (all parts and derivatives)	Little egret	III (Ghana)
Ciconiiformes	Ephippiorhynchus senegalensis (all parts and derivatives)	Saddlebill stork	III (Ghana)
Ciconiiformes	Hagedashia hagedash (all parts and derivatives)	Hadada ibis	III (Ghana)
Ciconiiformes	Lampribis rara (all parts and derivatives)	Spotted-breasted ibis	III (Ghana)
Ciconiiformes	Leptoptilos crumeniferus (all parts and drivatives)	Marabou stork	III (Ghana)
Ciconiiformes	Threskiomis aethiopica (all parts and derivatives)	Sacred ibis	III (Ghana)
Anseriformes	Anatidae, all species in family native to Ghana (all parts and derivatives)	Ducks, Geese, Swans, Screamers	III (Ghana)
Falconiformes	Aquila spp. all species except that in App., I or with earlier date in App. II	Eagles	II
Falconiformes	A. heliaca	Imperial eagle	I
Falconiformes	Circus spp.	Harriers	II
Falconiformes	F. peregrinus	Peregrine falcon	I
Falconiformes	F. punctatus	Mauritius kestrel	I
Falconiformes	Gyps fulvus	Griffon vulture	II
Falconiformes	Haliaeetus spp. (except species in App.,I)	Sea and fish eagles	II
Falconiformes	Harpia harpyja	Harpy eagly	I
Falconiformes	Milvus milvus	Red kite	II
Falconiformes	Sagittarius serpentarius	Secretary bird	II
Galliformes	Agelastes meleagrides (all parts	White-breasted guineafowl	III (Ghana)

	and derivatives)		
Galliformes	Argusianus argus	Great argus pheasant	II
Galliformes	Francolinus ochropectus	Tadjoura francolin	II
Galliformes	F. swierstrai	Sweistra's francolin	II
Gruiformes	Anthropoides virgo	Demoiselle crane	II
Gruiformes	Balearica negulorum	Crowned crane	II
Columbifomes	Columbidae; all species in family native to Ghana (all parts and derivatives)	Pigeons	III (Ghana)
Columbifomes	Nesonenas (=Columba) mayeri (all parts and drivatives)	Pink pigeon	II (Mauritius)
Psittaciformes	Psittacula krameri (all parts and derivatives)	Ring-neck parakeet	III (Ghana)
Psittaciformes	P. k. echo	Mauritius ring-neck parakeet	I
Cuculiformes	Musophagidae, all species in family native to Ghana except species in App. II (all parts and derivatives)	Turacos	III (Ghana)
Crocodylia	Crocodylidae, all species in family except those in App. I or with earlier date in App. II	Crocodiles	II
Crocodylia	C. cataphractus	African slender-snouted crocodile	I
Crocodylia	C. niloticus (except App. II populations listed below)	Nile crocodile	I
Testudinata	Pelusios spp. all species native to Ghana (all parts and drivatives)	African mud turtle	III (Ghana)
Testudinata	Pelomedusa subrufa (all parts and derivatives)	Helmeted terrapin	III (Ghana)
Testudinata	T. triunguis (all parts and derivatives)	Three-clawed turtle	III (Ghana)
Anura	B. superciliaris	Cameroon toad	I
Anura	Nectophrynoides spp.	African vivparous toads	I
Cypriniformes	Caecobarbus geertsi	African or Congo blind barb.	II