accounted for by the bush clearing operations in the valley of the Sitilo stream (see Map 6) which commenced at the Pongola river and were continued up to the Swaziland border. This had the effect of driving the flies ahead of the clearing gangs with consequent dispersion into those bush leaders forming the source of this stream. These flies were dealt with subsequently by five applications of insecticide.

It is interesting to note, further, that in contradistinction to the state of affairs in the Mkuzi game reserve where flies disappeared from the dispersion zones long before final elimination was achieved within the breeding areas, the reverse was the case here. The explanation may possibly be sought in the nature of the country, which consists of numerous interconnecting narrow bushed valleys to which tsetse flies must remain confined for climatic reasons, and the variety and difference in degrees of efficiency of the measures employed. The effect was that of dispersing flies along the bush-covered leaders.

It must be borne in mind, finally, that in any area in which some breeding has taken place it may be possible for a few flies to survive for periods of up to eleven months, i.e. for as long as five months in the pupal stage during the colder weather, and up to six months as adults. The chances of recording all such flies by the survey methods employed are extremely remote.

### 3. *The Umfolozi game reserve.*

Operations commenced in this reserve in April 1947. Use was made of Anson aircraft of the South African Air Force and, to start with, the insecticide applied was DDT which was replaced with BHC in 1948, for reasons of economy.

At the commencement of operations the incidence of Nagana in the Ntambanana settlement area, situated within the valley of the Enseleni river to the south of the Umfolozi reserve, was high and treatment of this area was deemed advisable. Consequently aerial applications were undertaken in both the Umfolozi and the Ntambanana settlement simultaneously.

The reduction in the incidence of *G. pallidipes* in the Ntambanana settlement is compared with the position in the Umfolozi reserve in the accompanying graph, Figure No. 13. The years 1945 to 1947 are dealt with in order to indicate the relationship existing between the Umfolozi reserve, a breeding area, and the Ntambanana settlement, a dispersion area, in which subsequent pupal surveys revealed that no breeding had occurred (see Map 4).

It will be noted that the August-September peaks in fly incidence as revealed by Harris trap catches, are very well defined for Umfolozi in both 1945 and 1946. No corresponding peaks for these months are apparent in the Ntambanana area, but more gradual rises in the density of flies become apparent during the ensuing months. This has been interpreted as indicating reinforcement of this area by flies dispersing from the Umfolozi reserve during the periods of peak abundance.

When applications of insecticide commenced in April 1947, fly incidence was reduced fairly rapidly in the Umfolozi reserve, whereas the rate of reduction in the Ntambanana settlement area occurred with much greater rapidity to the point of final elimination in August, normally a peak period in breeding areas.

The progress of the campaign in the Umfolozi game reserve for the period 1947 to 1951, is dealt with in the following graph, Figure No. 14.

It has been necessary to make use of various scales in order to portray the rate of decrease in fly incidence. This creates the impression that the reduction was more gradual after the commencement of spraying than was actually the case. In October 1947, bait cattle were introduced to supplement the Harris trap surveys and thus increase the efficiency of the surveys throughout the reserve. The five groups (of two each) to start with, were added to gradually until in April 1950, the total number of groups operating had been increased to 22. This was considered sufficient to thoroughly cover the entire area. The introduction of bait cattle surveys, considerably more efficient than trap surveys, create the impression of an increase in the apparent density of flies. For this reason the two methods must be recorded separately.

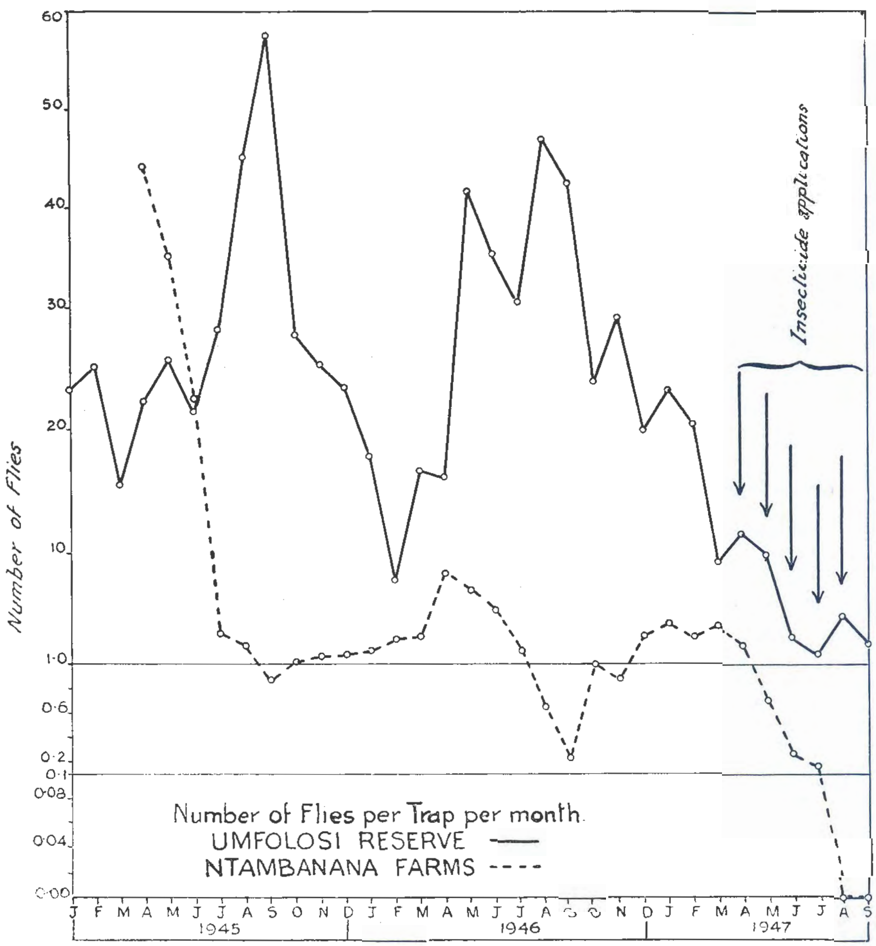



FIG. 13.

Aerial applications with five to six Anson Aircraft were conducted efficiently throughout 1947, at intervals of approximately three weeks to one month. In 1948, no spraying was carried out during the winter months and difficulties were experienced with serviceability of aircraft during 1949. This resulted in several breaks in the programme. Between October 1949 and March 1950, applications by Anson aircraft ceased. Later in March they were continued on a very much reduced scale with three machines only. These were further reduced to one or two for the ensuing months. At the end of March 1951, the aircraft were withdrawn entirely.

The incidence of *G. pallidipes* in the Umfolozi reserve and surrounding buffer zones, in terms of the Harris trap surveys, decreased rapidly to start with as the result of the applications of insecticide by aircraft. Thereafter, from about October 1947, the rate of decline was less rapid but, nevertheless, was sustained at a progressively decreasing rate. The bait cattle surveys showed a similar decrease in the incidence of fly, but as elimination point was approached, as revealed by the trap surveys, the rate of reduction in terms of bait cattle surveys, increased until the two curves practically met at the zero point during 1950.

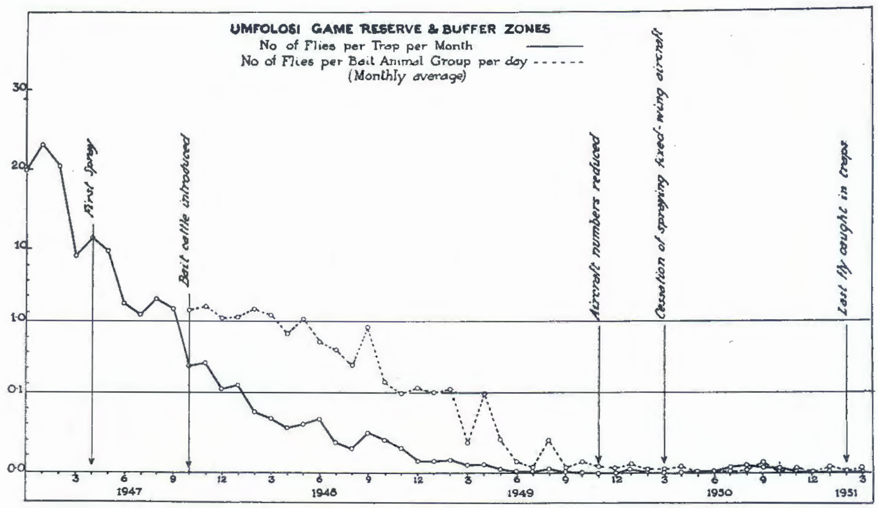



FIG. 14.

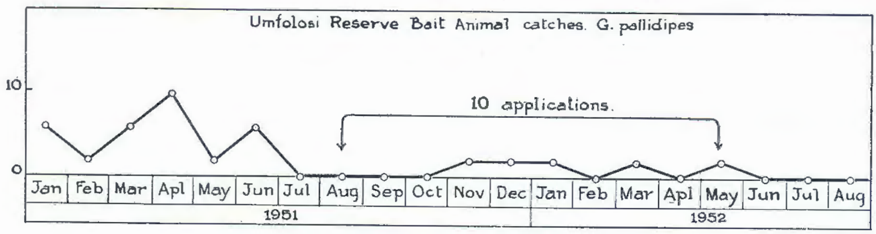



FIG. 15.

The reasons for this continued retardation in decline of fly incidence is attributable, firstly to progressively less regular insecticide applications. Secondly, the terrain played a prominent part in increasing the difficulty of eradicating the flies. The country is undulating and consists of numerous densely bushed valleys draining into the Black and White Umfolozi rivers, which form the boundaries of the reserve proper. Although reasonably accessible to aircraft, greater difficulty was experienced in many parts in obtaining as efficient a penetration of the insecticidal smoke into the bush than was the case in the Mkuzi reserve, where the country is flat. It must be assumed, therefore, that some breeding of flies, which escaped destruction, continued for a considerable time. Finally, the area requiring treatment was many times the size of the area treated in the Mkuzi reserve, and comparatively small sections only could be dealt with at a time. The result was that flies from valleys or areas awaiting treatment had every chance of dispersing into sections already dealt with and in this way escaping destruction until the following or later applications.

Applications of insecticide ceased at the end of March 1951, but actually no regular spraying schedule had been carried out in the Umfolozi area during the previous year. Flies had been reduced practically to elimination point, but occasional flies were still being taken, often at points widely separated. This demonstrated the ability of *G. pallidipes* to persist in an area at extremely low densities. The tendency in fly incidence, however, was still towards final disappearance and, in February 1951, the last fly to be recorded in the area, so far as the Harris trap survey was concerned, was taken. It must be mentioned, however, that occasional applications of BHC in valleys where flies were captured were undertaken by means of a helicopter diverted from the Hluhluwe game reserve for the purpose. This no doubt assisted in maintaining the decrease in fly incidence noted.

In August 1951, a final series of aerial applications of BHC in smoke form commenced with the object of bringing about final eradication of *G. pallidipes* in the Umfolozi reserve and surroundings. This work was undertaken by a firm of contractors using light aircraft, namely, Piper Cruisers. Applications were spaced at three-weekly intervals and the work was performed extremely efficiently with 100% serviceability of the six planes available throughout.

The results are recorded in Figure 15 with surveys undertaken by means of 22 groups of bait cattle only, as the Harris traps throughout the reserve proved valueless in recording flies at the extremely low density present in the area at this stage.

It is extremely difficult to account for the persistence of the isolated flies recorded over more than two years during which period virtual elimination seemed to have been reached. In view of the low reproductive potential of tsetse flies it might have been anticipated that elimination would have followed a reduction of flies to so low a level. It must be concluded that the survey methods employed probably show up only a fraction of the flies present.

### 4. *The Hluhluwe game reserve.*

This reserve had been fairly satisfactorily isolated by the two mile wide barrier clearing which followed its boundaries and was in the course of construction at the time that applications of insecticide were started in May 1947 (see Map 6).

Surveys had been carried out up until June 1947 by Harris traps which were in a poor state of repair and of which the hessian covers were badly weathered. These traps were re-covered with new hessian and a large number of new traps brought into operation during July. The effect was an immediate increase in the apparent density of fly throughout the reserve. This is reflected in graphical form in Figure No. 16.

The reserve, from the geophysical point of view, may be divided into two main parts. The area to the south of the Hluhluwe river, which runs obliquely from the southwest curves eastwards and leaves the reserve at about the centre of its eastern border, consists of undulating country heavily bushed with a savannah type of vegetation. This section is comparable to the Umfolozi reserve. It constitutes the main habitat of *G. pallidipes* and is fairly accessible to aircraft of the fixed-wing type. The northern portion is extremely mountainous and covered in the numerous steep valleys with dense forest for the most part evergreen. This constitutes the habitat of *G. brevipalpis*. The lower portions of the valleys north of the Hluhluwe river form a zone in which *G. pallidipes* merges into the habitat of *G. brevipalpis,* although this latter species has been recorded over the whole reserve (see Map 5).

The Hluhluwe reserve was not included in any of the game shooting campaigns previously described and consequently carries a very high density of game of all descriptions, including large herds of buffalo and many black rhinoceros.

Bait cattle surveys were put into operation in April 1948 (Figure 16). To start with, 15 groups of two cattle each were used in 1948, and these were added to from time to time as indicated in Figure 17, until October 1951, when there were 28 groups dispersed throughout the entire area.

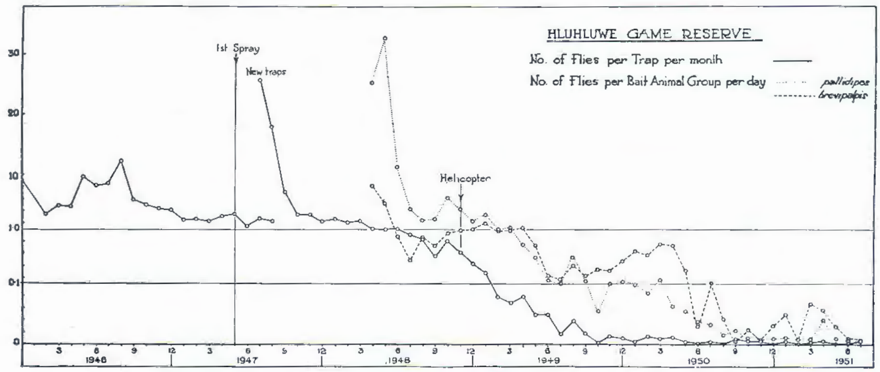



FIG. 16.

The reduction in fly density recorded by the Harris trap survey (Figure 16) includes both *G. pallidipes* and *G. brevipalpis.* The curve descends more gradually than is the case in the Umfolozi reserve. This is attributable to the following factors; firstly, the reduced efficiency of the trap for *G. brevipalpis,* secondly, the fact that the habitat of *G. brevipalpis* was largely inaccessible to fixed-wing aircraft and, thirdly, the methods employed during 1947 and 1948 for its destruction were not very efficient. The advent of helicopters in November 1948, which operated in the mountainous areas simultaneously with fixed-wing aircraft in the lower-lying more accessible areas, considerably increased the drop in total density. The bait cattle survey (Figure 17) clearly reflects the lower degree of efficiency in the destruction of *G. brevipalpis* due to its occurrence in dense forest near the crest of hills. Here air currents frequently reduced the efficiency of the insecticide by dispersing it before thorough penetration into the bush was achieved.

Prior to the introduction of helicopters, DDT was applied to the northern mountainous areas by means of thermal smoke generators and in dust form, according to the methods described in Chapter VII, (*c*) and (*d*).

In the following graphs, Figures 18 and 19, an attempt has been made in certain valleys within the Hluhluwe reserve, to compare the various methods of treatment applied in terms of trap surveys and bait cattle surveys. The latter, unfortunately, came into operation rather late.

It will be noted that although both smoke generators and dust applications tend to reduce the incidence of flies, the fixed-wing aircraft and helicopters represent a much more efficient means of achieving this end.

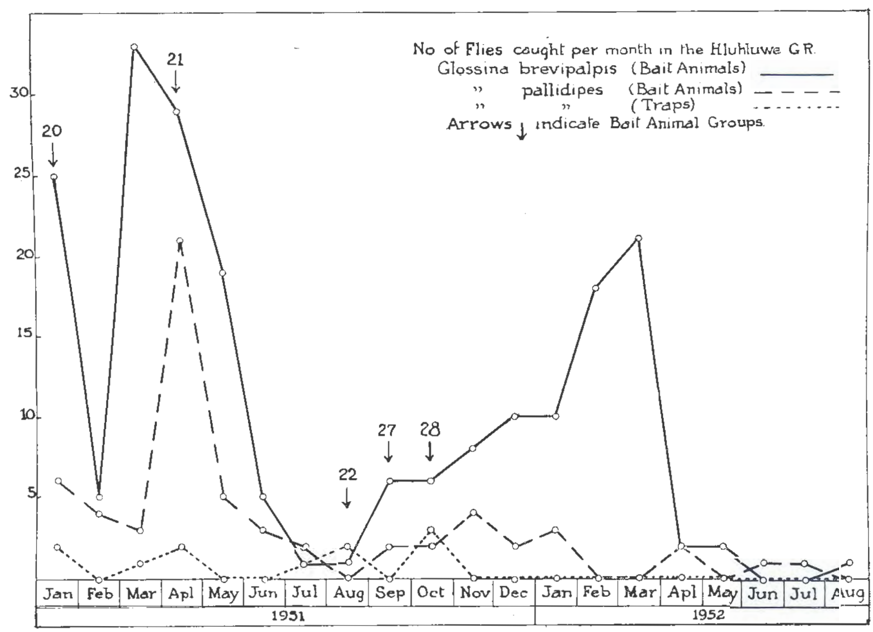
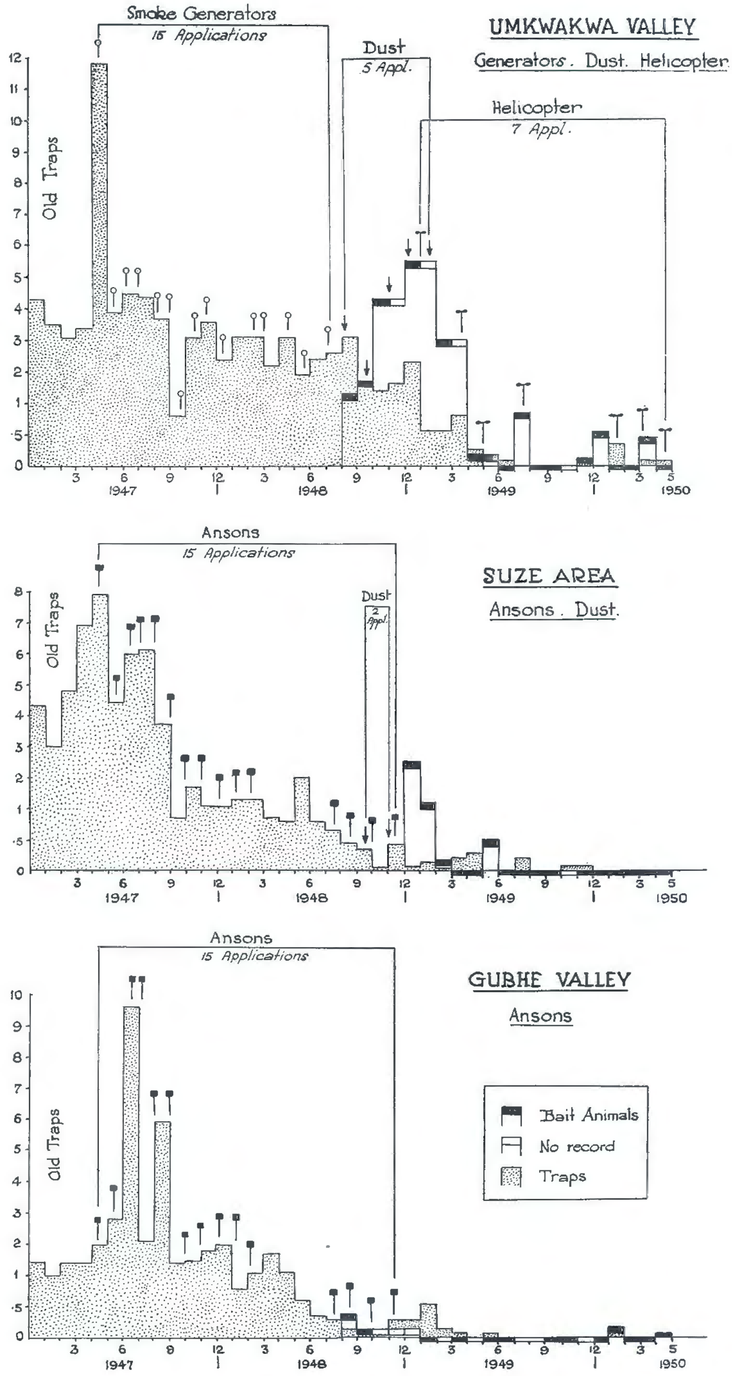



FIG. 17.

The same difficulties in continuing the applications of insecticide by aircraft during 1949 to 1951 were experienced in the Hluhluwe as was the case in the Umfolozi reserve. Helicopter operation was more satisfactory, however, in the mountainous areas to which their use was confined, but during the latter portion of 1950 and early 1951, the sustained regular applications of insecticide by these aircraft was not entirely satisfactory.

In August 1951, the work of applying the insecticide was taken over by private contractors using light aircraft of the fixed-wing type in the more level portions of the reserve to the south and helicopters in the northern mountainous areas. The contract called for the application of insecticide at three-weekly intervals during the summer months of 1951–1952, i.e. from August to the end of May. This schedule was well maintained and the results achieved in terms of trap and bait animal surveys have been portrayed in Figure No. 17.



Smoke Generators
15 Applications
Dust
5 Appl.
Helicopter
7 Appl.
UMKWAKWA VALLEY
Generators. Dust. Helicopter.
Old Traps
1947
1948
1949
1950
Ansons
15 Applications
Dust
2 Appl.
SUZE AREA
Ansons. Dust.
Ansons
15 Applications
GUBHE VALLEY
Ansons
Bait Animals
No record
Traps


FIG. 18.

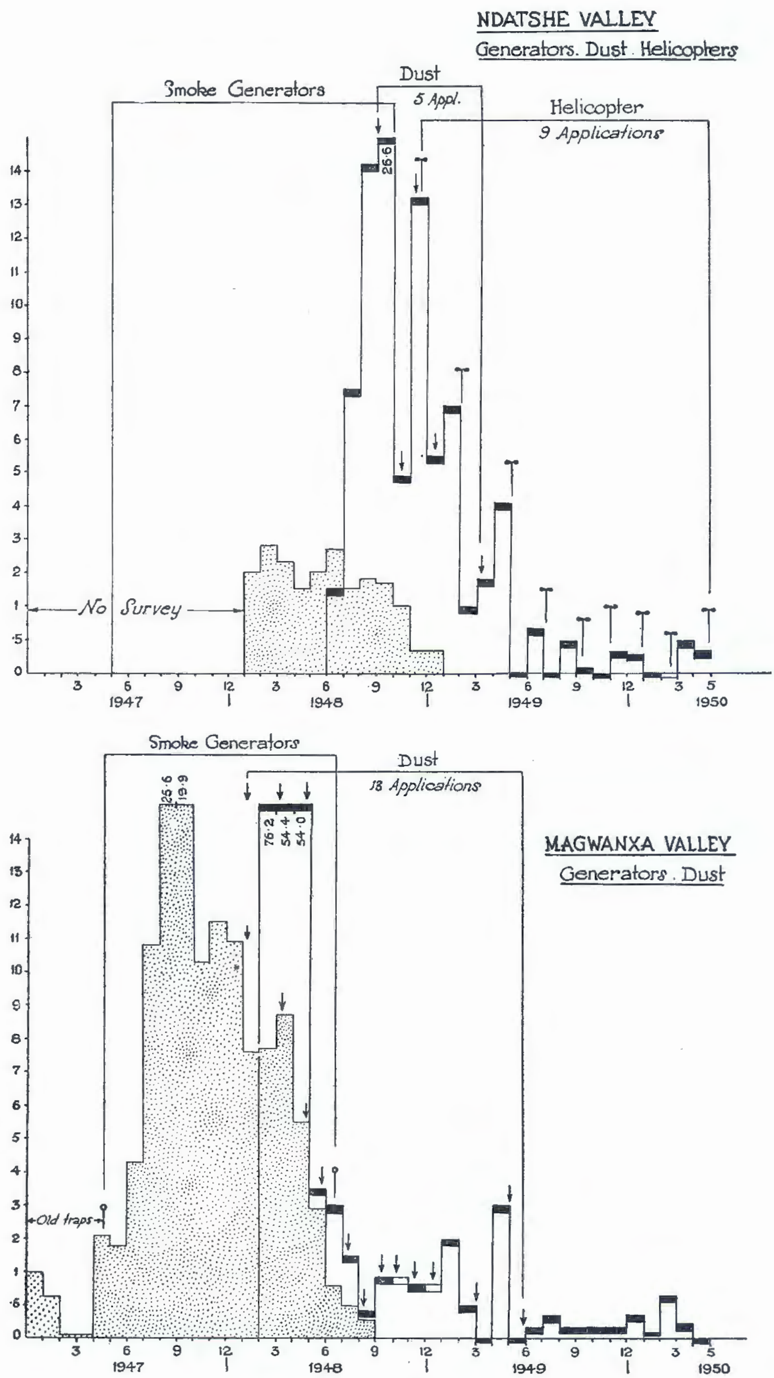

NDATSHE VALLEY
Generators. Dust. Helicopters
Smoke Generators
Dust
5 Appl.
Helicopter
9 Applications
26.6
No Survey
1947
1948
1949
1950
Smoke Generators
Dust
18 Applications
25.6
19.9
76.2
54.4
54.0
MAGWANXA VALLEY
Generators. Dust
Old traps

FIG. 19.

## XI. Estimate of Costs of the Campaign.

It will be readily appreciated that a campaign of the nature described, conducted over a period of more than seven years, has entailed a great deal of experimental work of an exploratory nature. An estimate of costs is difficult and must be dealt with under various headings.

The methods employed may be divided into:—

(*a*) Surveys, entailing those by Harris traps and bait animals and those involving pupal casings;

(*b*) Bush eradication, consisting of the creation of barriers and discriminative or thicket clearing;

(*c*) Insecticide applications, involving DDT by means of thermal smoke generators and in dust form, DDT to cattle by means of dipping and DDT or BHC by aircraft of the fixed-wing type and by helicopters.

### 1. *Surveys.*

An estimate of costs connected with the surveys conducted in Zululand would be of little value as these represented largely a continuation of the work, so far as the Harris traps were concerned, which had been in existence for many years. The bait animal surveys involved the provision of bait cattle and the necessary native personnel to handle them, together with European staff, part of whose duties only entailed supervising this work.

So far as the pupal-casing surveys were concerned, two gangs of eight natives were employed, but this work was also undertaken by natives employed upon other phases of the general operations under the supervision of European personnel. Costs, therefore, involve salaries only.

### 2. *Bush eradication.*

The following figures have been abstracted from the final report of the Division of Soil Conservation and Extension under whose charge this work was conducted.

Barrier clearings. This involved total clearing of all trees and bush over an area two miles wide and approximately 94 miles in total length. Costs varied according to the density of the forest and bush and have been considered as follows:—

(i) Dense forest—from £6. 8s. 3d. to £8. 11s. 8d. per acre. (These figures include preclearing of thickets and undergrowth by hand prior to machine pulling of trees).

(ii) Medium forest and bush. From £3. 4s. 9d. to £5. 6s. 10d. per acre. Preclearing varied in this case from 5s. 2d. to 7s. 6d. per acre, whereas tree removal amounted to £2. 19s. 7d. to £4. 19s. 4d. per acre.

(iii) Scattered bush—from 3s. 5d. to £1. 1s. 2d. per acre.

Discriminative or thicket clearing, as practised in the valleys leading into the Pongola and Mkuzi rivers in the Magut area, was undertaken by hand and averaged £1. 2s. 6d. per acre.

The overall costs of bush clearing in Zululand has amounted to an average of £1. 5s. 7d. per acre.

3. *Insecticide applications.*

(i) *DDT smoke generators.*—These averaged 3s. 6d. each and were spaced 70 yards apart or roughly 1 per acre. A minimum of eight applications would be necessary to effect eradication under conditions where complete coverage of breeding grounds with insecticide could be achieved. This is virtually impossible due to the tendency of DDT being deposited in the vicinity of the generator, as has been explained. The figure of eight applications is used for comparison with the other methods, to be described, in order to arrive at an estimate of costs and amounts to £1. 8s. 0d. per acre for the smoke generators only.

In practice each native is able to carry no more than 16 generators in a canvas carrier. This necessitates the replenishing of his supply from time to time, and the method is inevitably very time-consuming in that all types of bush and thicket must be negotiated on foot. The area it is possible to cope with per day is restricted to approximately an average of no more than 50 acres per boy depending upon the terrain, bearing in mind that applications are possible only during favourable weather conditions. Additional costs are high and involve the transportation of native and European personnel and their equipment to the site of operations. The cutting and making of roads in difficult terrain is frequently necessary.

An accurate overall figure for the application of insecticides by means of smoke generators is not possible from the rather scanty records kept in Zululand, but would probably approximate £2. 0s. 0d. per acre.

(ii) *DDT in dust form.*—5% DDT dust was applied at the rate of 5 lb. per acre by either hand- or machine-operated dusters. The cost of the dust amounts to 8s. 6d. per 5 lb., sufficient for one acre. Assuming the necessity for eight applications for the sake of comparison, this would amount to £3. 8s. 0d. per acre for dust alone. To this must be added the cost of the dusters and their maintenance, together with labour and transportation charges similar to those applying to the smoke generator method.

Again no accurate figure is possible, but it may be assumed that on the basis of eight applications, the costs per acre are in excess of £4. 0s. 0d.

(iii) *Applications of DDT to cattle by means of dipping.*—The application of DDT to cattle must be regarded as supplementary to the eradication measures applied within breeding areas. Only where cattle predominate numerically over game animals in any area, thereby providing the main food supply for flies, can the method by of any value.

The execution of the dipping campaign in Zululand, involving 144 dipping tanks and a total of roughly 150,000 head of cattle for twelve months dipping at weekly intervals, required a total sum of £25,000.

If this amount is spread over the 6,820 square miles or 4,364,800 acres comprising the area infested with *G. pallidipes* (excluding breeding areas treated by other methods) the cost per acre amounts to 1·37d.

(iv) *Aerial application of BHC in smoke form.*

(a) *Fixed-wing aircraft: Ansons.*—Based upon figures obtained during the course of the operations in Zululand, the costs amount to approximately 2s. 3d.

per acre per application or 18s. per acre for eight applications. The costs are made up as follows:—

> Aircraft of this type necessitate their being based at a well-prepared aerodrome. This frequently entails a considerable amount of unproductive flying to reach the site of operation. Operational costs amount to £22 per flying hour. Ground coverage with insecticide, on the basis of 120 m.p.h. forward speed and a swathe width of 70 yards, amounts to 50 acres per minute. Each aircraft is capable of 30 hours flying per month, on an average, of which 10 hours represents actual insecticide application. This comprises 30,000 acres per aircraft per month, or, total flying costs amount to 5·28d. per acre. This figure includes maintenance and personnel. Insecticide, or aerosol, consisting of 4% of the gamma isomer of BHC in diesel (fuel) oil, amounts to 8s. 6d. per gallon. This is fed into the exhaust stacks at a rate of 10 gallons per minute—equivalent to 50 acres, or 1 gallon per 5 acres. The cost amounts to 20·4d. per acre.
>
> This gives a total cost of 25·68d. per acre per application or 17·12 shillings per acre for eight applications.

*Piper cruisers.*—Flying costs in this case amount to £12. 10s. 0d. per aircraft per hour of which half represents time spent on applying insecticide. These light aircraft can be based on air-fields prepared close to the scene of operations as they are capable of taking off and landing over relatively short distances and on rough surfaces. Being more manoeuvreable than the heavier type of aircraft, their turning radius is short. This enables them to complete a swathe and to commence with succeeding swathes in a much shorter time. Finally, these aircraft were fitted with fuel-line pumps which ensured an even rate of flow of the insecticide in all positions of the aircraft. This feature was not incorporated in the Anson aircraft and, consequently, they were forced to apply insecticide while flying on an even keel or ascending. This necessitated considerably more dead flying on the part of the Ansons.

Ground coverage with insecticide on the basis of 100 m.p.h. forward speed and a swathe width of 25 yards amounts to 15 acres per minute. Thirty hours per month operation can be averaged of which 15 hours represents actual insecticide application. In this way each aircraft covers 13,500 acres per month. Total flying costs amount to 6·7d. per acre. Insecticide (4% gamma BHC aerosol) is fed into the exhaust stacks at a rate of 1·3 gallons per minute which is equivalent to 15 acres to give a cost of 8·84d. per acre.

The total cost amounts to 15·54d. per acre per application for each aircraft, or 124·32d. (10·36s.) per acre for eight applications.

(b) *Helicopters—Sikorsky S51.*—The operating costs of this type of aircraft amount to approximately £45 per flying hour inclusive of pilot and maintenance.

Application of insecticide is conducted at varying forward speeds and flow rate of insecticide is controlled by the pilot according to the forward speed. The usual forward speed is 40 m.p.h. and the flow rate of insecticide averages 3·3 gallons per minute. Swathe width averages 70 yards, which gives a figure for ground coverage by insecticide of approximately 17 acres per minute.

Spraying time, in relation to flying time amounts to approximately half. On a monthly basis it has been possible to operate helicopters for approximately 30 hours per month of which approximately half (or 15 hours) represents actual time of insecticide application. This is equivalent to a coverage of 15,300 acres per month per aircraft. From this data, operating or flying costs amount to 21·18d. per acre.

Insecticide costs, on the basis of 3·3 gallons per minute and a swathe width of 70 yards, which is equivalent to a coverage of 17 acres per minute, amounts to 13·92d. per acre.

Total costs, i.e. flying time plus insecticide costs, amount to 35·1d. per acre per application. For a total of eight applications the costs amount to £1. 3s. 4d. per acre.

For the sake of comparison with a method of tsetse fly control which has been practised very widely in Africa and used to a limited extent only in Zululand, namely, discriminative or thicket clearance to render the habitat of the fly untenable, the various methods of insecticide dispersion discussed may be summarized as follows. A hypothetical number of applications in each case is given which is considered to represent the minimum required in easily accessible terrain to effect eradication, in order to serve as a basis for such comparison.

| | | | | |
|---|---|---|---|---|
| Discriminative or thicket clearance ... ... ... | £1 | 2 | 6 | p. acre |
| DDT smoke generators (8 applications)—say | £2 | 0 | 0 | ,, |
| DDT dusting (8 applications)—say ... ... ... | £4 | 0 | 0 | ,, |
| Ansons aircraft (BHC 8 applications) ... ... | | 17 | 0 | ,, |
| Piper cruisers (BHC 8 applications) ... ... ... | | 10 | 4 | ,, |
| Helicopters (BHC 8 applications) ... ... ... | £1 | 3 | 4 | ,, |
| Dipping in DDT (dispersion areas) for 12 months | | 1·37d. | | ,, |

4. *Summary of costs of advocated methods.*

Assuming that, of the methods actually applied, those which have proved the most practical and economical only had been employed throughout, the costs could be computed on the following basis:—

| | | | | |
|---|---|---|---|---|
| Discriminative bush clearance ... ... ... ... | £1 | 2 | 6 | p. acre |
| Piper cruisers (8 applications) ... ... ... ... | | 10 | 4 | ,, |
| Helicopters (8 applications) ... ... ... ... ... | £1 | 3 | 4 | ,, |
| Dipping in DDT (12 months) ... ... ... ... ... | | 1·37d. | | ,, |

Items 2, 3 and 4 have been omitted in favour of the less expensive and more practical light aircraft (e.g. Piper cruisers), and helicopters used. Discriminative clearing could be omitted but was actually used and is included. If the above costs per acre were to be applied to the area of Zululand actually reclaimed from *G. pallidipes* as representing the most economical method of procedure in the light of experience and present knowledge, the costs must be apportioned as follows:—

| | | | |
|---|---|---|---|
| Discriminative clearing—approx. ... | 2,000 | acres | £ 2,200 |
| Piper cruisers (8 applications) app. | 115,200 | ,, | £ 59,520 |
| Helicopters (8 applications) app. ... | 25,600 | ,, | £ 29,867 |
| Dipping—12 months app. ... ... ... | 4,364,000 | ,, | £ 25,000 |
| Totals | 4,507,600 | ,, | £ 116,637 |
| Approximately | 4,500,000 | ,, | £ 200,000 |

Cost per acre = 10·6d.

It is, of course, obvious that in computing costs on the above basis many discrepancies exist which would form an integral part in any campaign conducted over any area as extensive as that comprising the fly belt of Zululand. No account has been taken of the following:—

*Capital expenditure.*

1. Accommodation, housing, tents, etc.
2. Equipment, e.g. bush clearing equipment, exposure cages, etc.
3. Vehicles.
4. Bait cattle.

*Transportation:*

(*a*) Between permanent base and scene of operations. In the present instance about 800 miles.
 (i) Railage on aerosol fluid and equipment.
 (ii) Aircraft liaison.

(*b*) Local.
 (i) Motor vehicles—maintenance and transportation of stores equipment and personnel.

*Labour* (a) *Native:*

(i) Bait animal surveys.
(ii) Pupal casing surveys.
(iii) Road construction.
(iv) Aerodrome, maintenance and loading of aircraft.
(v) Motor vehicle drivers.
(vi) Game control.

(b) *European:*

(i) Laboratory.
(ii) Supervisory.
(iii) Administration and records.

It is not possible to give any accurate figure to cover the costs involved in the above-mentioned items, but adequate provision for all eventualities would be made by doubling the overall costs of the operations per acre. On this basis the costs would amount to under 2s. per acre which, in terms of the ground reclaimed permanently from the threat of Nagana, would appear to represent an extremely sound investment.

The actual figure expended in Zululand amounts to between 9s. and 10s. per acre. It must be borne in mind that this figure includes an enormous amount of exploratory research in evolving ways and means of disseminating the insecticides, the cost of insecticides, labour and transportation. It represents considerable wastage in both flying time and insecticide during the course of devising the methods of application of insecticides finally adopted.

## XII. Discussion.

The evidence brought forward in this paper appears to indicate that the Zululand fly belt, which incorporates *Glossina pallidipes* as the dominant species, has persisted as an isolated entity at least within recorded time. That some land bridge existed at one time between Zululand and the rest of the continent of

Africa, where *G. pallidipes* shows a similar tendency towards localisation, seems reasonable to assume. An even greater tendency towards localisation exists in the case of *Glossina brevipalpis,* by virtue of its more specialised climatic requirements. *Glossina austeni* also displays a marked tendency towards limitation to certain vegetational thicket types. However, evidence has been obtained both in Zululand and Portuguese East Africa, of its occurrence in irregularly distributed localities largely confined to the coastal plains, from Zululand into East Africa.

In relation to Nagana in domestic animals, the savannah species (*G. pallidipes*) is the only Zululand tsetse fly capable of causing extensive epizootics. This is due to its faculty for dispersing into vegetational types in which the other two species are not able to exist for any length of time. In this way a far greater degree of contact between *G. pallidipes* and domestic animals is liable to occur than is possible with either *G. brevipalpis* or *G. austeni*. Domestic animals seldom wander into their domains, unless forced to, in their search for water. Even in such cases, the fact that these species are largely crepuscular in habits necessitates a somewhat exceptional set of circumstances before any very great degree of contact can occur. During the course of the present eradication campaign, evidence has been obtained that dispersion in the case of *G. pallidipes* appears to occur when the density of fly reaches a peak. At this stage, what might be termed a " population pressure " becomes manifest within the breeding areas. These breeding areas can be determined within very close limits by means of pupal casing surveys, as has been shown. They represent areas, which under the most adverse conditions, are capable of supporting a community of tsetse flies due to the balance which exists within them between the flies and their climatic and food requirements. In relation to the entire area infested by *G. pallidipes* in Zululand, the breeding areas comprise no more than 3% in extent. Evidence exists, as a result of the surveys conducted, that a similar state of affairs applies to both *G. brevipalpis* and *G austeni*. In relation to the areas into which these species will disperse and which are strictly limited in themselves, the breeding areas are very much more extensive.

Increased activity and a tendency to spread into territory surrounding the breeding areas have manifested themselves in the case of *G. pallidipes* at intervals of roughly ten years. The explanation for this phenomenon is not clear. No correlation appears to exist between such periods of increased activity and seasons of increased rainfall, as far as can be judged from available records. The studies of Fiedler, du Toit and Kluge (1953) on parasitism by bombyliids, previously mentioned (Chapter IV), may afford an explanation of the cyclical activity of this species, but it must be admitted that these considerations are largely speculative. Further investigation into this problem in an area in which the tsetse fly population has remained undisturbed, would perhaps yield information of considerable value.

During the course of the studies on the bionomics of the *Glossina spp.,* which embraced both *G. pallidipes* and *G. brevipalpis,* the duration of the period of pupation during the colder periods of the year from about April to August or September, is of considerable interest. Under natural conditions the limits of pupation may approach five months during the colder weather. That such a period might be inferred, finds support in the results obtained by the first series of insecticide applications in smoke form, applied in the Mkuzi game reserve between August and November 1946. Within this period of four months *G. pallidipes* was reduced from an average of 1,350 flies per week to about 10 or less per week. It must be admitted that 100% destruction of all adult flies with each application cannot be assumed, but according to numerous exposure tests of tsetse flies in cages, the mortality achieved appeared to exceed 90%.

Furthermore, reinvasion of the reserve proper from surrounding areas could be excluded, as flies had reached zero in these areas, as judged by the surveys conducted within them. At this period of the year, namely early summer, all pupae at the commencement of operations should have hatched by the middle of September, if the classical pupation period is accepted. Flies persisted, although at a much reduced density, until completion of the insecticide treatments. Thereafter the fly density continued at a low level until the end of the summer of 1947, when a gradual increase in numbers became noticeable.

From this, and evidence subsequently accumulated, the conclusion was arrived at that better results would be achieved by extending the time between applications. With a given number of applications spaced at intervals of three weeks to one month, a longer period of time is covered. This ensures that all pupae present in the ground at the commencement will be given an ample opportunity of hatching and the resultant adults destroyed.

The mass of evidence on the constitution of the biotope, particularly of *G. pallidipes,* accumulated as a result of the various methods of survey employed, has demonstrated very clearly how misleading the placing of too much emphasis on one method only may be. Mortality in livestock alone, as a method of assessing the density of tsetse flies, may lead to extremely incorrect conclusions being drawn. In this respect, high densities of flies have been recorded where cattle have been closely herded adjacent to breeding areas, but such local densities may be of a temporary nature only. Local concentrations of flies may be encountered in dispersion areas, where vegetational conditions appear to be ideal, but which are visited only periodically by game animals. This was the case in localised bushed areas surrounding the Mkuzi game reserve. In spite of high fly densities, little or no evidence of breeding could be demonstrated in these localities.

Trap surveys, while serving a useful purpose when the density of tsetse flies is high, become practically valueless when the density drops to a low level. Under these conditions bait animal surveys constitute the only means known at present of arriving at an assessment of relative density of fly. In comparison with pupal-casing surveys, which indicate the areas in which larval deposition has been most consistent, all surveys for adult flies fail largely to present a clear picture of the true breeding areas.

Only when the true breeding areas in relation to the dispersion areas have been determined is it possible to undertake eradication by means of insecticides successfully and economically by this direct attack upon tsetse flies.

It follows that breeding areas will stand in direct relationship to the greatest permanent accumulation of host animals within the environmental requirements of the particular species of tsetse fly to be dealt with. The essence of a successful outcome to a campaign envisaging the elimination of the fly species consists in disturbing the host animals as little as possible, thereby encouraging the fly to remain within this area until they can be dealt with.

The aircraft lends itself admirably to the application of insecticides to extensive areas of country. The method of insecticide dispersion which has proved itself to be by far the most practical and economical is the smoke or exhaust aerosol method described. No account is taken of residual deposits of insecticide upon vegetation, the aim being the complete destruction of all adult flies with each application. Depending upon the type of aircraft used from 13,500 to 30,000 acres can be covered per month by a single aircraft. The type of aircraft used in the latter phases of the campaign in Zululand has proved to be extremely effective at the low emission rate of insecticide applied, namely, 1 gallon per 15 acres.

Six aircraft are capable of covering 126·5 square miles per month, which need comprise breeding areas only. If it be assumed that the figure of 3%, which comprised the breeding areas in relation to the total area infested in Zululand, holds for similar infested areas in Africa, six aircraft are capable of covering 4,217 square miles per application.

During the course of the present campaign a considerable amount of experimentation was inevitable in evolving the entire method of operation. Consequent loss of peak efficiency and considerable wastage resulted. The experience gained points to the fact that under good conditions complete eradication of *G. pallidipes* could be achieved with eight, or at most ten, applications of BHC in exhaust aerosol form spaced at from three-weekly to monthly intervals. This statement is subject to accurate surveys of breeding areas having been conducted and that the terrain be readily accessible to aircraft of the fixed-wing type. In undulating country intersected with numerous heavily bush-covered valleys, but still accessible to fixed-wing type aircraft, more applications may be necessary. This is due to the fact that individual valleys must be dealt with separately and flies may infiltrate into previously treated valleys from valleys not yet treated, in this way escaping destruction for one or more applications.

In mountainous terrain helicopters appear to afford the only practical solution. Eradication inevitably takes longer, due to the slower method of operation which limits the areas it is possible to treat simultaneously. For the same reason DDT smoke generators or dusting are even less efficient due to difficulties in negotiating the terrain and securing uniform coverage with insecticide.

Few, if any of the fly belts of the savannah species of tsetse flies in Africa are of limited extent. The Zululand fly belt comprised some 7,000 square miles—an area far too vast to permit of overall treatment by insecticides. Within this belt, however, breeding was proved to be limited to those areas harbouring large *permanent* populations of game. It was perhaps fortuitous that this somewhat artificial state of affairs existed as the result of the gradual settlement of the country, which forced the major portion of the game to retreat to certain localities for the sanctuary they afforded. However, this picture of the limitation of the major breeding areas to the game sanctuaries emerged only as a result of the pupal-casing surveys instituted. To start with, the criteria of cattle mortality and adult tsetse fly incidence seemed to reveal a more or less homogeneous distribution of fly over the whole of the territory.

Development and settlement are occurring all over Africa. Game animals are gradually becoming more restricted. Their tendency is towards concentration in those areas where they are likely to meet with the least interference from man and where more or less optimal environmental conditions for the particular species exist. Many species, however, display migratory habits. These frequently represent adaptation to seasonal fluctuations in climate, characteristic of vast tracts of Africa. From the point of view of control measures against tsetse flies they must be taken into account. This tends to complicate the problem of control but does not present insurmountable difficulties. Even these mass migrations of game show a tendency to disappear with the advance of civilisation, as has occurred in the Union of South Africa for instance, where seasonal game migration is today something of the past.

The methods of insecticide application employed so successfully in Zululand for the eradication of *G. pallidipes* may prove equally successful for this species in other parts of Africa. In the extensive areas occupied by it, however, elimination cannot be anticipated under a period of at least eight months. Consideration must be given to such aspects as duration of pupal and adult survival periods and the fact that movement of flies will inevitably occur into areas treated from those awaiting treatment.

The first consideration is the determination of the permanent breeding areas by the method of pupal casing surveys described. A careful study of game distribution and habits is of the greatest assistance in this respect to serve as an index of where the breeding areas are likely to be found. It must be borne in mind that only where all the environmental requirements, to ensure the maintenance of a game population sufficient to serve the nutritional needs of a tsetse fly population exist, can breeding occur.

When the breeding areas have been established, these may prove too extensive to make eradication practical with the means available. Should this prove to be the case, the question of their sub-division into areas capable of being dealt with within a cycle of from three weeks to one month, must be considered. Such sub-division may be brought about by bush eradication. Barrier clearings, in the light of available evidence, require the removal of all bush over a minimum width of two miles. Discriminative or thicket clearing may also be resorted to in order to render certain areas untenable to the fly and in this way concentrating the flies within other predetermined areas sufficiently limited of extent to permit of their treatment. Both methods are extremely costly, especially when viewed in the light of their maintenance over a long period, and can only be accomplished over an extended period of time. A more practical method, less costly in nature and likely to bring about the desired result within a shorter period, is judicious game control. This entails the selection of sanctuaries within the limits of the breeding areas into which game may be concentrated from the surrounding areas. Care is necessary in the selection of such sanctuaries that a sufficiency of permanent water, grazing and vegetational cover exist to meet the requirements of the game and the flies which they support. Once created no interference of game is permissible within them, whereas continued shooting and harrying of game is confined to the peripheral zones until such time as the game within the latter areas has been largely eliminated. Operations for the treatment of the concentrated breeding areas so created may now be undertaken. *

In how far the methods described are applicable to *G. morsitans* would depend upon the extent of the permanent breeding areas of this species in relation to the areas into which it is capable of dispersing. Breeding areas would have to be determined by means of pupal-casing surveys and accurately plotted.. Some evidence exists that these may be found, particularly in the Miombo (Brachystegia) woodlands, confined to the evergreen vegetational types fringing the mbugas or drainage basins and lines, so characteristic of the habitat of this species in many parts of Africa.

Should this assumption prove to be correct, it would appear that treatment of these breeding areas, particularly during the dry season or leafless period of the deciduous woodlands, when the flies are largely confined to the evergreen glades, would exert a profound effect upon the population. Dispersion into the

* That the method is practical has been clearly demonstrated in the area south of the Umfolozi game reserve. This area was declared a buffer zone in which controlled shooting was undertaken in 1937–39. The result was the concentration of game in the reserve proper and the cessation of all breeding within this buffer zone, which Harris previously used for the collection of most of the pupae for his studies on the bionomics of *G. pallidipes*.

woodlands during the rains would be greatly impeded due to the reduction in density which could be effected in the breeding areas, and elimination may not prove difficult. *

In the case of *G. austeni,* the species is much more restricted in range to a thicket type of vegetation due to its environmental requirements. It, nevertheless, inhabits very extensive areas over the eastern coastal plains of Africa and its eradication would appear to constitute a more formidable problem. Its range of dispersion in relation to its breeding localities, in terms of pupal concentrations, is very much more restricted. This suggests that very extensive areas of thicket will require treatment in order to achieve eradication, and in view of the difficulties associated with the demonstration of adults of this species by methods of survey known at present, satisfactory proof of its final elimination would be by no means easy.

*G. brevipalpis* is confined almost exclusively to the Hluhluwe game reserve so far as the central portions of Zululand are concerned. In this reserve, as well as in the very restricted localities in which it has been taken in the Umfolozi reserve, the campaign, aimed at the eradication of *G. pallidipes,* has embraced this species as well. At the time of going to press, its entire elimination appears to have been achieved. The mountainous, heavily forested terrain forming its habitat has necessitated the use of helicopters and its eradication has presented no easy task. The methods adopted, however, have been identical to those employed against *G. pallidipes* and the species has proved itself equally amenable to this form of attack.

In the northern part of Zululand, *G. brevipalpis* occupies the gallery forests fringing the Pongola and Usuta rivers. Beyond their confluence the river so formed is referred to as the Maputo and the species inhabits a similar type of riverine gallery habitat to a short distance from its mouth in Portuguese territory.

The incidence of Nagana in this area which carries large numbers of cattle has always been low. The country is comparatively well watered, which obviates the necessity of cattle having to traverse the riverine galleries in search of water. Little contact exists, therefore, between *G. brevipalpis* and cattle, and only during periods of drought, are cattle forced to water in the rivers, when outbreaks of the disease of a minor nature have been met with. For this reason and the fact that the eradication of *G. brevipalpis* would entail international co-operation, the campaign has not been extended to include the northern, isolated habitat of this species.

An aspect of the campaign described which appears to have aroused a certain amount of controversy is its possible effect upon the normal insect fauna of the region. Grave misgivings have been expressed as to the side-effects the mass destruction of beneficial insects and those constituting the normal food of many species of animals would have upon both the fauna and flora.

It must be admitted at the outset that vast numbers of insects are destroyed at each application. Careful observations have revealed, that with the exception of the larger and more heavily chitinized members of certain orders, such as the *Coleoptera, Hemiptera* and *Hymenoptera,* the majority of insects are susceptible to BHC in smoke form and very large numbers succumb.

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* It may be inferred from the account of Fuller (1929) that the breeding haunts of *G. morsitans* in the Transvaal were possibly confined to what he termed the " bosrande ", slightly elevated ridges covered with many evergreen trees and shrubs so characteristic of the northern Transvaal. This would limit the area requiring treatment and the elimination of *G. morsitans* from the Transvael by the method described here may have been a comparatively easy task.

In view of the fact, however, that as has been stated, the area involved in actual applications of insecticide has comprised only about 3% of the entire region infested with *G. pallidipes,* repopulation of the treated portions from the surrounding untreated zones occurred very soon. Furthermore, residual deposits of insecticide upon vegetation and other objects played no part, nor would the period between applications have coincided with the developmental periods of most insect species. The result was, that in spite of a temporary depletion in insect numbers, especially following applications of insecticide, specimens of all the normal orders were constantly obtainable.

In the absence of actual counts of numbers, observations have shown that there has been no noticeable depletion in the total of insectivorous species of birds, amphibia and reptiles.

## XIII. Conclusions.

As the result of the campaign for the eradication of *G. pallidipes* from Zululand, commenced in 1945 and now at the time of writing, December 1952, nearing completion, a number of conclusions based upon the experience gained, appears to be permissible.

1. Of the three species of tsetse flies present, namely, *G. pallidipes, G. brevipalpis* and *G. austeni,* the first named only is capable of causing widespread epizootics of Nagana amongst cattle. This is due to its capacity of dispersing widely into savannah woodland, in which the latter two species are unable to exist, and thereby coming into close contact with domestic stock.

2. The habitat of *G. pallidipes* is capable of division into clearly defined breeding areas of limited extent and extensive dispersion areas not readily definable.

3. Pupal-casing surveys constitute the only known means of determining accurately the limits of the breeding areas. From the experience gained in Zululand they comprise 3 percent or less of the dispersion areas.

4. Two annual peaks in the density of this species occur. One such peak is manifested immediately prior to the onset of cold weather (about April or May) and represents the culmination of summer breeding activity. The other is associated with the onset of the warm weather in spring (August or September) and represents the mass hatching of accumulated pupae deposited at the end of the previous summer. The reason for the occurrence of the latter peak is to be found in the greatly extended duration of the pupal period which occurs during the winter months.

5. The method described of applying insecticides, (BHC for preference due to rapidity of action and relatively low cost) by means of aircraft in smoke or thermal aerosol form is regarded as thoroughly and economically practical.

6. The breeding areas only need be treated as the reduction in fly density within them following treatment causes the cessation of dispersion. In the absence of reinforcement by dispersion from the breeding areas flies die out of their own accord in the dispersion areas.

7. It has been concluded that treatment of breeding areas should commence just prior to the onset of the spring peak, and applications spaced at three-weekly to monthly intervals, should continue for at least eight months; preferably to the onset of cold weather in April or May.

8. Planned game control, to limit the extent of breeding by confining game within certain regions, serves to subdivide very extensive breeding areas.

9. *G. pallidipes* is able to persist in breeding areas at extremely low densities. If total eradication is not achieved the survivors may build up again fairly rapidly unimpeded by parasitism, as pointed out by Fiedler, du Toit and Kluge (1953) in an article discussed in the text.

10. The method of insecticide dispersion is not so readily applicable to *G. brevipalpis* and *G. austeni*, as their breeding and dispersion areas appear to almost coincide in extent. This necessitates the treatment of large areas, frequently inaccessible to fixed-wing aircraft. Furthermore, no satisfactory methods to determine the presence of adults of the latter species exist, thus making the estimation of results difficult.

In conclusion it must be stressed that the eradication of *G. pallidipes* only has been aimed at in Zululand. The reasons are that it is the only species considered to be of economic importance and its primary breeding areas are confined to Zululand. The eradication of *G. brevipalpis* in the Hluhluwe game reserve was undertaken on account of its localised occurrence in this area with that of *G. pallidipes*. Both *G. brevipalpis* and *G. austeni* extend beyond the border of Zululand and their eradication would entail the co-operation of the Portuguese authorities, without which such an attempt would be foredoomed to failure.

## XIV. Summary.

1. The distribution of Nagana and its importance as a limiting factor in the development of the livestock industry in Africa are stressed.

2. The relationship between the tsetse fly belt within the Union of South Africa and those occurring in Portuguese East Africa is discussed, emphasis being laid upon the isolation of *Glossina pallidipes* in the Union.

3. Within Zululand the range of dispersion of *G. pallidipes, G. brevipalpis* and *G. austeni,* occupying approximately 7,000 square miles, have been plotted and the breeding areas accurately determined.

4. The bionomics of the *Glossina* spp., in Zululand and the dominant role of *G. pallidipes* in the causation of epizootics of Nagana are dealt with.

5. The cyclical appearance of Nagana epizootics at fairly regular intervals of approximately ten years and theories attempting to explain this phenomenon are considered.

6. Methods of survey for establishing the relative density of adult and immature flies are dealt with and their merits in arriving at a conception of the biotope of the different species discussed.

7. The preliminary investigations and the methods finally adopted for the application of DDT and BHC, together with the technique employed for the eradication of *G. pallidipes* over the entire, and *G. brevipalpis* in a localized area of Zululand, are described in detail.

8. The value of bush clearing as an important aid in the control of tsetse flies and the manner in which it was used in Zululand are pointed out.

9. Costs connected with the application of the procedures actually employed are compared and attention is drawn to the potentialities of the methods advocated following the experience gained.

10. The possible application of the methods used in Zululand to the eradication of at least some *Glossina* spp., in other parts of Africa is discussed.

11. In view of insufficient knowledge regarding methods of survey the practical eradication of *G. austeni* requires further investigation. Its elimination from the Union necessitates international co-operation, which would also be necessary in the case of *G. brevipalpis* on the international border with Portuguese East Africa.

12. The direct and indirect effects of mass applications of insecticides to extensive areas of bush upon the fauna and flora are considered.

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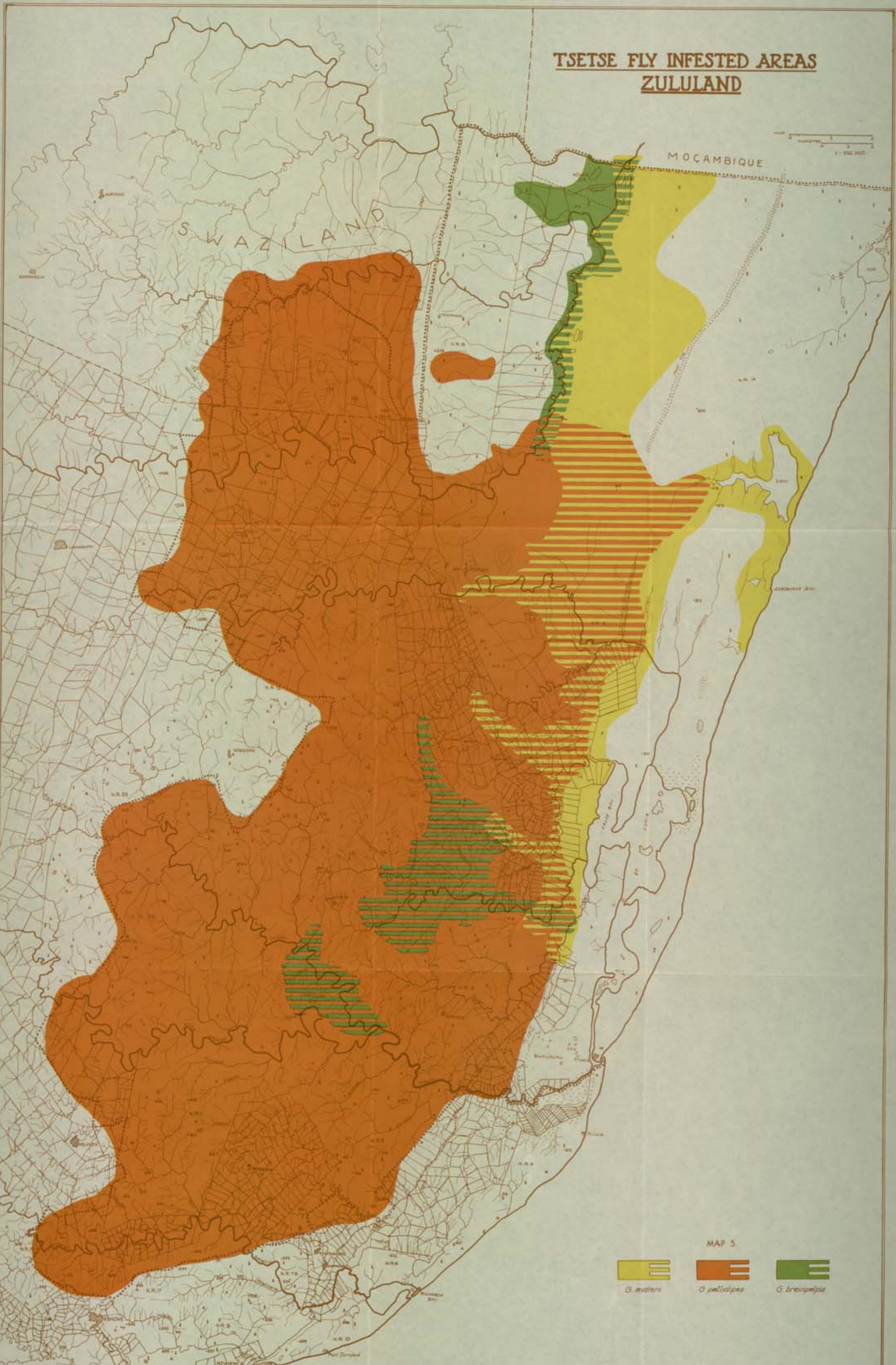
TSETSE FLY INFESTED AREAS
ZULULAND
MOÇAMBIQUE
SWAZILAND
MAP 4
NUMBER OF PUPAE (CASINGS) PER BOY PER DAY :-
0
1 - 10
10 - 100
100 - 200 & OVER
NO BREEDING
LOW BREEDING AREA
HIGH BREEDING AREA
VERY HIGH BREEDING AREA.


TSETSE FLY INFESTED AREAS
ZULULAND
MOÇAMBIQUE
SWAZILAND
MAP 5.
G. austeni
G. pallidipes
G. brevipalpis


TSETSE FLY INFESTED AREAS
ZULULAND
MOÇAMBIQUE
SWAZILAND
MAP 6.
D.D.T. Dipping Tanks.
Discriminative Clearings.
Barrier Clearings.
Game Reserves.