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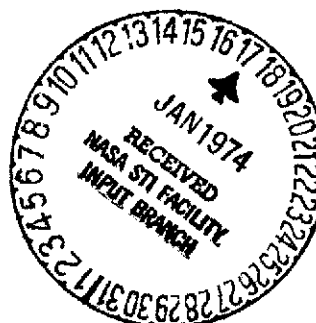
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TESTING FEASIBILITY OF DETECTING
LOCUST BREEDING SITES
BY SATELLITE

Principal Investigator: D.E. Pedgley

Centre for Overseas Pest Research
College House
Wrights Lane
London W8 5SJ
England



September 1973

Final Report to NASA on ERTS-1 experiment
Period: July 1972 to August 1973

National Sponsoring Agency:
Department of Trade and Industry
Abell House
John Islip Street
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Testing feasibility of detecting potential locust breeding sites by satellite

Date: September 1973

No. of pages: 16

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Abstract

ERTS-1 imagery has monitored the growth of vegetation over a 500 km² breeding site of the Desert Locust (Schistocerca gregaria Forsk.) that produced more than 40 small swarms. This took place on the Red Sea coast of Saudi Arabia during the period September 1972 to January 1973

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1. Preface

The aim of this project has been to test the feasibility of locating potential locust breeding sites by satellite. ERTS-1 imagery of the Red Sea coastal plain of Saudi Arabia has been used for the period September 1972 to January 1973. Comparison with two ground surveys for vegetation, and the use of daily records from eight raingauges, clearly demonstrates that the satellite was able to follow the spread of vegetation over an area of 500 km² following three spells of rain that resulted in breeding by the Desert Locust (Schistocerca gregaria Forsk.) sufficient to produce over 40 small swarms. A similar operational satellite would clearly be a powerful tool in routine survey of the whole of the invasion area of the Desert Locust (some 3 x 10⁷ km²), as well as of other locust species in the arid and semi-arid tropics. An APT system would provide the maximum warning for control organisations.

2. Objective

Sites favourable to breeding by the Desert Locust are places in the arid and semi-arid regions of northern and eastern Africa, and south-western Asia, that have been wetted recently by rain or runoff, and where vegetation has started to grow. Moist ground is needed for successful incubation of eggs laid in it; vegetation is needed to provide food and shelter for both parents and subsequent nymphal stages. Preferred sites are those with a soil comprised of silty sand, not drying to a hard surface that would impede oviposition yet retaining moisture at depths of 5-10 cm. The rain required to produce such a habitat is that which will wet a minimum of, say, 15 cm of soil to its field capacity. The necessary amount of rain depends on such factors as soil texture, slope and drainage, but in general falls greater than 20 mm could be important. Runoff along wadis from distant sources can provide

locally favourable habitats. Incubation takes 10 days or more, increasing with lower temperatures, and the five nymphal stages each take five days or more, again increasing with lower temperatures. Hence, the period from laying to fledging as a flying insect can be as little as six weeks, even allowing a further five days for wings to become fully usable. Since rain in the regions concerned is largely seasonal, several successive falls may produce a habitat suitable for breeding for up to several months, so that more than one generation can be produced. For background reading, reference may be made to:

Rainey, R.S. 1963. W.M.O. Techn. Note 54, 115pp.

Waloff, Z. 1966. Anti-Locust Memoir 8, 111pp.

(obtainable from the Centre for Overseas Pest Research).

Currently used methods for locating areas suitable for breeding are of two principal types:

- (a) looking for areas of recent rainfall;
- (b) looking for areas of new annual vegetation or renewed perennial vegetation.

The first alternative has the advantage that it can give an earlier indication of suitable sites and thus provides a more efficient tool when forecasting locust developments. Areas of recent rainfall are located:

- (a) on the large-scale, from daily weather analyses, by identifying likely rain-bearing clouds, using both conventional data and meteorological satellite images, and subsequently checking against rain-gauge data;
- (b) on the small-scale, by ground and aircraft reconnaissances in areas chosen for their known seasonal chances of receiving rain.

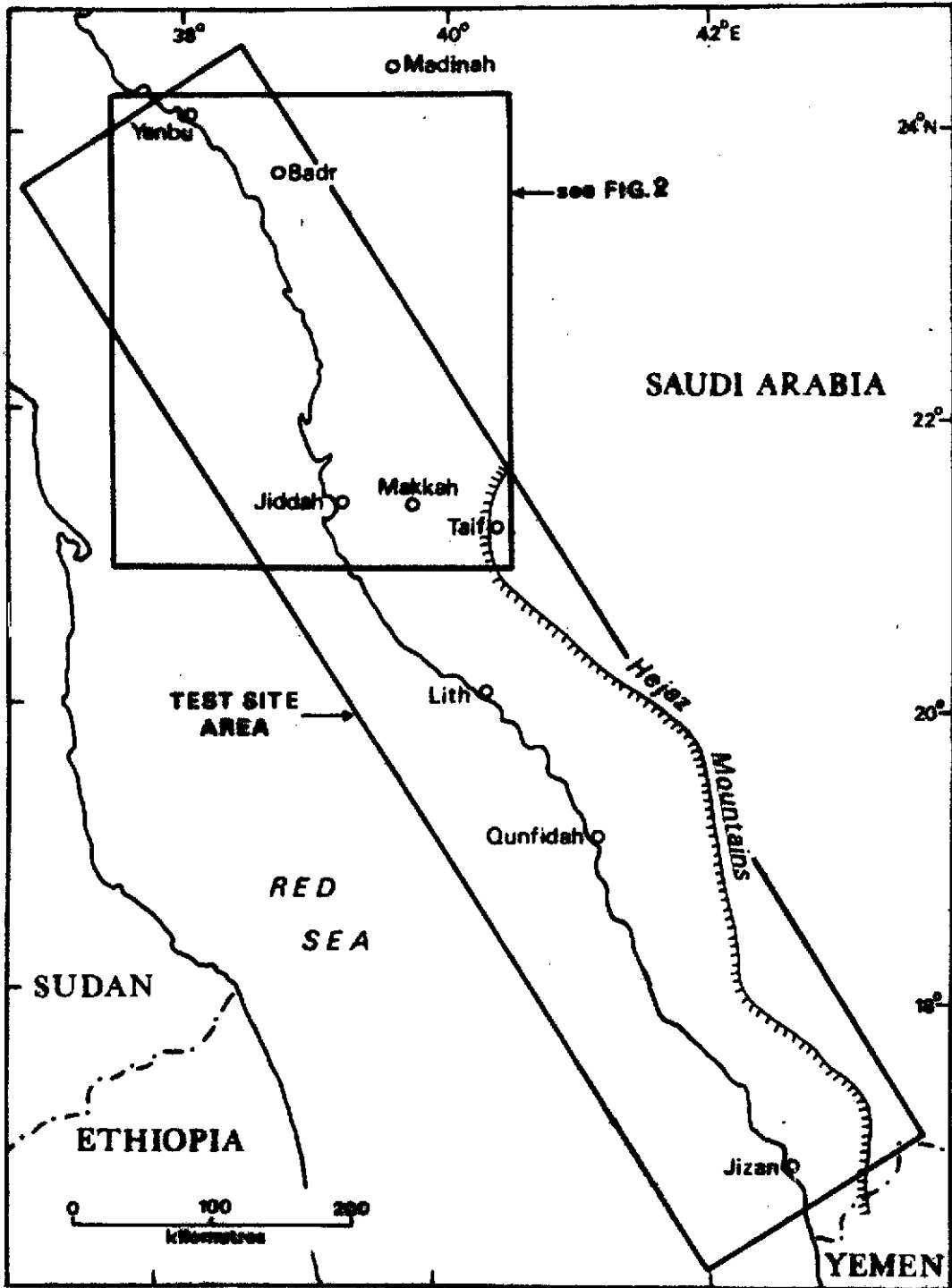


Fig. 1. Location map showing ERTS-1 test site area on the Red Sea coastal plain of Saudi Arabia.

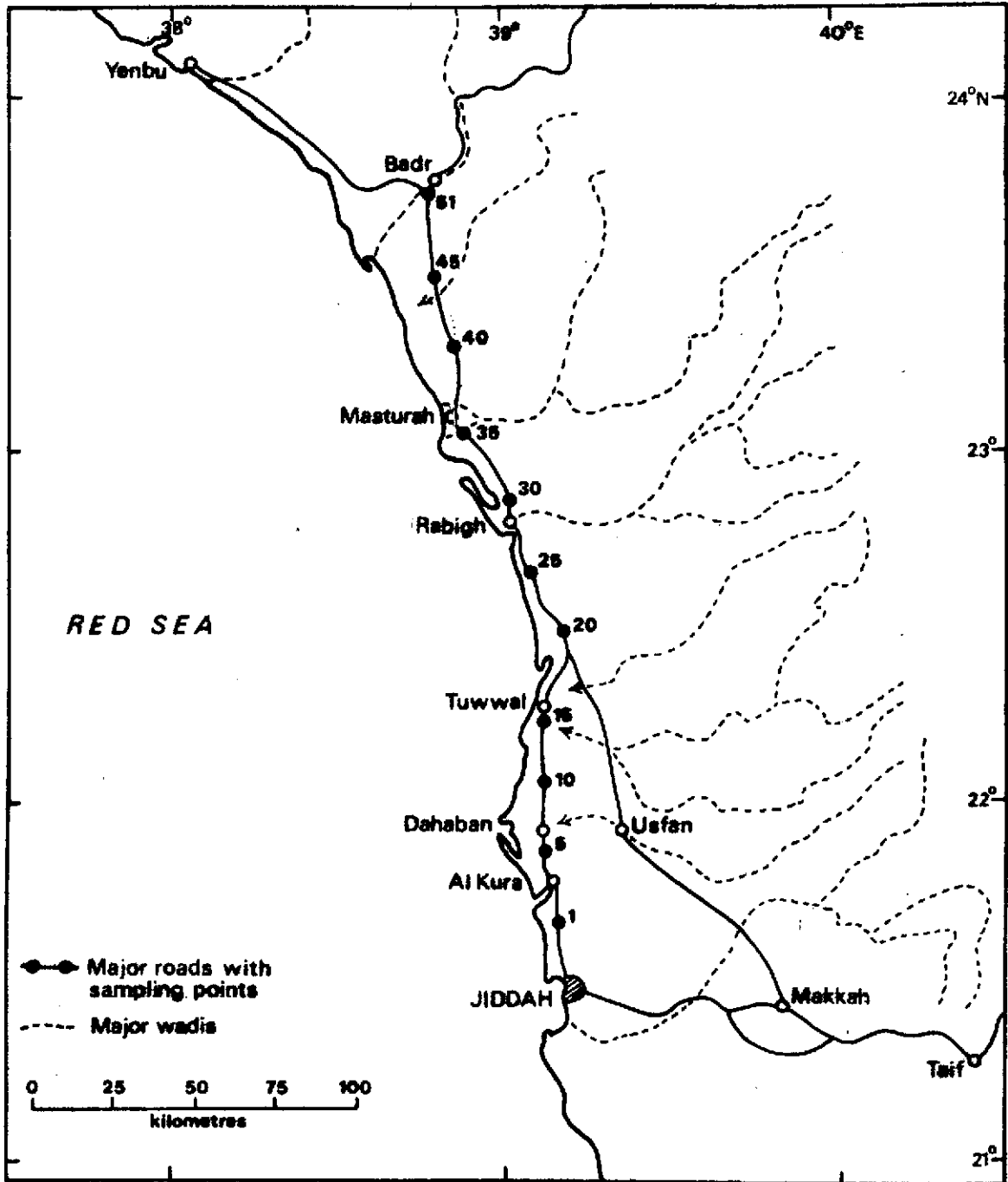


Fig. 2. Location map showing positions of 51 sampling points along the road between Jiddah and Badr.

3. Activities

The area chosen for field tests was the Red Sea coastal plain of Saudi Arabia from Gizan (17°N) to Yenbo (24°N) - see Fig. 1. This area was chosen because:

- (a) the Centre for Overseas Pest Research had staff there as a result of a 3-year agreement with the government of Saudi Arabia in which assistance was given in locust research, survey and control;
- (b) it is one in which there may be several generations of locusts in one year;
- (c) strong seasonal contrasts in rainfall distribution occur;
- (d) cloud amounts are small for long periods in most seasons.

Within this area, a smaller, routine sampling area was chosen, in which a series of 51 sampling points was set up at approximately 5 km intervals along the road northward from Jiddah towards Medina, as far as Badr (Fig. 2). At each of these points samples of soil moisture and assessments of greenness of the vegetation were taken at 18-day intervals from 22 November 1972 to 28 March 1973 (i.e. 8 sets of observations), coinciding with overpasses of ERTS-1. These points were chosen because it was hoped they would be able to help locate the edges of areas wetted by rain, and because they could be visited easily in one day using a good, hard surface road. Routine sampling to the south of Jiddah, although an area more likely to receive rain, would have involved difficult logistic problems. In that area there are only rough tracks and five days would have been needed for each survey; resources of manpower and vehicles were not sufficient for the necessary 18-days repetition.

Unfortunately, negligible rains fell over the routine sampling area, so there were no changes in soil moisture or vegetation greenness that could be detected by ERTS-1. However, substantial rains did fall between October 1972 and January 1973 over the field test area south of Jiddah, particularly between Lith and Qunfidah (Fig. 1), with the result that there was widespread breeding by the Desert Locust. Survey and control teams were sent into the field, and they were able to provide maps of vegetation distribution for comparison with ERTS imagery. Of course, these surveys were not timed to correspond with ERTS overpasses, nor were they made at 18-day intervals, nevertheless the following discussion will show that the observations made on these surveys were of great value in interpreting the ERTS imagery.

The coastal plain between Lith and Qunfidah is a gently undulating region 10-30 km broad, consisting essentially of alluvial deposits. Silty soils of the deltas associated with the major wadies contrast with the intervening sandy or gravelly plains. Wind-blown deposits often encroach on the foothills to the east, beyond which the country is very broken to the south-west facing scarp that continuously reaches an altitude of about 2 km. The alluvial plains effectively end near $18^{\circ} 30'N$, where extensive lava sheets reach the sea, but to the north of this there are some small areas of lava. Salt flats fringe much of the coast.

4. Comparison of satellite imagery with ground observations

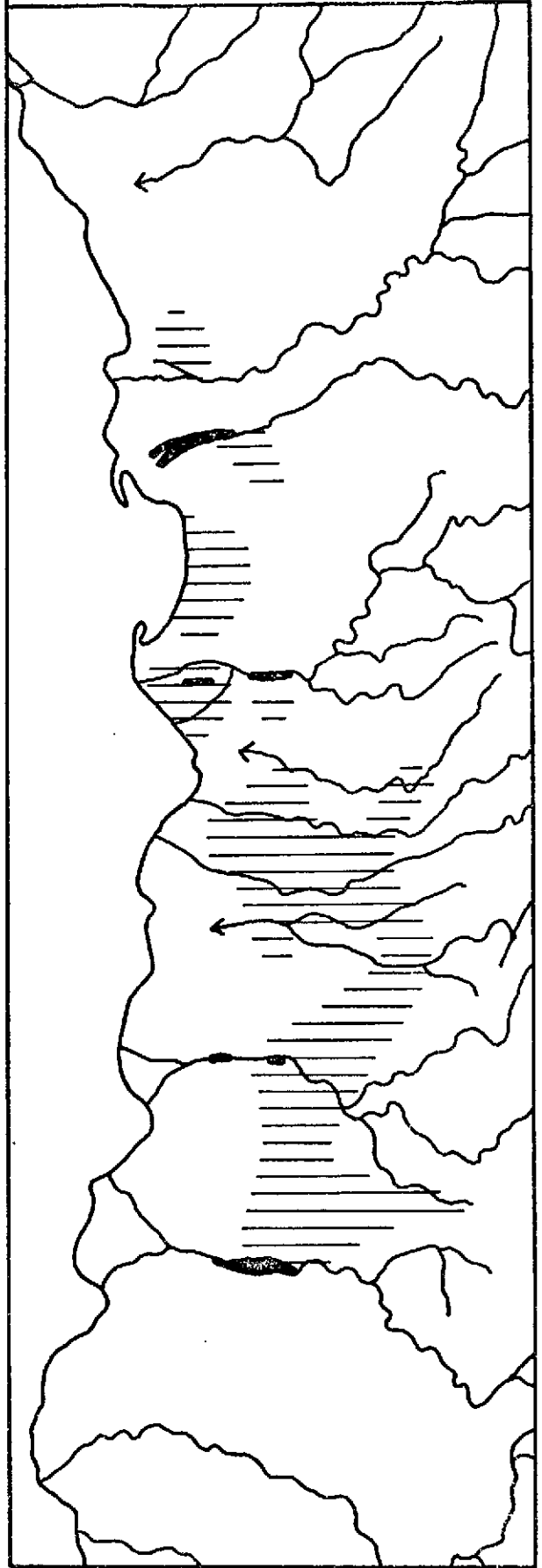
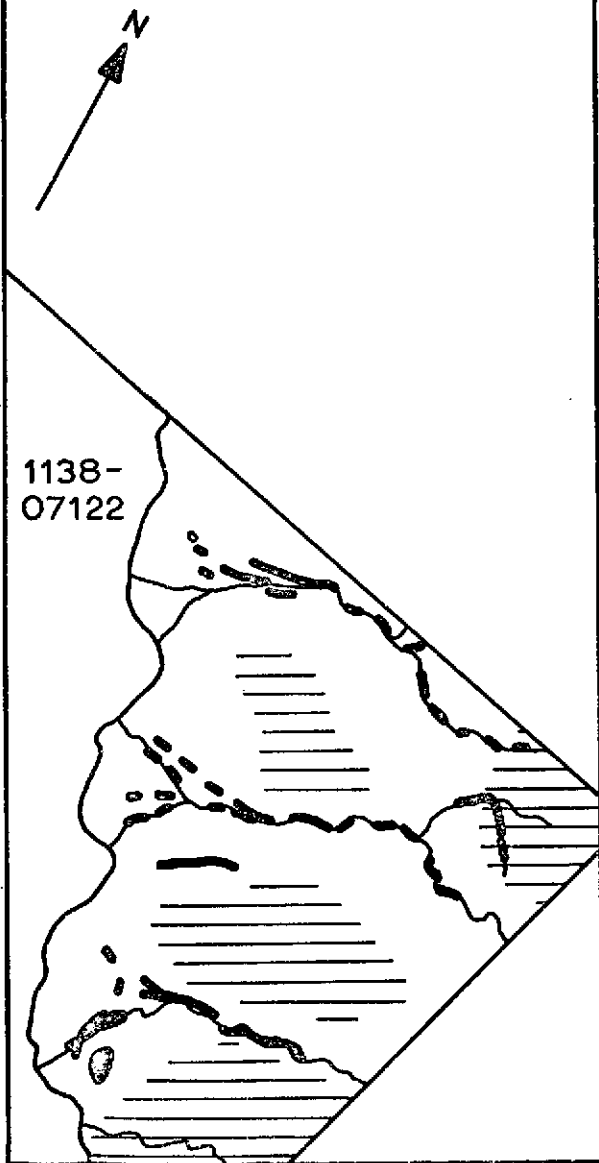
A total of about 170 images, mostly in all four spectral bands, has been received. Images came from eight adjacent orbits in each sequence, but the coverage varied with each sequence. False colour images, using bands 4,5 and 7, have been analysed from five occasions. Comparisons with ground data could be made on only two days.

- (i) 8 December 1972 (image 1138-07122). Fig. 3(a) shows the approximate boundaries of magenta colouration (possible vegetation), found by visual inspection; they are subjective and to some extent unreal because the edges of areas of natural vegetation resulting from particular rainfalls are vague, in contrast with the edges of cultivated areas. Fig. 3(b) shows approximate boundaries of areas of vegetation found on a ground survey between 26 November and 8 December. The only region of overlap is between Wadi Qanunah and Wadi Yiba (for place names see Fig. 6), where agreement is not close, although both showed areas free of green vegetation on the seaward side. This vegetation mostly consisted of the perennial tussock grass Panicum, and communities of annuals especially Dipterygium and Heliotropium, both of which are preferred food plants of the Desert Locust. Some smaller areas had open stands of Acacia, or patches of other shrubs. Positions of some wadi cultivations were confirmed.
- (ii) 13 January 1973 (images 1174-07113 and 1174-07115). Fig. 4 compares field reports with areas of possible vegetation observed by satellite. Agreement is good. Widespread vegetation was present on the coastal plain south of Wadi Lith, whilst the satellite image (1174-07113) suggested Wadi Iyar as the northern limit. This small discrepancy may have been partly caused by difficulties in locating the boundaries. An aircraft survey on 19 February gave the northern edge between Wadi Iyar and Wadi Shaqah ash Shamiyah, indicating a drying out of the northernmost vegetation. Two particular points are worth noting.
- (a) A small area of dry vegetation south-east of the delta of the Wadi Shaqah al Yamaniyah lay in a barren region on the satellite image. The existence of this area was confirmed by an aircraft

8 Dec 1972

S-A

26 Nov-8 Dec 1972

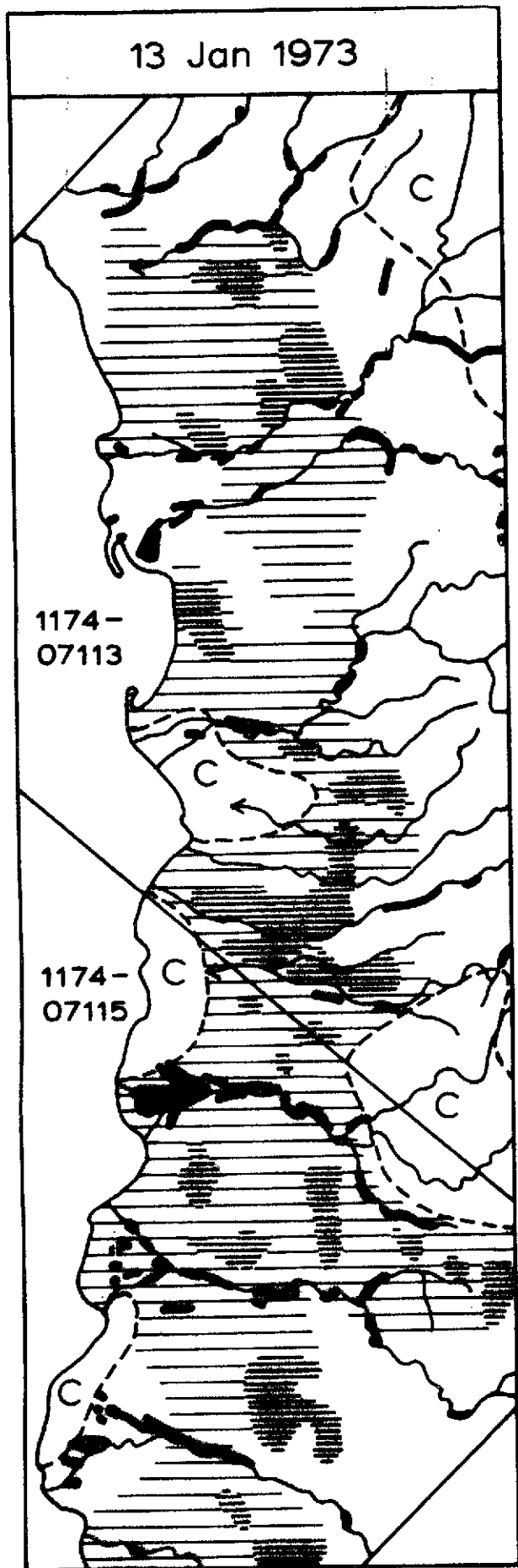


(a)

(b)

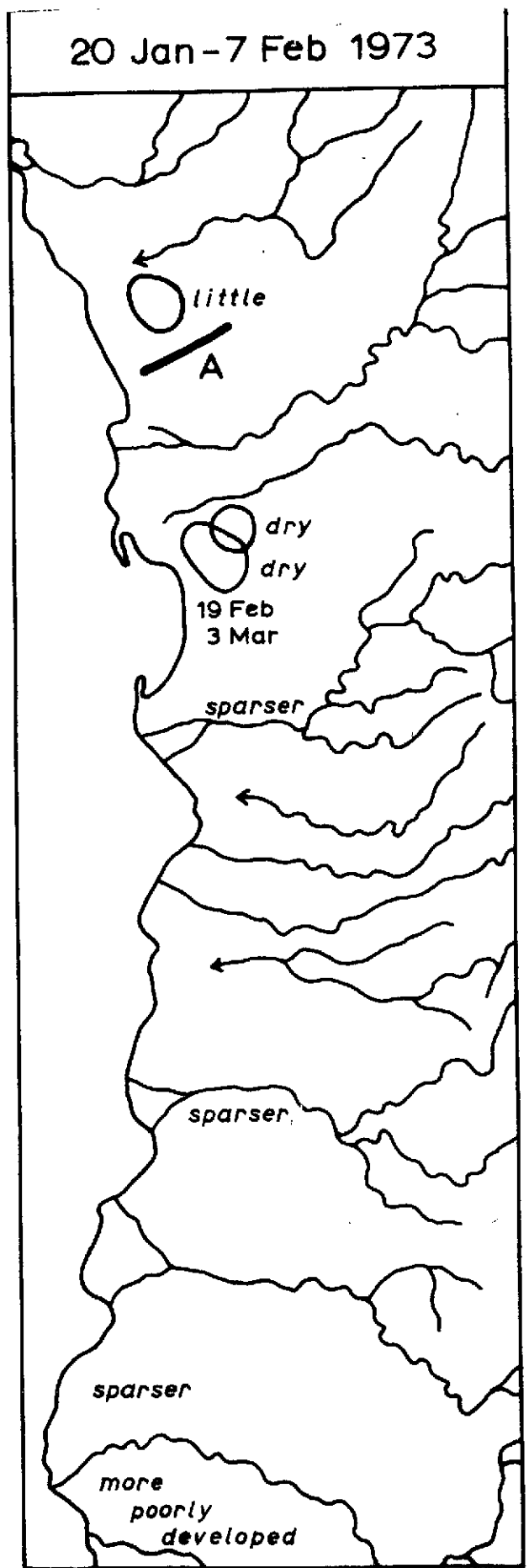
Fig. 3. (a) Approximate distribution of areas of possible vegetation (magenta colouration) on ERTS-1 image 1138-07122 for 8 December 1972.

(b) Approximate distribution of areas of vegetation seen on a second survey from 26 November to 8 December 1972.



(a)

S-B



(b)

Fig. 4. Similar to Fig. 3, but for 13 January 1973 (images 1174-07113 and 1174-07115) and 20 January to 7 February 1973.



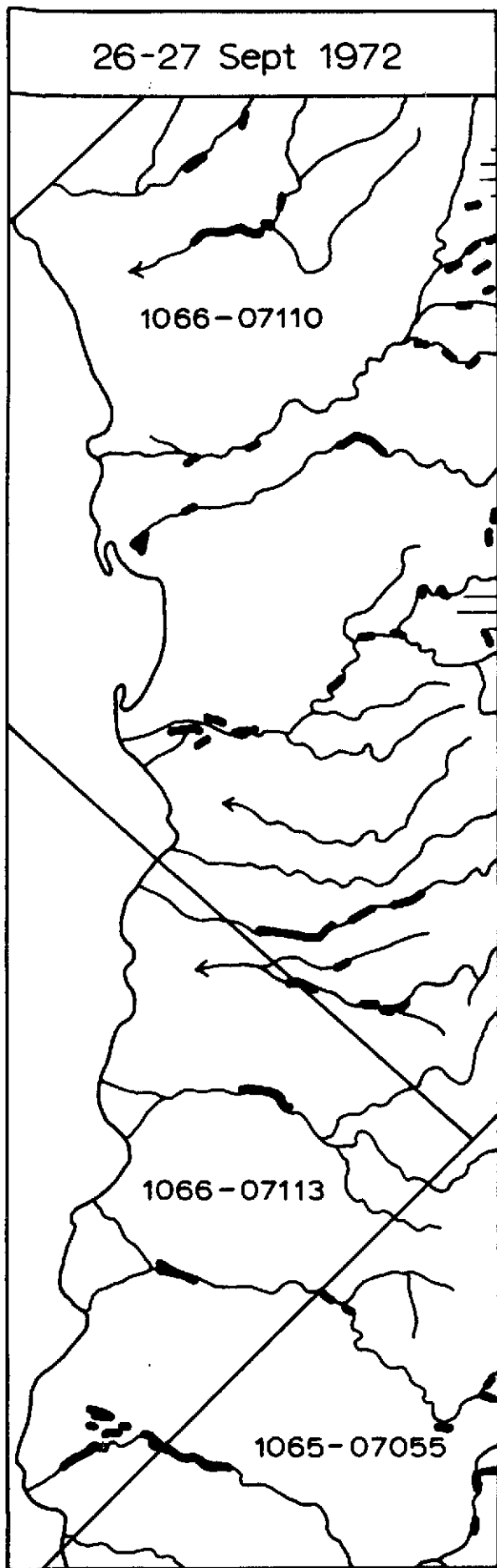
(a)



(b)

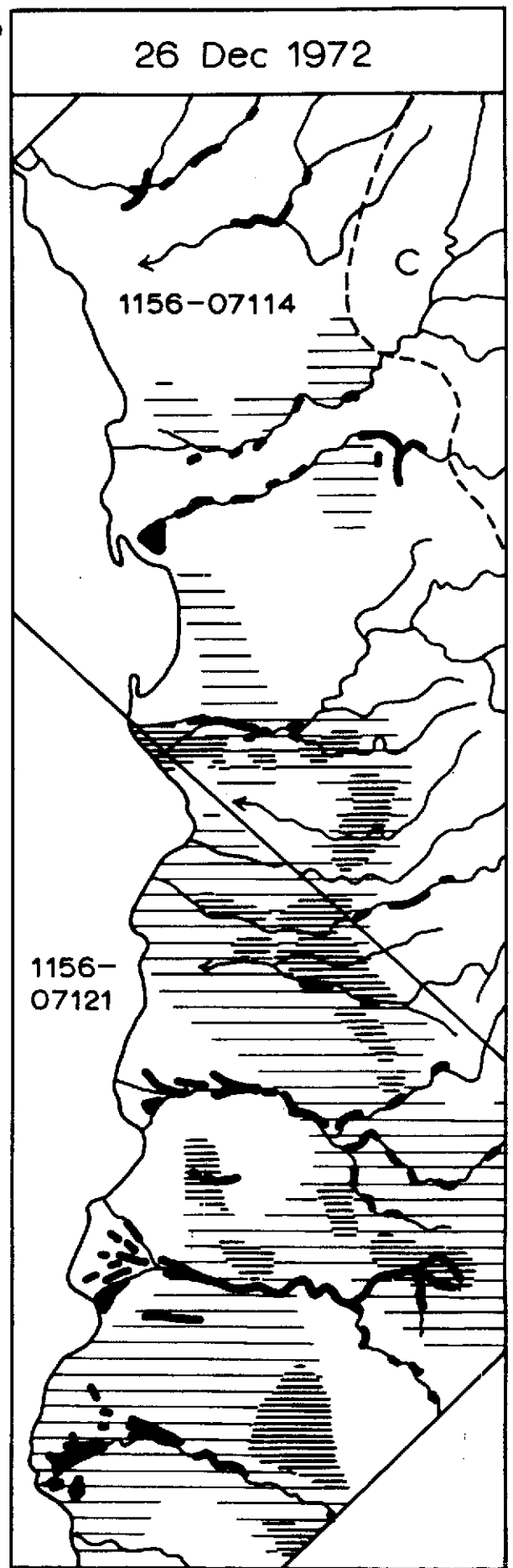
Fig. 5. (a) Parts of image 1065-07055 (26 September 1972) and images 1066-07110 and 1066-07113 (27 September).

(b) Parts of images 1156-07114 and 1156-07121 (26 December 1972).



(c)

b-D



(d)

(c) Inferred distribution of vegetation, based on (a).

(d) Inferred distribution of vegetation, based on (b).

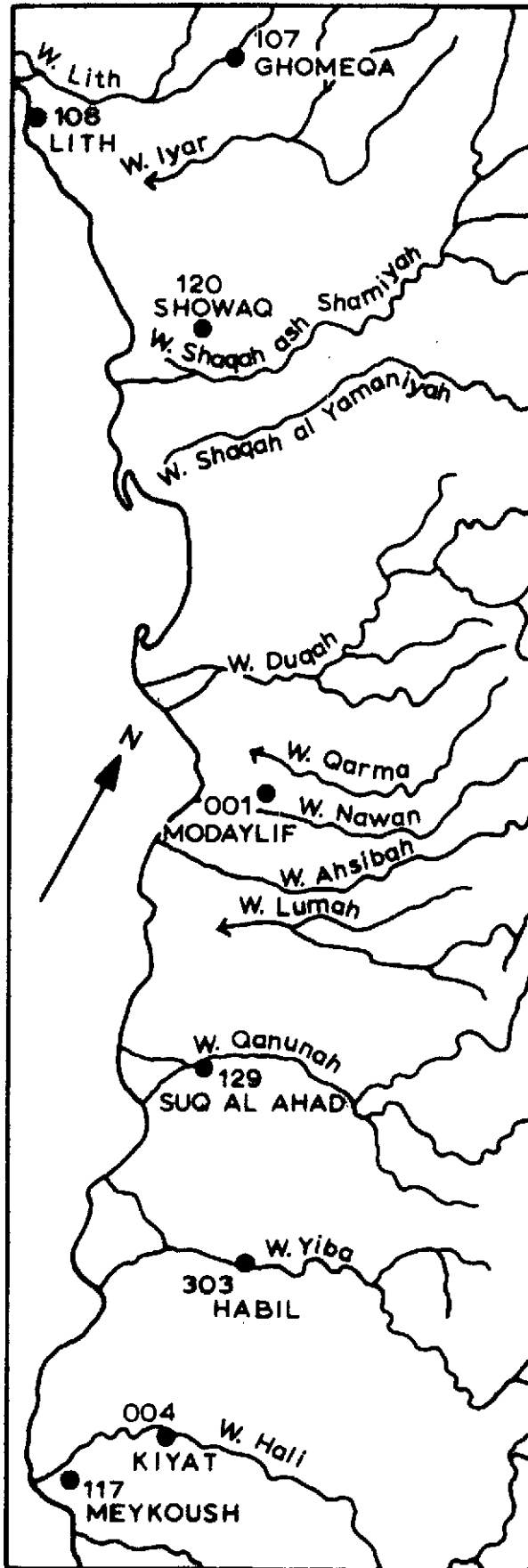


Fig. 6. Locations of places named in the text. Also positions of rain gauges.

survey on 19 February, and a further ground survey on 3 March.

- (b) The region of sparse vegetation between the deltas of Wadis Yiba and Hali is well shown on image 1174-07115.

These two examples indicate that although sparse natural vegetation can be detected by the satellite such vegetation can also be missed.

5. Spread of natural vegetation, September 1972 to January 1973

The reasonable agreement between observed vegetation distribution and the areas of possible vegetation on satellite images allows an analysis of other images. This is attempted for five separate occasions when false-colour imagery was available, from which the spread of vegetation over the four-month period September 1972 to January 1973 could be deduced. The results will be applied in the following two sections to known occurrences of rain and locusts. For 26-27 September, false colour imagery covered the whole area from Wadi Lith to Wadi Yiba (images 1065-07055, 1066-07110, 1066-07113), parts of which form the mosaic of Fig. 5(a). Variations in contrast between images made some comparisons difficult. Fig. 5(c) shows the inferred distribution of vegetation, which may be divided into three types.

- (i) Irrigated cultivations such as gardens, date palmeries and grain fields, mostly located
 - (a) in valleys near the foot of the scarp, and
 - (b) where major wadis cross the plains, especially in their deltas.
- (ii) Natural perennial vegetation, e.g. coastal mangrove and areas of Salvadora in some wadis. Areas of salt bush (Sueda) in deltas and near the coast showed as dark patches and were only vaguely magenta;

they occupied the same areas on each image.

- (ii) Natural vegetation, presumably renewed as a result of recent rains, and characterised by large changes in both area and colour intensity. Some areas occurred along the scarp, increasing in size southwards as is to be expected from the occurrence of monsoon rains (see next section), but there was no such vegetation on the coastal plains. Boundaries were not clear-cut, perhaps because runoff was rapid. Parts of these areas may be relict woodland, which is known to be preserved on certain isolated mountain massifs and parts of the higher scarp.

By 19 November, not only had wadi cultivations increased in extent but also there were patches of vegetation on the plains between Wadis Qanunah, Yiba, Hali and Amq (for place names see Fig. 6). Although the patches are likely to be mostly natural vegetation, especially Panicum, Dipterygium and Heliotropium, there are known to have been some cereal plantings such as Pennisetum, another preferred food plant of the Desert Locust. By 8 December, Fig. 3(a), there had been a further increase in the extent of vegetation patches on the plains.

On 26 December, most of the area was again covered by images 1156-07114 and 1156-07121, parts of which are shown in Fig. 5(b), from which Fig. 5(d) has been drawn. Comparing with Fig. 5(a), there were two significant changes.

- (i) Wadi cultivations. There were notable increases in area in the four deltas of Wadis Hali, Yiba, Qanunah and Shaqah ash Shamiyah, and increases in length along the lower courses of many wadis. There was also some tendency for a decrease in the amount of cultivation in the upper courses of the wadis.

(ii) Natural vegetation. There had been a large increase in area - to almost the whole coastal plain south of Wadi Duqah, together with patches near the two Wadis Shaqah, but some large areas were still devoid of green vegetation. In many places there was an increase in intensity of the magenta colouration (shown in Fig. 5(d) as denser stippling), presumably reflecting increases in both density and height of vegetation. Areas of salt bush remained dark.

By 13 January (Fig. 4) there had been a further increase in the area covered by natural vegetation - almost the whole coastal plain south of Wadi Iyar.

6. Occurrence of rain and its relation to the spread of vegetation

Records from eight daily raingauges (Fig. 6) were kindly provided by the Hydrology Division of the Saudi Ministry of Agriculture and Water Resources. These records were supplemented by reports from locust survey teams and by interrogation of local people.

The usual distribution of rains over the coastal plains and adjacent scarp between Lith and Qunfidah (based on about six years' records) is as follows.

(i) July-September (summer, or monsoon rains):

scattered showers along the scarp, increasing in frequency and intensity from north to south; a few light showers fall on the plains but amounts are likely to be less than 10 mm.

(ii) October-February (winter rains):

some showery days on both scarp and plains; on the plains this is the only 'rainy season', with totals averaging 50-150 mm, increasing southwards.

(iii) March-June (spring rains):

scattered showers on some days along the scarp but almost none on the plains.

The observed distribution, based on the eight gauges, was as follows. After a dry July, there were a few showers in the last week of August; amounts were mostly less than 10 mm, and they are unlikely to have provoked much vegetation. This is consistent with the absence of vegetation shown by Fig. 5(a) and (c), four weeks later. In September, the only rain was a few millimetres at Wadi Hali on the 24th. During the last week of October there were scattered showers giving 15-20 mm from Wadi Qarma southwards. These rains were no doubt the origin of the diffuse patches of vegetation seen on 19 November (image 1119-07064), i.e. three weeks later, and more extensively on 8 December (Fig. 3(a)). In November, there were only isolated light showers on the last few days, but December brought two good spells of rain:

5th-11th, when falls exceeded 10 mm at all gauges, and were about 50 mm over central parts of the area;

27th-31st, when 25-75 mm fell, mostly in the north of the area.

Rains continued during the first week of January 1973, with falls generally 50-100 mm. The last rain was reported from Wadi Hali at the end of the second week. No rain fell in February or March, so the seasonal total, October to January, was about 150mm at most places - about average in the south, but above average in the north.

The increase in area and density of vegetation in Fig. 5(b) and (d) must represent growth initiated by the rains of late October and further stimulated by the rains of early December, i.e. about three weeks before picture time.

The northern limit of dense inferred vegetation at Wadi Duqah is consistent with the observed northern limit of October rains, whereas the sparse growth further north was probably initiated by the early December rains. The further increases in area and density seen on 13 January (Fig. 4) presumably indicate continued growth stimulated by the late December and early January rains, i.e. on to two weeks before picture time. The inferred vegetation boundary at Wadi Iyar on 13 January suggests that effective December and January rains were at most only isolated further north; moreover, the ground survey between 20 January and 7 February, and an air survey on 19 February both support this suggestion.

7. Occurrence of locusts and their relation to the spread of vegetation

First reports of Desert Locusts on the coastal plain since December 1971 were of scattered adults and hoppers (the nymphal stages) in late July and early August 1972 among cultivations in Wadis Qarma and Nawan. Since a ground survey across the whole area on 3-7 March had found no locusts, it is possible that the observed population had come in the meantime from the highlands to the north-east, where scattered adults had been seen at several places in May, June and July. Alternatively an inconspicuous or unreported low density population may have persisted among cultivations, or even on the nearby plains following showers in mid-June (there having been no significant rain in May), but these rains were almost certainly insufficient for breeding outside irrigated cultivations. Low density populations of adults and hoppers continued to be reported from cultivations between Wadi Shaqah ash Shamiyah and Wadi Qarma in September and October.

In early November, a swarm of unknown size was seen near Habil on the Wadi Yiba (Fig. 6). The origin of this swarm is still in doubt. It is unlikely to have been produced from the small populations already mentioned, but it could have come from breeding further south, or even east among the foothills, or alternatively it could have come from much further east in the Arabian peninsula, particularly since strong east winds had swept the area in late October when a tropical cyclone had taken a most unusual track westwards along the Gulf of Aden.

Following the swarm report, survey and control teams came on to the coastal plain. Scattered and grouping adults were found widely from the second half of November onwards between Wadi Shaqah ash Shamiyah and Wadi Yiba, with a maximum density of 4,000 per hectare over 20 km² near the swarm sighting. Most of these locusts probably invaded the area from outside. They bred widely, so that some bands of hoppers were seen marching across country by early December. This successful breeding had clearly occurred because the soil had been wetted sufficiently for egg-laying following the first significant rains late in October. The resulting growth of vegetation between the wadis (Fig. 3) had provided widespread and ample food and shelter outside cultivated areas. The increase in population and its northward spread continued so that during January there were 47 reports of swarms between Wadi Lith and Wadi Hali, all small - the maximum size being 3 km². By January, locusts had been seen in many places over an area of some 500 km² between W. Lith and W. Hali, in a variety of habitats and plant communities. Although there were only three more swarm reports in February, widespread scattered adults and hoppers continued to be reported into March, with groups of adults and bands of hoppers. A second generation was being produced, but by April the main population was found in Wadi Lith and Wadi Shaqah ash Shamiyah, and

there were no reports in May. This rapid decline in April can safely be attributed to the application of insecticides, including the use of two spray aircraft in February and March. In addition, the absence of rain in February and March led to a drying of the vegetation, already detectable in places by early March, and widely so by April.

Thus, locusts arrived (probably during November), in time to take advantage first of all of the late October rains and subsequently of the heavier and more widespread rains in December and January, and multiplied in two generations to give a serious situation that was brought under control by the timely application of insecticide.

8. Conclusions

Although there were only a few ground observations to check satellite imagery, they enabled analysis to be made of false colour images on a sequence of five occasions which, together with rainfall data, give a consistent pattern of the growth and spread of vegetation on the Red Sea coastal plain of Saudi Arabia from about Lith to Qunfidah following three spells of rain between October 1972 and January 1973. None of these rains fell less than two days before the dates of available images. Two gauges had falls of about 10 mm 2-3 days before the image for 8 December but there was no evidence of the presence of surface soil moisture as might be expected by a darkening of the ground. This is consistent with 2-3 days being sufficient for drying out of the topmost 1 cm or more of soil (Report No 2 for this project, January 1973). Thus, it seems unlikely that other than daily satellite coverage would be sufficient for locating areas recently wetted by rain in regions similar to those investigated here.

On the other hand, the arrival and subsequent breeding by numerous locusts (sufficient to produce many small swarms) in a region where the spread of vegetation was clearly shown by satellite imagery, demonstrates the powerful potentialities of an earth resources satellite in routine surveying for potential breeding sites. The breeding area involved in this study was small, some 500 km²; moreover, it was relatively easily accessible to survey and control teams. However, the two surveys used here needed approximately 100 man-days and about 3000 km driving along rough tracks or across country.

If this is contrasted with

- (i) the 3×10^7 km² within which breeding can occur during plague periods, depending upon the incidence of suitable rains, and
- (ii) the vastly greater expenditure on money, manpower and machines needed to provide surveys as detailed as those made here (for the size of area, probably as detailed as any undertaken before and in any country) than that usually available for survey,

it is clear that the only way of obtaining routine data of comparable standard over the whole region open to infestation is by use of a satellite. The same satellite could be used to gather similar data for other locust species, e.g. in South America, South Africa and Australia.

9. Recommendations

It has been demonstrated that ERTS-1 can locate a potential locust breeding site. Whether breeding actually takes place must be found by conventional surveys. If an operational satellite were to be used in this way, it would be necessary for images to be in the hands of potential users within four weeks, and preferably two weeks. Within such periods, locusts can reach an

advanced nymphal stage, or even fledge prior to migration. Little time would then be left to send control teams into areas likely to be infested. Thus an automatic picture transmission (APT) system would be desirable, preferably with a simple receiver, bearing in mind the probable costs to the 60 or so countries involved. Moreover, the combination of images from several spectral bands for simple visual interpretation of false colour products may prove too complex for routine operation. Perhaps APT channel 5 images would be sufficient - a time series would show the development of vegetated areas, particularly if picture quality was comparable on all orbits. With an APT system, images at intervals of about two weeks would be adequate for tactical planning by national or international control organisations. Such an interval, plus a further week to allow time for action to be taken, would be sufficient for survey and control teams to be sent to 'danger spots' before any locusts could have had time to fledge.

The site used for this experiment was not ideal for several reasons.

1. Regular sampling at times of overpasses was not possible because the area was not easily accessible.
2. The plant communities were not typical of many other parts of the Desert Locust breeding area. Thus, in the southern Sahara, Schowia and Tribulus are the preferred food plants, but in all places various grasses are also eaten extensively.
3. Rainfall varies greatly from year to year. The experimental period fortunately had good rains; other years could easily have rains insufficient for breeding.

It is clearly desirable to repeat the experiment in other parts of the Desert Locust breeding area, preferably in those central parts where populations are more likely to be present at times when swarms are few. Examples of such areas are:

1. southern Sahara, from Mauritania to Sudan;
2. southern Pakistan and Rajasthan;
3. the Mekran of western Pakistan.

In these areas there are national and international control and forecasting services, assisted by the Food and Agriculture Organisation of the United Nations, that are likely to use imagery on a real time basis from any operational satellite.

Acknowledgments

Grateful thanks are due to Salem Hadramy, Director, Locust Research Station, Jiddah for willingly providing staff, vehicles and equipment for surveys made during the course of this project. Members of his staff directly involved were Yagoub Ashour, Ahmed Ibrahim and Ahmed Assad. Staff members from the Centre for Overseas Pest Research who provided data and assistance were G.B. Popov, J. Tunstall, M.J.K. Paskin, A.R. Wooler, D.E. Padgham and A.W. Harvey. Thanks are also due to Dr. J.C. Davies, head of the COPR team in Jiddah.

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