PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Forecasting Infestations of a Migrant Pest: The African Armyworm Spodoptera exempta (Walk.)

P. O. Odiyo

Phil. Trans. R. Soc. Lond. B 1979 **287**, 403-413
doi: 10.1098/rstb.1979.0072

Phil. Trans. R. Soc. Lond. B **287**, 403–413 (1979)
Printed in Great Britain

Forecasting infestations of a migrant pest: the African armyworm *Spodoptera exempta* (Walk.)

By P. O. Odiyo
East African Agriculture and Forestry Research Organization,† *Muguga, P.O. Box* 30148, *Nairobi, Kenya*

[Pullout 1]

A service for forecasting infestations of the larvae of *Spodoptera exempta* in Kenya, Tanzania and Uganda has been in operation since 1969; it uses nightly moth catches from a network of light traps, together with reports of larvae and meteorological information, to provide weekly forecast probabilities of larvae damaging cereal crops and grazing, in order that control measures may be organized in time. The principles on which the forecasting service is based, operational aspects, and the performance of the service to date, are summarized and illustrated by the formulation and subsequent verification of actual forecasts for representative periods of January and April for 7 years, as examples of the regular assessments undertaken to improve the accuracy of the forecasting service.

1. Introduction

The African armyworm, the larva of a noctuid moth, *Spodoptera exempta* (Walk.), is a pest of cereals and grasses in Africa south of the Sahara, southwest Arabia, southeast Asia, Australasia and Hawaii (C.I.E. 1972, Brown & Dewhurst 1975). Following very severe infestations throughout East Africa during the 1960–1 season, Brown (1962) reviewed the literature on the species, and then, on behalf of the governments of Kenya, Tanzania and Uganda, launched a research project from 1962 to study the biology, ecology and economic importance of the armyworm, so that in future farmers would know when and how to control the larvae more effectively.

2. Pest status

Armyworms feed on and often destroy young stages of major cereal crops and grazing over wide areas (table 1), and farmers who replant can lose the second crop if rains are inadequate. Recent examples from Kenya have included 900 ha of severely attacked wheat in Nakuru district, sprayed by aircraft in June 1977; in March 1977 the range officer at Kajiado reported that 'armyworms destroyed about 73000 ha of livestock grazing land south of Sultan Hamud . . . turning the ranches bare again . . . within 3 months' (similar damage had been reported over 1400 ha in January).

The extent of damage is illustrated by the facts that two larvae can destroy a 10 day old maize plant with 6–7 open leaves, and that a single larva can consume 200 mg dry mass of maize leaves in the course of the sixth instar (Brown & Odiyo 1968). At such a rate, the 1.8×10^9 larvae in a single, well sampled Kenya infestation, which covered 65 km^2 of the Athi plains southeast of Nairobi in May 1965 at a mean density of 28 sixth instar larvae per square metre, could have been expected to be feeding at an average rate of some 50 tonnes dry weight of herbage per day during the week which this instar lasted. Since a representative 4 year old

† (EAAFRO); now Kenya Agriculture Research Institute.

Boran steer has been found to consume about 6 kg dry mass of herbage per day in the Kenya highlands, the sixth instar larvae in this particular infestation would have been feeding at a rate equivalent to that of about 8000 of such cattle (Brown *et al.* 1970, McKay 1971).

TABLE 1. INCIDENCE OF INFESTATIONS OF *S. EXEMPTA* LARVAE ON CEREAL CROPS AND GRASSES IN EAST AFRICA FOR 12 YEARS (1964–5 TO 1975–6)

season	crop									area infested/km²			
(year)	maize	sorghum	finger millet	wheat	rice	oats	barley	sugar cane	grasses	Tanzania	Kenya	Uganda	totals
1964–5	+	+	+	+	+			+	+	690	355	0.01	1045
1965–6	+	+	+	+	+	+	+		+	1139	1672	100	2911
1966–7	+	+	+	+	+		+		+	116	24	0	140
1967–8	+	+	+	+	+	+			+	10	0	0	10
1968–9	+		+		+			+	+	77	0	0	77
1969–70	+	+	+	+	+	+	+		+	288	550	0.3	838
1970–1	+	+	+	+	+			+	+	16542	7016	710	24268
1971–2	+	+	+		+				+	533	0.02	0	533
1972–3	+							+	+	21	0.6	0	21
1973–4	+	+	+	+	+	+		+	+	6866	1643	36	8545
1974–5	+	+	+	+	+				+	15053	809	0	15862
1975–6	+	+	+	+	+		+		+	603	2652	22	3277
totals										41939	14722	868	57527

3. RESEARCH FINDINGS

S. exempta has a short life-cycle which is completed in about a month in the field. Masses of larvae usually appear suddenly, from synchronized breeding by adult moths (Brown & Swaine 1966). Circumstantial evidence, from some 40 light traps distributed throughout East Africa and from field observations of outbreaks of larvae, indicates that long-distance migrations occur between moth emergence and the next breeding areas; these are usually in the vicinity of seasonal passages of low-level wind-convergence such as the Inter-Tropical Convergence Zone or the African Rift Convergence Zone (Brown, Betts & Rainey 1969, Haggis 1971). Furthermore, increasing levels of moth catches in light traps have been found to be followed by increased probability of infestations of larvae occuring 2–4 weeks later at distances up to 200 km from the trap (Betts & Odiyo 1968). Large light trap catches may therefore represent populations in transit, and should not be interpreted simply as evidence of breeding or emergence locally.

Between 1961 and 1976, larvae were reported in 40 of the 41 districts of Kenya, 42 of the 57 districts of Tanzania, and 15 of the 17 districts of Uganda. Monthly catches of moths at representative traps in the three countries over a 12-year period show fluctuations corresponding to increases and decreases in the number of districts infested in each month (figure 1). The scale of infestations has varied substantially from year to year, with total reported areas in the three countries ranging for example from 10 km² in 1967–8 to 24000 km² in 1970–1 (table 1).

A general northward progression of *S. exempta* populations, as illustrated in figure 2, has occurred in many but not all seasons. Since 1962–3, when recording of data was standardized, the first infestations of the season have most often been reported in Tanzania, including those of six out of the eight seasons that spread throughout East Africa, four out of the five that affected only Tanzania and Kenya, and the only season that affected Tanzania and Uganda

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

alone; no season has yet started in Uganda. The first outbreaks have usually been reported during December/January, with the subsequent wave of infestations occurring some 10–500 km to the north or northwest of the original ones. In the 1968–9 and 1970–1 seasons, when outbreaks began in the first week of November, this northward progression of populations was delayed until January. The whole of East Africa is virtually free from larvae during August–October.

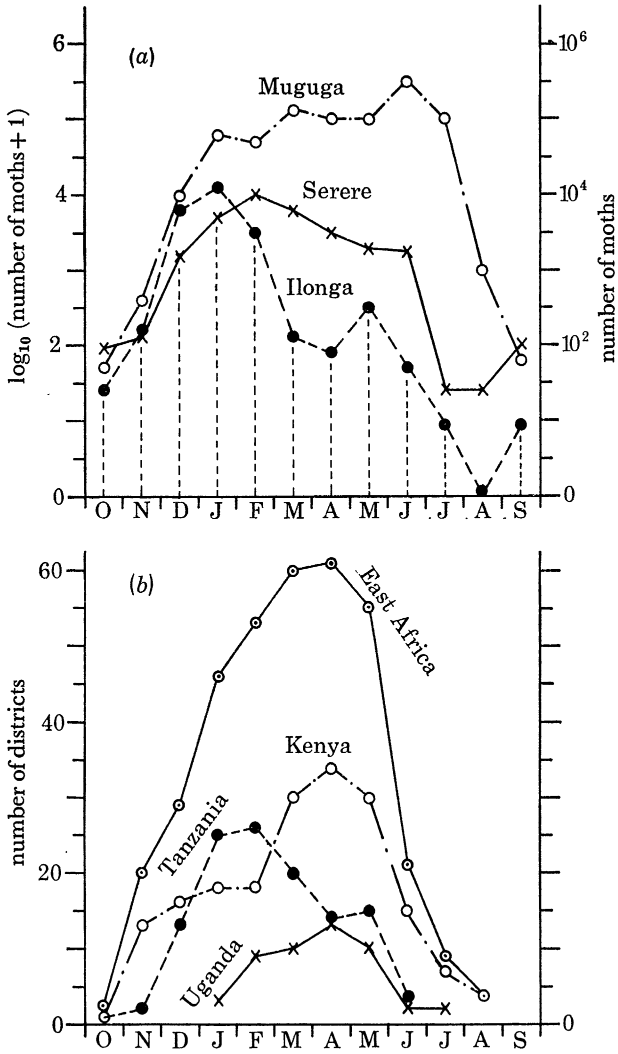


Figure 1. Monthly fluctuations of *S. exempta* moth catches and infestations of larvae in East Africa. (*a*) Total moth catches at Robinson-type light traps (125 W MB/U bulbs) at Ilonga in Tanzania, Muguga in Kenya and Serere in Uganda, October 1964 – September 1976. (*b*) Numbers of districts infested with larvae, October 1960 – September 1976.

4. The armyworm forecasting service for East Africa

Following recommendations of the Specialist Entomology and Insecticides Committee (S.E.I.C.), including representatives of government departments and other organizations concerned in Kenya, Tanzania and Uganda, a forecasting service was launched in 1969, to facilitate effective control of young larvae (Betts *et al.* 1970). Each season forecasts indicating where

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

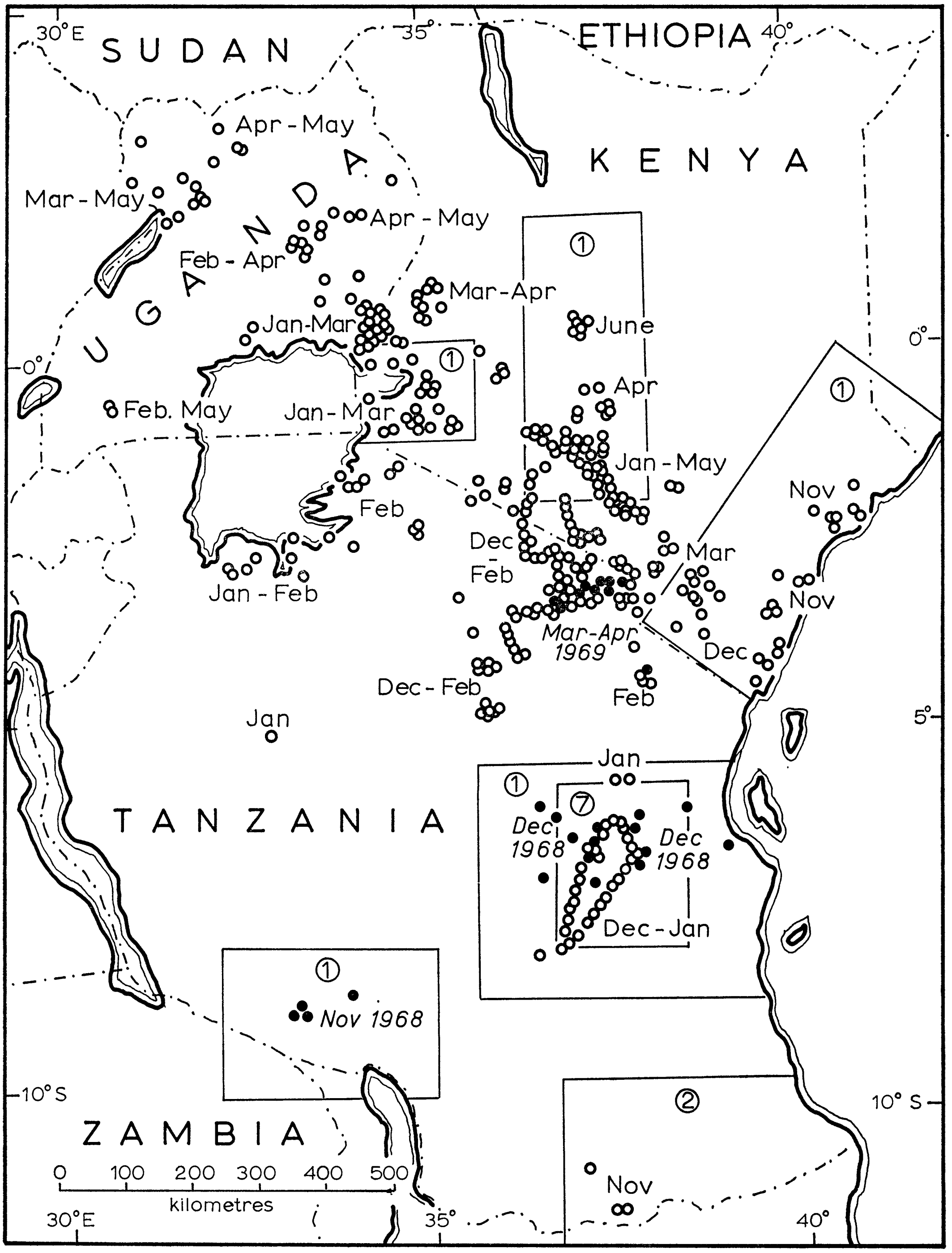


FIGURE 2. Seasonal starting points and contrasted seasonal developments. Distribution of infestations of, *S. exempta* larvae: ●, 1968–9; o, 1970–1. Rectangles indicate areas where the first infestations ofindividual seasons have occurred; numbers in circles show how often these have occurred in the rectangle concerned during the 14 years 1962–3 to 1975–6.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

current populations have been reported, the state of development of known infestations, and where the next breeding is expected to occur, have been issued weekly (experimentally in the first season), to District and Provincial Agricultural Offices in the three countries, in English and Swahili and with a short press summary for wider publicity. The S.E.I.C. (1971) recorded that 'the forecasting service provided by EAAFRO was accurate and was the first essential step in developing a well organized programme of armyworm control', and the Committee, with the Ministries of Agriculture of the three countries, has continued to support the forecasting service.

Records of infestations are mapped and estimates of moth emergence dates made, taking account of the age of the larvae and the probable duration of development in each affected area (Betts 1976, Rose 1975); these estimates are considered in relation to the moth trap catches, to help in identifying possible 'links' between successive generations (Betts, Odiyo & Rainey 1969). Each week the nightly totals of *S. exempta* moths in most of the traps are telegraphed to the forecasting office, though delays due to various causes still pose problems, as illustrated below. In addition, moth samples are sent in monthly, so that a constant check on identifications can be maintained. Sex pheromone traps for catching male moths are also currently being used experimentally alongside light traps (and elsewhere) in Kenya and Tanzania (Campion *et al.* 1976).

Weekly examination of synoptic charts at the East African Meteorological Office in Nairobi can enable the forecaster to identify the proximity of wind-shifts to places with high moth catches (cf. Haggis 1971), in relating the positions of convergence zones to nightly changes in moth population as indicated by the traps. Rainfall records also provide evidence of mesoscale weather disturbances, with which convergent wind-flow is likely to be associated. Coincidence in space and time of such weather situations with large numbers of moths have been noted to precede breeding downwind, for example in the Kenya highlands in April 1965 (Brown, Betts & Rainey 1969).

5. Verification of forecasts: 1969–76

The basic contents of each individual forecast, both predictions of where fresh breeding is expected to occur during the next week, and statements that there probably will be no outbreaks of armyworms in given districts in that period, are checked against the subsequent reports of larvae. This is to enable the forecaster to see in retrospect why, where or how he overlooked, misinterpreted, or failed to receive data which could have made the forecast more useful to the recipients, and so, by identification and elimination of the errors, to improve his accuracy. This process has also provided a continuing check on the validity of the hypotheses on which the service is based, especially that the main populations in eastern Africa often migrate over distances up to some hundreds of kilometres between generations.

Verification is undertaken routinely, and successes and failures noted together with comments on causes of failure (Odiyo 1972, 1974, 1975*a*, 1975*b*, 1977; Odiyo & Muchiri 1976; Betts 1976). This is illustrated here by the changes in distribution of larvae, as forecast and as in fact found, in two sample weeks – in mid-January (forecast no. 10) and early April (forecast no. 21) in each of the past 7 years of the forecasting service (figure 3, pullout 1): two contrasting weeks (maps 7 and 14 of figure 3) are discussed in detail. January represents the period in East Africa when populations of *S. exempta* usually start shifting northwards (figure 3, bottom section), while April represents the period when larvae are most widespread across the equator (figure 3, top section), sometimes extending beyond East Africa into Ethiopia. Attention is drawn to the differences from one season to another in the extent of infestations in East Africa at the same time of year.

(a) *Analysis of a mid-season forecast – April* 1976

We consider first a season of heavy armyworm infestation. There had been widespread populations in Tanzania since late December 1975, and in southwest Kenya and in Uganda since late February 1976, with a very small infestation in southeast Kenya in early March. No outbreaks had been reported in the highlands or the rest of east Kenya, and no moths had been caught in Kenya until mid March. By this time moth emergences were expected in north central Tanzania, where one infestation had extended over 500 km^2, and from a few very small infestations near the eastern part of the Kenya–Tanzania border. High moth catches occurred at traps in northeast Tanzania, indicating that emergence had indeed begun (and that some further breeding might occur locally). Moths appeared at light traps in the Kenya highlands from the night of 15 March, with a peak catch of 2900 at Muguga on the 23rd. These catches indicated a major redistribution of moth populations, probably northwards, possibly eastwards, from previously infested areas, but since no moths were caught at traps in the northeastern highlands (Mwea Tebere) or farther east (Kiboko and Malindi) it was expected that infestations might occur in south Kenya and the Kenya highlands, but not in the north and east. Moth emergence was also expected to begin about 22 March onwards in southwest Kenya and Uganda. However, since catches from traps in these areas were not received in time to be used for the forecast, the latter had to be based, for these areas, on the assumption that the general northward progression of moths from central Tanzania towards southwest Kenya and Uganda might be continuing, possibly supplemented by local production of moths, and that there could probably be some further breeding. Forecasting the possibilities for further infestations in Tanzania was more difficult, again because of delays in the receipt of many of the trap catches.

In the event, the following forecast was issued on 31 March, valid for 2–8 April (reference numbers relate to table 2).

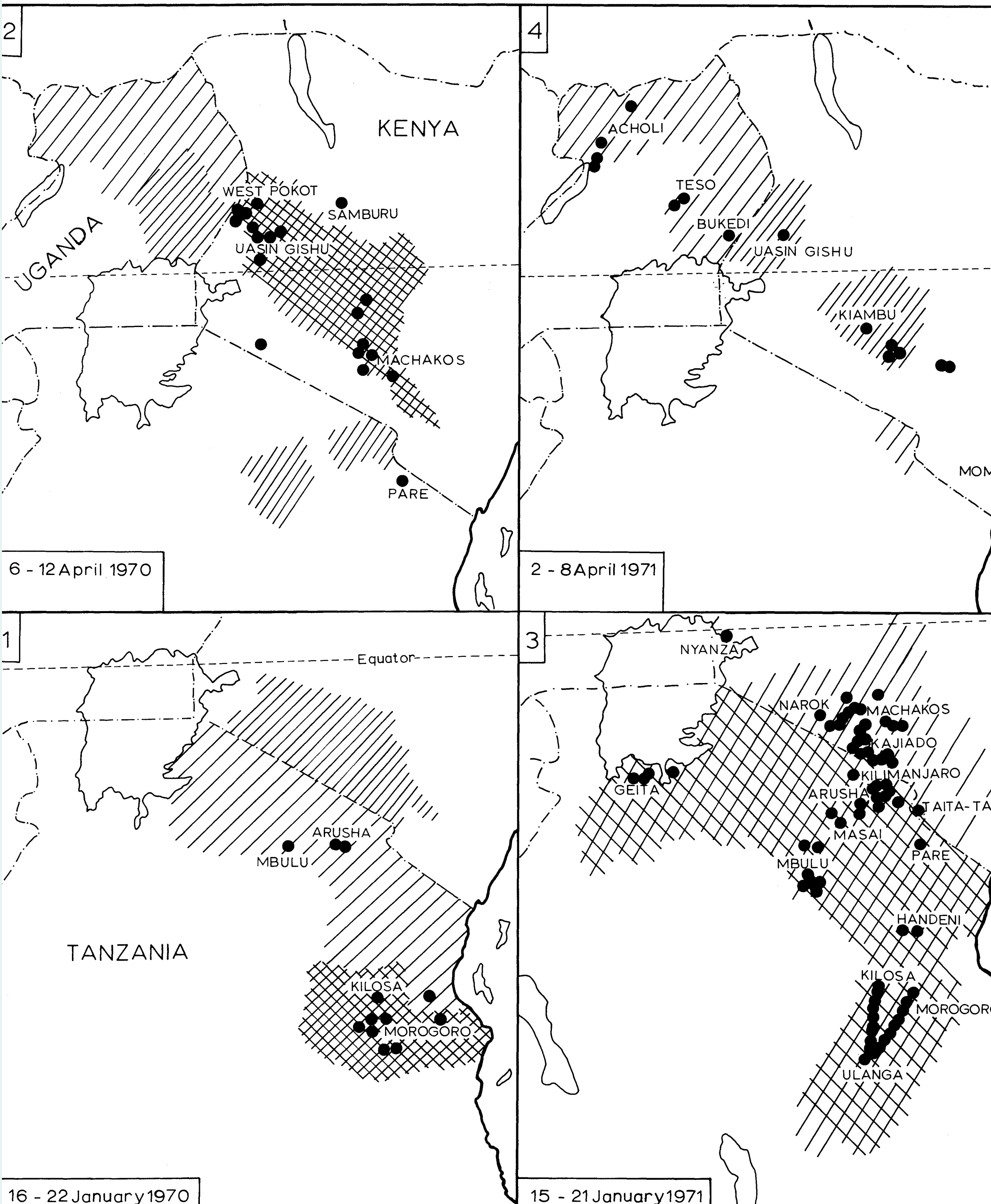
'Fresh outbreaks are expected in Kenya and north Tanzania. In Kenya, they are expected to occur in Machakos[1], Kajiado[2], Nairobi[3], and Kiambu[4] districts; they may also occur in Narok[5] and Nakuru[6] districts, and possibly also in Baringo[7], Laikipia[8] and the rest of the Central Province[9].

'In Tanzania, larvae are expected in Arusha[10] and Kilimanjaro[11] districts, they may occur in Mbulu[12], northern Masai[13] and Mwanza[14] region, and possibly also in Shinyanga[15] and Maswa[16] districts, as well as Mara region[17].

'In Uganda, outbreaks could still be discovered in the Central[18], Teso[19], Bukedi[20], Lango[21], Acholi[22] and West Nile[23] districts.'

In map 14 of figure 3 the forecast is shown graphically, together with the outbreaks which in fact occurred during the forecast period, presented in more detail in table 2 to correspond with each of the 23 separate points made in the forecast.

The basic hypothesis of long distance migrations, often of several hundred kilometres, between generations had enabled the forecaster to recognize the significance of the major immigration of moths across south Kenya, and to alert districts in these areas previously clear, including Machakos, where a large potential control target occurred. The major failure was the omission of southwest Kenya (Nyanza and Western Provinces) from the list of areas likely to be infested. This was due to failures of trap operation in southwest Kenya, to late reporting of moderately high catches at traps in Uganda (Serere, 114 moths in the week; Kawanda, 428


2
KENYA
UGANDA
WEST POKOT
SAMBURU
UASIN GISHU
MACHAKOS
PARE
6 - 12 April 1970
4
ACHOLI
TESO
BUKEDI
UASIN GISHU
KIAMBU
MOME
2 - 8 April 1971
1
Equator
ARUSHA
MBULU
TANZANIA
KILOSA
MOROGORO
16 - 22 January 1970
3
NYANZA
NAROK
MACHAKOS
KAJIADO
KILIMANJARO
GEITA
ARUSHA
TAITA-TAV
MASAI
PARE
MBULU
HANDENI
KILOSA
MOROGORO
ULANGA
15 - 21 January 1971

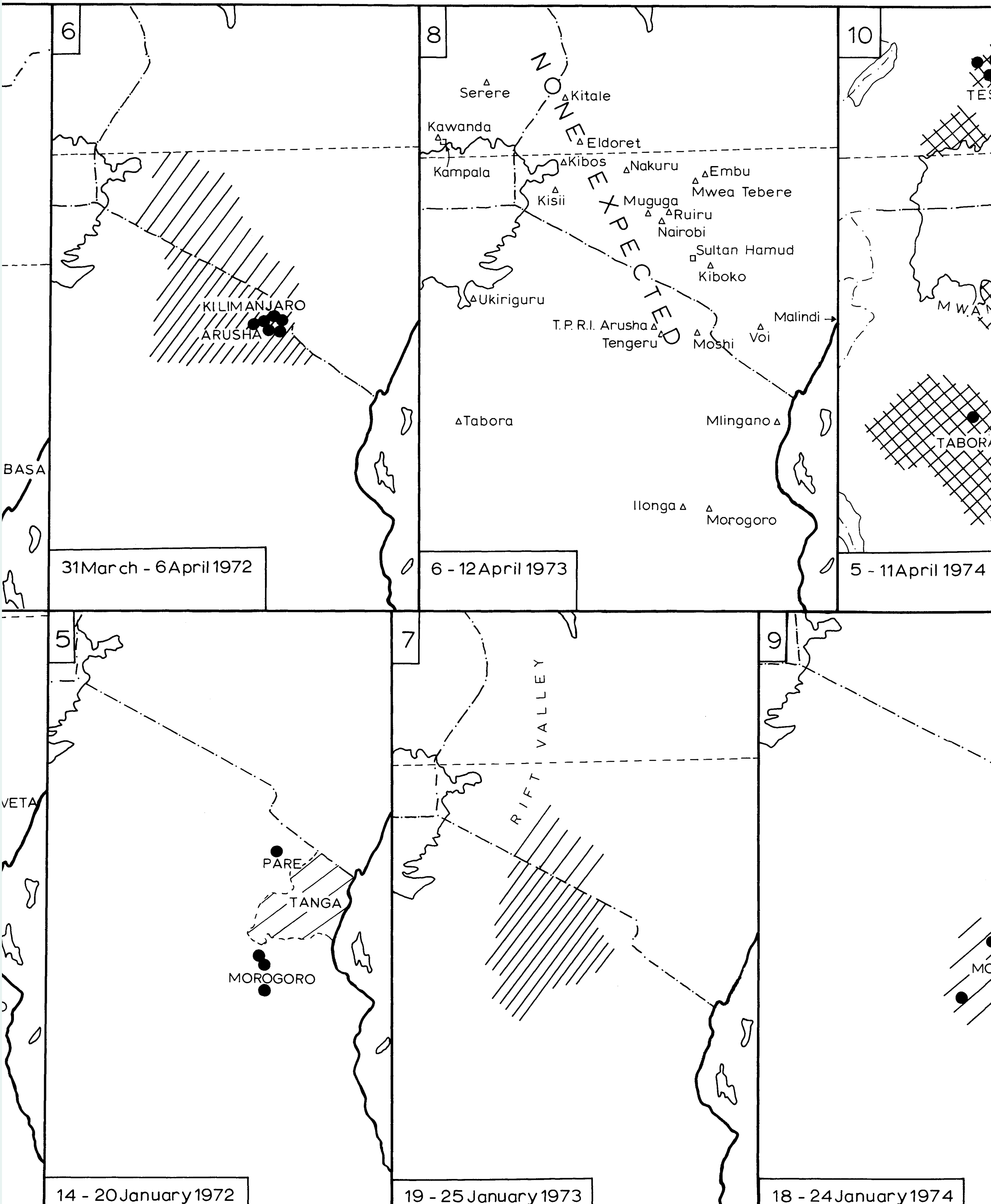
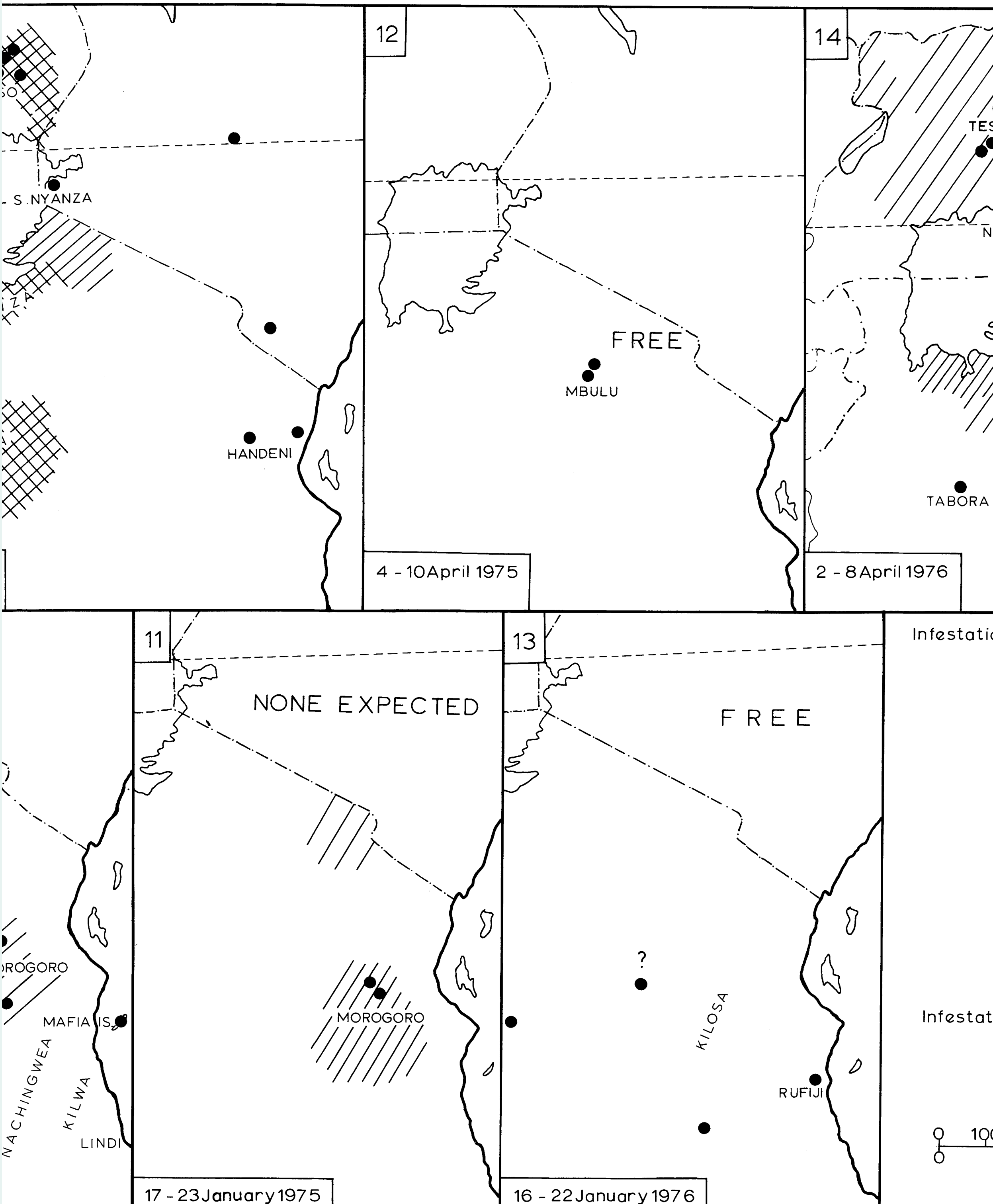


FIGURE 3. Cartographical verification of armyworm forecasts for two corresponding weeks, in January and Apri seasons (1969–70 to 1975–6). Map 8 includes sites of all light traps mentioned in tex



ril, in each of seven successive
xt.


BUSIA
KAKAMEGA
Equator
ANZA
KISUMU
KERICHO
MURANGA
S. NYANZA
NAROK
MACHAKOS
SERENGETI
LOITOKITOK
KILIMANJARO
ons forecast as:
expected
may occur
low probability
in areas outlined
ons present during forecast week
Trap site
200 300 400 500 Kilometres
100 200 300 Miles

moths; Kitale, in west Kenya, 70 moths in two nights), and to failure to recognize that 14 moths taken at Eldoret might represent the western extension of the main population.

TABLE 2. VERIFICATION OF THE FORECAST FOR THE WEEK 2–8 APRIL 1976

(*a*) *Infestations forecast correctly*

reference no.	*larvae forecast*	*infestations within forecast period*
	KENYA	
1	Machakos district	a radius of 5 miles from Machakos town (approximately 200 km²)
2	Kajiado district	1 km² of rangeland and cultivations at Loitokitok
5	Narok district	unknown size in Masai Mara
9	rest of Central Province (Muranga, Kirinyaga, Nyeri and Nyandarua districts)	71 ha of maize and pasture grasses in Muranga district
	TANZANIA	
11	Kilimanjaro	24 km² of maize, finger millet and grasses
17	Mara Region	unknown size, in Serengeti National Park
	UGANDA	
19	Teso district	'intensive' outbreaks in central, north and south Teso

(*b*) *infestations forecast incorrectly*

Ref. Nos: 3, 4, 6–8, 10, 12–16, 18, 20–23	no larvae reported from any of these areas

(*c*) *infestations not forecast, that occurred*

area	*infestations reported*
KENYA	
Nyanza Province	at many points in all four districts, including particularly some 200 km² of crops and grazing in South Nyanza district
Western Province (Kakamega & Busia districts)	14 km² of crops and pastures
Rift Valley Province (Kericho district)	'large' area on maize
TANZANIA	
Tabora district	4 ha on grasses

(*b*) *Analysis of a forecast early in the season*

By contrast, the 1972–3 season had very low populations throughout. The first outbreak, on 30 December 1972 on 60 ha of sugar cane and grazing in west Kenya, was unusually far west. Six light traps in Rift Valley and Nyanza Provinces – only 40–140 km away – had not yet caught any *S. exempta* moths, though those in Uganda had started catching moths one week before the date of the outbreak. Very low populations were recorded in Tanzania up to early January when catches increased at traps in the northeast, reaching 657 on 8–9 January at Tengeru and 251 on 5–6 January at the Tropical Pesticides Research Institute northwest of Arusha. Both these traps have histories of high catches, often exceeding 1000 moths in a night when populations in the area are large and once, at Tengeru, over 107000 *S. exempta* in one night (on 21 December 1970). Therefore a few hundred moths in January 1973 implied only a moderate population, and it was considered that a single moth caught at Moshi, 75 km east of Tengeru, probably represented the east end of the distribution area of this population.

It therefore seemed possible that there might be infestations in Arusha district and in the grasslands generally west of Arusha in north Tanzania and adjoining southwest Kenya, but not elsewhere since catches at other East African traps were only low. This moderate probability forecast, initially issued the previous week, was carried forward into the sample week 19–25 January 1973 (illustrated in figure 3, map 7), amended – as quoted below – only to indicate that the larvae would be older:

'Outbreaks of older armyworm larvae may still be reported in the Arusha, Masai and Mbulu districts of Northern Tanzania, following the high moth population recently recorded in the area, and there is still a possibility of infestations being discovered across the border in Kenya's west Kajiado and east Narok districts. No infestations are expected to occur elsewhere in East Africa.'

In the event, no infestations at all were reported, and, in view of the very limited subsequent developments during this season, it is improbable that any large populations were indeed around, although small infestations might easily have been overlooked in the grazing lands which occupy much of the area concerned.

(c) *Forecasting performance at the same times in seven seasons*

(i) *The* 1969–70 *season.*

Figure 3, *map* 1. Forecast for 16–22 January was based on moth populations which extended from Uganda to Tanzania and were numerous in the Nairobi area during 5–11 January. However, when increasingly high catches from Ilonga trap in Kilosa district for the same week (peak 814 on 7–8 Jan.) were received a day later, a supplementary forecast, concentrating on the Kilosa-Morogoro areas, was issued on 15 January.

All known subsequent infestations were covered by this forecast.

Figure 3, *map* 2. Forecast for 6–12 April was issued following reports of several infestations of larvae in south central Kenya, including Machakos district, west Kenya (Kakamega) and east Uganda (Bukedi), and of moths from north Tanzania through Kenya to Uganda, numerous around Nairobi in spite of being close to full-moon period. Only three infestations were not covered, one in Pare district of northern Tanzania, one in Narok and the other in Samburu district of Kenya.

(ii) *The* 1970–1 *season*

Figure 3, *map* 3. Forecast for 15–21 January was issued following reports of widespread infestations of young to older larvae (and pupae) in south central Kenya and across north Tanzania during 4–10 January. Moths had also started to emerge in Machakos and Serengeti areas, and catches in Kenya were decreasing (except at Voi), while those in Tanzania were quite large. All but the northernmost of subsequent infestations were covered by the forecast.

Figure 3, *map* 4. Forecast for 2–8 April was preceded by small outbreaks of young larvae in west Kenya (e.g. Uasin Gishu district), and by older larvae and pupae in neighbouring Kakamega district and in Kisii and Kisumu districts of Nyanza Province. High concentrations of moths were recorded around Nairobi (with Ruiru recording unprecedented peaks of 20720 and 14872 on 24–25 and 25–26 April respectively), while the remaining traps seldom had above 10 moths in a night. Uganda had moderate catches at Serere and Kawanda, while Tanzania had relatively high catches at Moshi but low ones elsewhere. All known outbreaks except two were covered by the forecast.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

(iii) *The* 1971–2 *season*

Figure 3, *map* 5. Forecast for 14–20 January was preceded by very slight increases in catches of moths during 3–9 January, though in Tanzania only Mlingano near Tanga caught up to 9 moths and Ilonga only 2, while in Kenya, only 2 moths were caught at Muguga on 4–5 January and none in Uganda. No larvae had been reported. The only known infestations occurred outside Tanga Region, in places without light traps.

Figure 3, *map* 6. Forecast for 31 March–6 April followed a small but severe outbreak on maize and finger millet near Moshi, Kilimanjaro district, on 26 March and moderate increases in moth catches through north Tanzania (Tengeru from 140 on 14–15 March to 484 on 21–22), with lower catches in Uganda (up to 9 moths at Kawanda on 20–21 March), and medium ones in Kenya (single moths at Nairobi and Kibos, up to 20 in a night at Voi and up to 108 on 24–25 March at Muguga). Known outbreaks were within areas forecast.

(iv) *The* 1972–3 *season*

Figure 3, *map* 7. Forecast for 19–25 January discussed in detail above.

Figure 3, *map* 8. Forecast for 6–12 April followed an absence of recorded infestations of larvae during 26 March–1 April, and very low moth catches (below five per night) throughout East Africa. No larvae were subsequently reported.

(v) *The* 1973–4 *season*

Figure 3, *map* 9. Forecast for 18–24 January followed scattered outbreaks of larvae $1\frac{1}{2}$–3 cm long attacking sorghum, maize and grazing, reported between 1–4 January over an area of some 6500 km^2 in Lindi, Nachingwea and Kilwa districts of southeast Tanzania, 400 km southeast of the nearest light trap at Morogoro. It was full-moon week, and numbers of moths caught were very low (below three in a night in Tanzania and Kenya and nil in Uganda during 7–13 January). Known outbreaks, except one in Mafia Island, were covered by the forecasts.

Figure 3, *map* 10. Forecast for 5–11 April was preceded by reports of slight increases in moth catches in Kenya around Nairobi, in Tanzania between Tabora and Mwanza, and in Uganda near Kampala, though no larvae had been reported during 25–31 March. Infestations were missed, in south Nyanza and three eastern districts of Kenya and Tanzania.

(vi) *The* 1974–5 *season*

Figure 3, *map* 11. Forecast for 17–23 January was issued after rapid increases in moth numbers near Arusha, nil catches at Ukiriguru, Tabora and Morogoro, and no reports from Ilonga, which had however had high catches during 30 December–5 January. Also considered were reports of nil catches in Kenya and Uganda, and no outbreaks so far. Reported subsequent outbreaks in Morogoro Region were predicted correctly.

Figure 3, *map* 12. Forecast for 4–10 April was issued when no infestations of larvae had been reported since 27 February, and moth catches were low throughout East Africa (below three in a night). Two outbreaks in north Tanzania were missed, because of failure of the nearest light traps.

(vii) *The* 1975–6 *season*

Figure 3, *map* 13. Forecast for 16–22 January followed reports of slight increases in moth catches in Kenya (below nine in a night), no catches in Uganda, no reports from Tanzania, and no infestations of larvae since 1 January when larvae were near Kilosa: sixth instars collected there on 9 January 1976. All five outbreaks were therefore missed, due to absence of trap reports.

Figure 3, *map* 14. Forecast for 2–8 April discussed in detail above.

(viii) *Conclusions from verification of forecasts*

There was a high rate of success both early and later in the seasons, but with some failures which were due to problems such as trap operators being on leave or sick without competent replacements and telephones not working, so that vital information was received too late or not at all; or the forecaster overlooking or misinterpreting important data. The basic requirements for the continued and greater success of the service therefore include improved communication, i.e. prompt, regular and reliable reporting of catches of moths and infestations of larvae; continuing research and analysis, including assessment of population changes between and within generations; and comprehensive and versatile application of experience and new findings.

However, most of the infestations were predicted correctly at all levels of armyworm populations during the past seven years, including, for example, the first recorded infestations of the 1969–70 season, in east central Tanzania, and of the 1970–1 season in southeast Kenya (Odiyo 1975*b*), while during the 1975–6 season, 96% of all recorded areas in Tanzania, 89% in Kenya and 100% in Uganda (table 1) were covered by the forecasts. Therefore the scientific principles and operational guidelines of the service appear to be sound and adequate for *S. exempta*, and might possibly be found appropriate for other migrant noctuids as well.

My grateful thanks go to my assistant, C. E. Muchiri, for running the service during my absences, as well as helping out with the illustrations; J. Gichuru and J. Muriu for helping with routine checking, identification and documentation of incoming and local specimens of moths and larvae; Agricultural Officers in Tanzania, Kenya and Uganda and collaborating research stations which run light traps; I.C.I.P.E. research centre, Nairobi, for regular exchange of information on armyworm outbreaks; the National Armyworm Coordinators for Tanzania (A. M. Mushi), Uganda (D. K. Byaruhanga), and Kenya (C. P. F. de Lima), for their interest in and support for the forecasting service; Miss E. Betts of C.O.P.R. London for her continued interest in armyworm problems; and the Commonwealth Foundation and the Ministry of Overseas Development for air fares and subsistence for my present visit to London.

I am especially grateful to Dr R. C. Rainey, F.R.S. of C.O.P.R., London, for consistent and inspiring professional encouragement he has given me over the years and to Dr B. N. Majisu, Director, EAAFRO, for his moral and official support in my work and for approving the publication of this paper.

References (Odiyo)

Betts, E. 1976 Forecasting infestations of tropical migrant pests: the Desert Locust and the African Armyworm. *Symp. R. ent. Soc., Lond.* **7**, 113–134.

Betts, E. & Odiyo, P. 1968 A preliminary note on the use of light trap data for forecasting outbreaks. *Rec. Res. E. Afr. agric. For. Res. Org. 1967*, pp. 111–112.

Betts, E., Odiyo, P. & Rainey, R. C. 1969 Development of forecasting methods. *Rec. Res. E. Afr. agric. For. Res. Org. 1968*, pp. 123–124.

Betts, E., Rainey, R. C., Brown, E. S., Mohamed, A. K. A. & Odiyo, P. 1970 Inauguration of an experimental armyworm forecasting service in East Africa. *Rec. Res. E. Afr. agric. For. Res. Org. 1969*, pp. 110–112.

Brown, E. S. 1962 The African Armyworm, *Spodoptera exempta* (Walker) (Lepidoptera, Noctuidae): a review of the literature. London: Commonwealth Institute of Entomology.

Brown, E. S., Betts, E. & Rainey, R. C., 1969 Seasonal changes in distribution of the African Armyworm with special reference to eastern Africa. *Bull. ent. Res.* **58**, 661–728.

Brown, E. S. & Dewhurst, C. F. 1975 The genus *Spodoptera*, (Lepidoptera, Noctuidae) in Africa and the Near East. *Bull. ent. Res.* **65**, 221–262.

Brown, E. S. & Odiyo, P. 1968 The rate of feeding of the African Armyworm and its significance for control operations. *E. Afr. agric. For. J.* **33**, 245–256.

Brown, E. S., Stower, W. J., Yeates, M. N. D. B. & Rainey, R. C. 1970 Armyworm control on rangeland: a further application of aerial drift spraying. *E. Afr. agric. For. J.* **35**, 350–358.

Brown, E. S. & Swaine, G. 1966 New evidence on the migration of the African armyworm. *Bull. ent. Res.* **56**, 671–684.

Campion, D. G., Odiyo, P. O., Mushi, A. M., Hall, D. R., Lester, R. & Nesbitt, B. F. 1976 Field tests with the synthetic sex pheromone of the African armyworm. London: C.O.P.R. *Misc. Rep.* **25**.

Commonwealth Institute of Entomology 1972 *Laphygma exempta* (Wlk.). *Distrib. Maps Insect Pests*, **53**.

Haggis, M. J. 1971 Light-trap catches of *Spodoptera exempta* (Walk.) in relation to wind direction. *E. Afr. agric. For. J.* **37**, 100–108.

McKay, A. D. 1971 Seasonal and management effects on the composition and availability of herbage, steer diet and live-weight gains in a *Themeda triandra* grassland in Kenya. II. Results of herbage studies, diet selected and live-weight gains. *J. agric. Sci., Camb.* **76**, 9–26.

Odiyo, P. O. 1972 Reliability of the first full scale forecasting service. *Rec. Res. E. Afr. agric. For. Res. Org. 1971*, pp. 200–202.

Odiyo, P. O. 1974 Reliability of the [armyworm] forecasting service. *Rec. Res. E. Afr. agric. For. Res. Org. 1972*, pp. 133–137.

Odiyo, P. O. 1975*a* Reliability of the [armyworm] forecasting service. *Rec. Res. E. Afr. agric. For. Res. Org. 1973*, pp. 196–198.

Odiyo, P. O. 1975*b* Forecasting the first [armyworm] outbreaks in East Africa: 1969–73. *Rec. Res. E. Afr. agric. For. Res. Org. 1973*, pp. 198–200.

Odiyo, P. O. 1977 Reliability of the 1974–75 [armyworm] forecasts. *Rec. Res. E. Afr. agric. For. Res. Org. 1975*, pp. 138–139 & 141.

Odiyo, P. O. & Muchiri, C. E. 1976 Armyworm forecasting for East Africa in the 1973–74 season. *Rec. Res. E. Afr. agric. For. Res. Org. 1974*, pp. 149–151.

Rose, D. J. W. 1975 Field development and quality changes in successive generations of *Spodoptera exempta* (Wlk.), the African armyworm. *J. appl. Ecol.* **12**, 727–739.

S.E.I.C. 1971 *Report of 15th meeting of the Specialist Entomological and Insecticides Committee*, 18–19 *November* 1971, *Nairobi*. pp. 10–11.

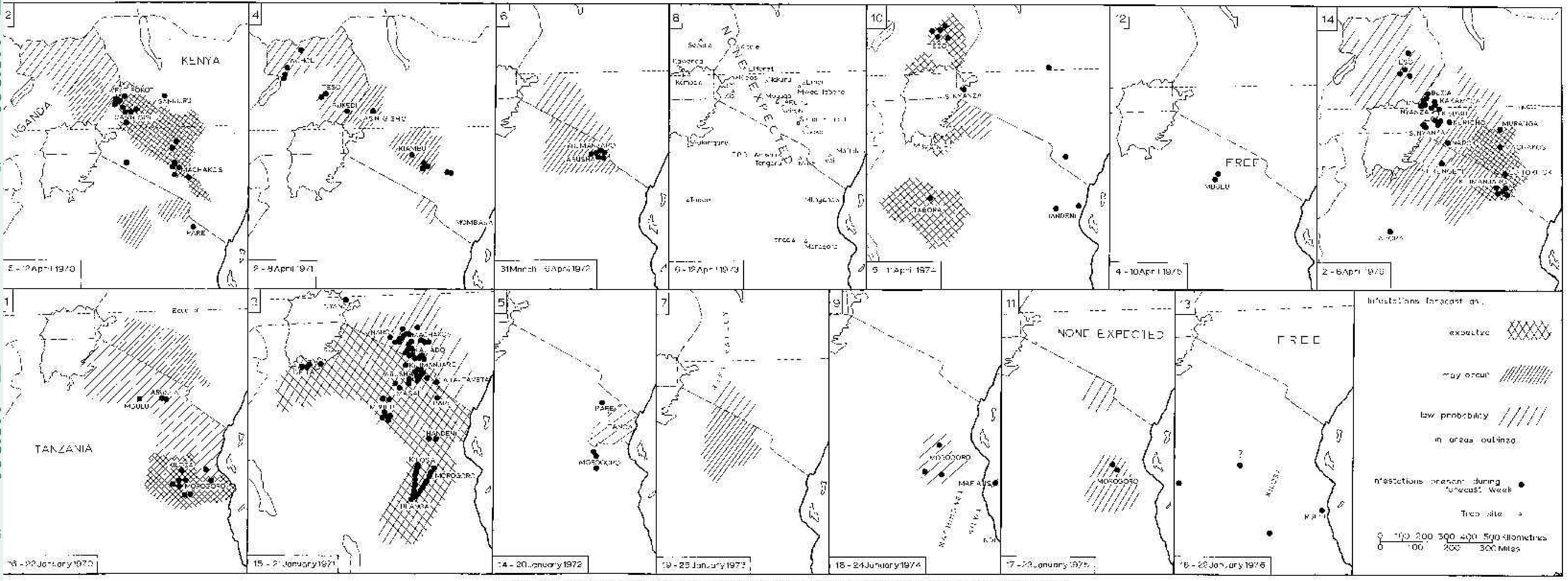


Figure 3. Cartographical verification of armyworm forecasts for two corresponding weeks, in January and April, in each of seven successive seasons (1969–70 to 1975–6). Map 8 includes sites of all light traps mentioned in text.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES