DEPARTMENT OF AGRICULTURE, SOUTH AUSTRALIA

Agronomy Branch Report

SEQUENTIAL SAMPLING FOR THE PASTURE COCKCHAFER, *Aphodius tasmaniae* HOPE (COLEOPTERA:SCARABAEIDAE), IN PASTURES IN SOUTH AUSTRALIA.

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5.1.3 Discussion

The mean larval densities in the untreated pasture at each site (Table 7) provided a range of densities about the expected economic injury level range of about 150 larvae per square meter which should have been suitable to show the effect of A. tasmaniae larvae on pasture production. However, these trials did not show the losses in pasture D.M. production which can occur on a property where the landowner does not treat similar densities of larvae in a pasture.

Six weeks after the pastures were treated with lindane, there were no signficant differences in D.M. yields between treated and untreated pastures at any of the sites (Table 8), even though there was an almost complete control of larvae in the treated pastures. Significant differences in D.M. yields between treated and untreated pasture may have been partly obscured by the sampling technique used at this time; the technique provided a low number of sample units with a large variation for each treatment. This technique was suggested by agronomists studying pasture responses. While sampling may have been a problem, the absence of grazing livestock on the trial appeared to be the main problem. A visual comparison of pasture in the trials with adjacent pastures which were grazed by sheep at reasonable stocking rates showed greater losses in the grazed pasture which could be attributed mainly to A. tasmaniae activity. This was most apparent around the trial site with the highest mean larval density. Because of the contagious distribution of larvae in a pasture, there were areas of the grazed pasture which had high densities of larvae comparable to the untreated pasture in the trial site, while there were nearby areas with lower densities. The areas with the higher density were almost completely bared of pasture while the pasture in those areas with lower densities did not suffer such extreme damage. There were no areas of pasture in the trial which had the level of damage seen in the grazed pasture. This observation suggested that the untreated pasture in the trials may have compensated to a large extent for any larval damage in the absence of the added stress of grazing sheep. The results from the trials at this stage, together with the good pasture cover on both treatments of the trials following a period when A. tasmaniae had been active, indicated that there was little chance to measure differences in D.M. yields of pasture which could be attributed to A. tasmaniae activity unless the pasture was mown to simulate grazing livestock. Mowing pasture was not a suitable alternative to the gradual stress imposed on a pasture by grazing livestock but it was all that was available at the time.

In mid-August (fifteen weeks after the application of lindane and ten weeks after mowing the pasture) an estimate of D.M. pasture yields was made only at Site IV because pasture growth on the other sites was negligible. Pasture growth during July and August is limited in the Adelaide Hills because of low soil temperatures. The D.M. yield was significantly greater on the treated pasture compared to the untreated pasture but only amounted to about 4 per cent more (Table 8). This site had the highest mean density of larvae (542 larvae per m^2) of the sites and the small increase in yield with the treated pasture was unrealistic compared to a normal, grazed situation. The larvae would have finished most of their feeding by this time and the pasture losses were expected to be at a maximum. The grazed pasture adjacent to the trial and infested with A. tasmaniae was suffering extensive damage.

Assessment of pasture D.M. yields in early-October (22 weeks after treatment with lindane) at Site III and IV showed significantly greater D.M. yields from the untreated pasture compared to the treated pasture (Table 8). The reason for these differences is not understood, but both sites had the higher mean densities of A. tasmaniae larvae and growth of the untreated pasture may have been stimulated by increased aeration of the soil and incorporation of organic matter and nutrients into the soil due to larval activity. It is interesting to note that there was no difference in D.M. yield between treated and untreated pasture at this time in Site I where the mean density of larvae was low (66 larvae per m^2). The main difference in pasture growth at Sites III and IV occurred in late-August and September when most larvae would be in the pre-pupal stage. This apparent, beneficial effect of high densities of larvae on growth of ungrazed pasture late in winter has no practical application because it would not outweigh the damage that larvae at these densities could cause to grazed pasture during the late autumn and winter when feed supply is critical.

At Site I, where there was a low mean density of larvae, no significant differences in D.M. yields between treated and untreated pasture were measured during the trial period (Table 8). An ungrazed trial was not sufficiently critical to detect small differences in pasture yields which could be expected with low densities of larvae.

The difference in D.M. yields of pasture measured at Site II after six weeks (Table 7) was due to an uneven nutrient gradient across the site and was not related to A. tasmaniae activity. Application of superphosphate did not overcome the problem and, for this reason, the site was discarded from this project. The problem experienced with this site is a real problem with A. tasmaniae damage assessment studies in the field. Trial sites need to be selected in autumn before larvae begin feeding on green plant material and, at this time, it can be difficult to assess both the composition and quality of a pasture because of its limited growth. When selecting sites, prior history of the pasture should be taken into account and reasons for any differences measured during the trial should be carefully evaluated.

The use of electronic pasture probes should be considered for estimating pasture D.M. yields in future damage assessment studies. In the above trials, the coefficients of variation of the D.M. yield estimates with a probe were mainly between 0.10 and 0.14, which enabled small differences in yield to be recognised. Also, estimates of yield with an electronic pasture probe are practically non-destructive and the pasture is only minimally disturbed.

5.2 Grazed Trial

Following the results of the ungrazed trials (Section 5.1), an unreplicated, paired-treatment trial was conducted in 1972 to study the effect of A. tasmaniae larvae on pasture D.M. production of a perennial ryegrass/subterranean clover pasture when the pasture was grazed with sheep.

Two areas of similar pasture, except that one area was naturally infested with larvae and the other sprayed with lindane to control larvae, were evenly stocked with sheep. Estimates of available pasture DM and liveweight of the sheep were made with the two treatments during autumn, winter and spring. An estimate of the growth of wool on the sheep during the trial period was also made. Any differences in these parameters could be attributed mainly to the influence of A. tasmaniae activity. The main differences were expected in available pasture D.M. and these could be used to assess the importance of A. tasmaniae damage.

5.2.1 Methods

Trial site

An area of 2.4 hectares of perennial ryegrass/subterranean clover pasture naturally infested with A. tasmaniae larvae was selected at Meadows in the Adelaide Hills. The area was fenced into two equal areas (1.2 ha) on 5/5/72. One area only was treated with lindane (280 g a ha active ingredient) on 9/5/72 using a boom spray mounted on a vehicle. A barrier strip, 6 m wide, was also treated around the outside of the trial site. The complete trial site was topdressed with superphosphate (200 g a ha) on 1/6/72.

Larval density

The mean density of larvae in the untreated half was estimated at the beginning of the trial. One hundred and fifty sample units, each a soil core 11.7 cm in diameter, were taken using stratified random sampling (by area). The larvae were hand sorted from the soil in the sample unit.

Stocking the trial

Both treatment areas were stocked on 13/7/72 with 18 month old merino wethers carrying about six weeks growth of wool. The stocking rate was 10 wethers per hectare for both treatments. The initial, total liveweight and potential wool production of the sheep on each treatment were similar. The two similar groups of sheep were obtained by weighing the sheep after two days without food prior to being put on the trial and estimating the relative wool on each sheep using the mid-side patch technique (Section 5.2.1). These two parameters for each sheep were compared graphically and then the sheep were stratified into two equal groups (Appendix III). Each sheep was individually tagged.

On 5/10/72, the stocking rate was increased to 20 wethers per hectare on each treatment. The additional sheep were two year old merino wethers. They were stratified into two equal groups by liveweight only.

Trial maintenance

The pasture in both treatments was inspected regularly for the presence of invertebrates, other than A. tasmaniae, which may influence pasture production. S. viridis appeared in October and both treatments were sprayed with phosmet (50 g a ha active ingredient).

The sheep were crutched and jetted with 0.04 per cent diazinon on 2/11/72 to prevent sheep blowfly strike.

Pasture estimates

The initial available D.M. of the pasture was estimated visually because the pasture was very low and the reliability of pasture cuts with available methods to estimate pasture yield would have been doubtful because of the almost certain inclusion of soil, sheep dung and other non-pasture material. Also the pasture was too low for an electronic pasture probe to be effective.

D.M. yields of pasture on both treatments were estimated 4, 17 and 25 weeks after the application of lindane to represent the available pasture D.M. at the end of the approximate autumn, winter and spring periods, respectively. Ten quadrats, each 0.5 m^2, were sampled at random from each treatment at each sampling time. The pasture in each quadrat was cut to ground level using a portable, motorised crutching unit. The D.M. of pasture in each quadrat was estimated by drying the pasture to a constant weight in an oven, as described in Section 5.1.1.

In addition to D.M. pasture estimates after 24 weeks, a 20 g subsample of dried pasture was taken from each quadrat to assess the proportion of the main plant species in the pasture. Subterranean clover, perennial ryegrass and capeweed were hand sorted from these subsamples and weighed separately.

Sheep liveweight

The sheep were weighed at least monthly using mobile stock scales and the individual weights of the sheep were recorded.

Wool production

The original 24 wethers put on the trial were used for a relative comparison of wool produced by the wethers on the two treatments. The mid-side patch technique to measure wool growth was used. On the day before the wethers were put on the trial an area, 10 cm x 10 cm, was shaved on the middle of the right hand side of each wether (the weight of this wool from each sheep was used to stratify the wethers as described earlier in Section 5.2.1). The 100 cm^2 mid-side patch was delineated by tattooing the skin. When the wethers were removed from the trial, the wool was cut from each of these patches for an estimate of wool growth during the period of the trial. The wool from each patch was scoured using the technique described by Chapman (1960) and the weight of cleaned, scoured wool from each patch at the beginning and end of the trial was measured.

5.2.2 Results

Trial site

The pasture was a well balanced subterranean clover (cultivar Mt. Barker)/perennial ryegrass pasture with a minor component of capeweed. The mean annual rainfall of the area is 890 mm and the daily rainfalls for 1972 are shown in Figure 8.

Larval Density

The mean density of larvae at the beginning of the trial was 5.2 (0-30) larvae per sample unit (108 cm^2) which was equivalent to 480 larvae per square meter.

Pasture estimates

Table 9 Summary of available pasture D.M. and comparison of the available D.M. of lindane treated and untreated pastures, both grazed by sheep.

Weeks after treatment with lindane	Available pasture D.M. (kg per ha)		t_{18}	Significance
	Treated	Untreated		
0	100*	100*	-	-
4	940 ± 92	830 ± 72	0.94	N.S.
17	1810 ± 210	608 ± 74	5.36	***
25	3720 ± 358	1704 ± 210	4.84	***

*visual estimate (Section 5.2.1)

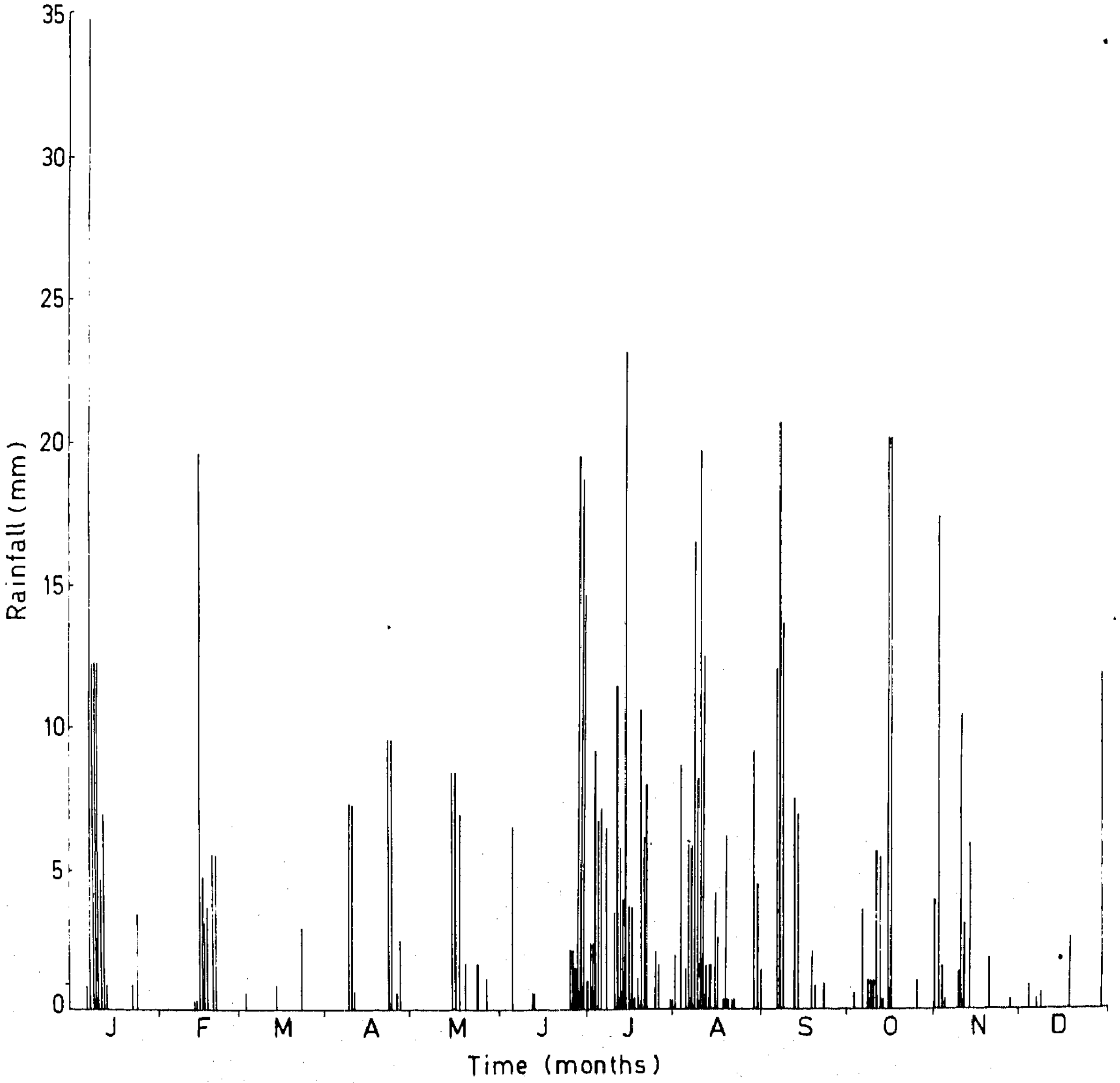

Figure 8 : The daily rainfall (mm) at Meadows, 1972.

Table 10. Summary of D.M. weights of the main plant species in 20 g sample units of dried pasture sampled after 25 weeks after the application of linane, and the comparison of the weights from lindane treated and untreated pasture.

Plant spp.	D.M. weight plant spp. per 20 g dried pasture		t_{18}	Significance
	Treated	Untreated		
Subt. clover	9.9 ± 1.2	14.2 ± 0.7	3.08	**
Perrennial rye-grass	4.5 ± 0.7	2.3 ± 0.3	3.02	**
Capeweed	5.6 ±·1.3	3.5 ± 0.6	1.49	N.S.

Sheep liveweight

Table 11. Summary of liveweights of wethers initially put on trial and a comparison of the live weights of the wethers on lindane treated and untreated pasture.

Weeks after stocking trial	Liveweight of wethers (kg)		t_{22}	Significance
	Treated	Untreated		
0	37.6 ± 0.8	37.6 ± 0.7	0.00	N.S.
5	45.7 ± 1.0	42.3 ± 1.1	2.24	*
9	49.6 ± 1.2	46.1 ± 1.0	2.23	*
14	58.1 ± 1.3	55.3 ± 1.2	1.56	N.S.
17	59.0 ± 1.2	56.4 ± 1.6	1.34	N.S.
21	56.7 ± 1.2	56.2 ± 1.1	0.31	N.S.

Table 12. Summary of liveweights of wethers added to the trial on 5/10/72 and a comparison of the liveweights of the wethers of lindane treated and untreated pasture.

Weeks after stocking trial	Liveweight of wethers (kg)		t_{22}	Signif-icance
	Treated	Untreated		
12	32.3 ± 0.9	32.4 ± 0.7	0.09	N.S.
14	43.3 ± 1.3	43.1 ± 1.0	0.12	N.S.
17	45.0 ± 1.5	43.6 ± 0.9	0.93	N.S.
21	43.9 ± 1.7	44.7 ± 1.0	0.41	N.S.

Wool production

Table 13. Summary of the weights of cleaned, scoured wool from the mid-side patch of the original wethers and a comparison of wool produced by wethers on treated and untreated pasture.

Weeks after stocking trial	Weight cleaned, scoured wool (g per 100 cm^2)		t_{22}	Signif-icance
	Treated	Untreated		
0	3.1 ± 0.2	3.1 ± 0.2	0.22	N.S.
22	32.4 ± 2.2	30.4 ± 1.3	0.78	N.S.

5.2.3 Discussion

The results from the ungrazed trials (Section5.1) indicated the need for grazing trials with livestock to assess the effect of A. tasmaniae larvae on pasture production. From these ungrazed trials, it appeared that the heavy losses of pasture D.M., which can occur in pastures infested with A. tasmaniae, were an additive effect of grazing stock and A. tasmaniae damage. However, only limited information is available on grazing trials and there is controversy amongst agronomists on the design and interpretation of the results of grazing trials. For this reason, and also because of the expense of conducting grazing trials, the unreplicated, paired-treatment trial was carried out mainly to test whether the inclusion of grazing livestock could give meaningful differences in pasture and animal yields which could be attributed mainly to A. tasmaniae activity.

Instead of the method used in this trial, a comparison of the number of sheep-grazing-days between the two treatments could have been made by adjusting the stocking rate independently on each treatment in an attempt to maintain comparable pasture D.M. levels on the two treatments during the trial period. This method was not used because of the technical and managerial difficulties envisaged in maintaining similar levels of pasture D.M. on the treatments.

The pasture used in this trial contained about 20 to 30 percent perennial ryegrass which would not be damaged by A. tasmaniae.

The reason for selecting a site with a perennial grass was that most pastures seen at the time of selecting a site which had only annual pasture species and were infested with A. tasmaniae had a very high component of capeweed and crowfoot. The results from using a good quality pasture would be more meaningful than results from trials carried out on poor quality, weedy pastures. Also, the inclusion of some perennial ryegrass in subterranean clover and annual grass pastures is not uncommon in the higher rainfall areas of South Australia and these pastures can be heavily damaged by A. tasmaniae because of the major annual component.

The mean density of larvae in the untreated pasture in the trial was 480 larvae per square meter which was considerably higher than the expected economic injury level of about 150 larvae per square meter. Estimates of density of larvae were not made on the treated area but a number of inspections of the pasture after the application of lindane indicated that there had been an almost complete control of larvae. The rainfall patterns at the time of treatment was suitable for good control. There was no rain for more than a week prior to treatment and it rained within six days after treatment (Figure 8). The rain after the treatment would have stimulated most of the larvae in the population to come to the surface to feed and ensured contact of larvae with the lindane before the lindane lost its insecticidal activity.

At the time of treatment, the larvae were mainly in the mid-second instar and only a small proportion of the population had begun feeding on green plant material. Because of the large difference in larval densities between the treated and untreated pasture, large differences in pasture D.M. yields were expected.

The available D.M. of treated and untreated pastures estimated at the beginning of June (four weeks after treatment with lindane) were not significantly different (Table 9). Pasture growth on the trial was limited up to this time because of the dry beginning to the growing season and feeding of larvae would have been limited because there were only a few days with rain (Figure 8). This latter fact was reflected in their slow development. Also, the trial had not been stocked with the wethers at this stage. However, available pasture D.M. estimated in early-September (17 weeks after treatment with lindane and after the trial had been stocked) showed a three-fold increase in the available pasture where A. tasmaniae was controlled compared to the untreated area (Table 9). The difference in available pasture D.M. at this time represented the loss of pasture D.M. in the untreated pasture during the winter period. Visual differences between the treated and untreated pastures at this time are shown in Plate 11.

This order of difference is often seen in grazed pastures on properties where A. tasmaniae larvae have not been controlled. The pasture estimates made at the end of October (25 weeks after treatment with lindane) represented the available pasture D.M. at the end of the spring production and showed a two-fold increase in available pasture D.M. where A. tasmaniae had been controlled compared to the untreated area (Table 9). The visual difference at this time of the year is shown in Plate III. Such a large difference in yields after the spring growth was not expected with this mean density of larvae because, although A. tasmaniae can cause large losses in pasture D.M. during early autumn and winter, the loss in yields during spring are usually not as great. Also, this difference occurred in a year where there was good growth of pastures during spring.

The only differences in liveweights between wethers on treated and untreated pasture were the small differences evident after the sheep had been on the trial for five weeks and nine weeks, respectively (Table 11). These weights were taken in mid-August and early-September when the pasture was sparse on the untreated area. The grazing behaviour of the sheep was observed each time the trial was inspected and it appeared that those wethers on the untreated area were grazing for longer periods and were moving about more than those on the treated pasture. The extra energy required to forage for food on the untreated pasture may partly explain the differences in liveweights.

When the pasture became more abundant on the untreated area later in the season there were no measurable differences in the liveweights of the wethers on the treated and untreated areas (Table 11 and Table 12).

The relative cleaned, scoured wool estimates made at the end of the trial showed that the same quantity of wool was produced by wethers grazing treated and untreated pastures, respectively (Table 13).

The trial was not stocked until mid-July because of limited pasture growth during the dry autumn and early-winter. Although the design of the trial allowed for wethers to be removed evenly from both treatments of the trial if the feed supply was critical on one of the treatments, it was decided that before the trial was stocked there should be sufficient pasture to maintain the initial 10 wethers per hectare through the winter period without supplementary feeding. This stocking rate of wethers gave a suitable number of wethers on each treatment to account for variability between sheep and to show any differences in liveweights and wool production which might have occurred during the trial period. Also, addition of feed to the site would have made it difficult to interpret any differences in available pasture D.M. yields. In early-October, the pasture on both treatments was more than adequate for the stock on the trial and plants in the treated pasture began to come into head because of undergrazing. The stocking rate of wethers was increased to maximise the vegetative growth of the pastures in each treatment.

A disadvantage of the technique was that the stocking rate during winter was governed by the stocking rate that the untreated pasture could support. This means that the treated area may be undergrazed, especially with high densities of larvae and heavy pasture D.M. losses in the untreated area. Undergrazing pasture can cause a change in the composition of the pasture. In this trial, the composition of the pasture in both treatments at the beginning was not assessed by measurement but appeared to be similar. However, at the end of the trial there did appear to be a difference and Table 10 shows that the D.M. proportion of perennial ryegrass was less in the untreated pasture compared to the treated pasture at the expense of the subterranean clover which was more. The capeweed was not significantly different between the two treatments, though there did appear to be more in the treated pasture compared to the untreated pasture. The difference between subterranean clover and perennial ryegrass may have been due to sheep heavily grazing perennial ryegrass in preference to subterranean clover in the untreated pasture during late-winter. At this stage, the pasture was sparse and the subterranean clover plants were very small and close to the ground while the perennial ryegrass was not damaged by <u>A. tasmaniae</u> and was more readily available to sheep. Where trials are carried out with the mean density of larvae closer to the economic injury level range, this disadvantage would probably not be as obvious.

6. SIMULATED SEQUENTIAL PLAN FOR A. tasmaniae in PASTURE

A sequential plan to determine the economics of treating an infestation of A. tasmaniae in pasture cannot be drawn up at this stage because damage assessment trials did not provide sufficient information to estimate the economic injury level of A. tasmaniae larvae in pastures. However, a simulated plan can be constructed using arbitrary economic injury levels to demonstrate the practicability of a plan using the actual values of the dispersion parameters of distributions of larval populations sampled in the field (Section 4).

A range of economic injury levels is used in the plan and the alternative hypotheses tested by the plan are whether the mean density of a population of larvae is less than the lower mean density of the range (H_1) or greater than the higher mean density of the range (H_2). The range of economic injury levels depends on the confidence which can be ascribed to the estimated economic injury level.

The equations for the decision lines in a plan based on a negative binomial distribution were described by Waters (1955) and are:

$d_1 = bn + h_1$ (lower line)

$d_2 = bn + h_2$ (upper line)

where d is the cumulative number of larvae per sample unit,

n is the number of sample units examined,

b is the slope of the lines,

h_1 and h_2 are the intercepts.

The slopes and intercepts are calculated as follows:

$$b = k \frac{\log (q_2/q_1)}{\log (p_2 q_1/p_1 q_2)}$$

$$h_1 = \frac{\log (\beta/(1-\alpha))}{\log (p_2 q_1/p_1 q_2)}$$

$$h_2 = \frac{\log ((1-\beta)/\alpha)}{\log (p_2 q_1/p_1 q_2)}$$

where $p_1 = \frac{m_1}{k}$ and $q_1 = 1 + p_1$

$p_2 = \frac{m_2}{k}$ and $q_2 = 1 + p_2$

and k is the dispersion parameter of the negative binomial distribution,

m is the mean density of larvae per sample unit.

The economic injury levels chosen for the simulated plan were:-

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- less than 120 larvae per square meter (1.29 larvae per 108 cm^2 sample unit); not economic to treat (H_1).
- more than 180 larvae per square meter (1.91 larvae per 108 cm^2 sample unit); economic to treat (H_2).

Subjective estimates of economic injury levels over a number of years indicated that this range of densities probably included the economic injury level for A. tasmaniae in pastures in most years.

The value of k used in the plan was 0.765 which was estimated from Figure 7 and corresponded to a density of 150 larvae per square meter - the mean density of the above range. Although the value of k varied with larval density, it was necessary to assume that k was the same over the range of economic injury levels to compute a sequential plan (Oaklands 1950).

The type I (α) and Type II (β) errors were both selected at 0.10.

Hence:

	Infestation level	
	H_1	H_2
mean = kp	1.291	1.937
$p = kp/_k$	$p_1 = 1.688$	$p_2 = 2.532$
$q = 1 + p$	$q_1 = 2.688$	$q_2 = 3.532$

From the above formulae,

$b = 1.572, h_1 = -16.54, h_2 = 16.54$

giving the decision lines,

$d_1 = 1.57n - 16.5$

$d_2 = 1.57n + 16.5$

The sequential plan is shown in Figure 9.

The decision lines for another simulated plan were calculated using the same economic injury levels and value for k but changing both the Type I and Type II errors to 0.20.

This was done to show how the predetermined accuracy could affect the average sample number curve and, hence, the practicability of a plan.

The decision lines of this second plan were:

$d_1 = 1.57n - 10.4$

$d_2 = 1.57n + 10.4$.

This sequential plan is shown in Figure 9.

6.1 Operating Characteristic Curve

The operating characteristic curve shows the chances of making a correct decision when infestations of different population levels are sampled. For sequential plans based on negative binomial distributions, the curve is described by Waters (1955):

$$L(m) = \frac{A^x - 1}{A^x - B^x} \quad \text{where } A = \frac{1-\beta}{\alpha};$$

$$B = \frac{\beta}{1-\alpha},$$

and x = "dummy variable"

$$\text{and} \quad p = \frac{1 - (q_1/q_2)^x}{(p_2q_1/p_1q_2)^x - 1}$$

$$\text{and} \quad m = kp$$

The values of L(m), p and m for the two sequential plans were computed for given values of x (Table 14).

Table 14. Computed values for the operating characteristic curves of the simulated sequential plans for *A. tasmaniae*

x	p	m	$\acute{m}$*	L (m) (=0.10, -0.10)	L (m) (=0.20, =0.20).
∞	0	0	0	1.000	1.000
1	1.69	1.29	120	0.900	0.800
$\frac{1}{2}$	1.89	1.42	132	0.750	0.667
$-\frac{1}{2}$	2.28	1.74	162	0.250	0.333
-1	2.53	1.94	180	0.100	0.200
-3/2	2.81	2.15	200	0.036	0.111
-4	4.82	3.69	343	0.0002	0.004
$-\infty$	∞	∞	∞	0.000	0.000

*$\acute{m}$ - mean number of larvae per m^2.

The operating characteristic curves are shown in Figure 10.

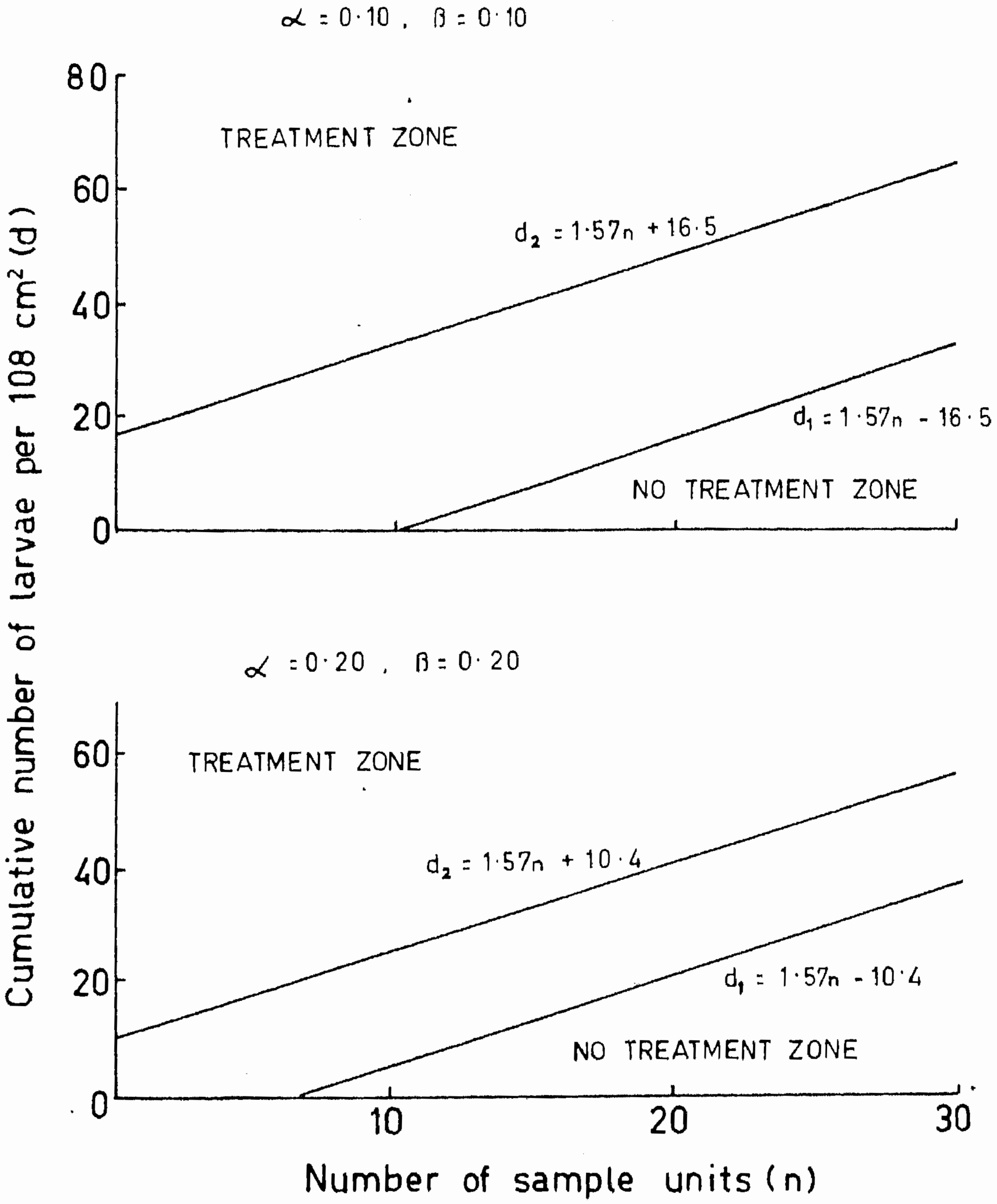


Figure 9 : Simulated sequential plans for *A. tasmaniae* larvae in pasture. (size of sample unit = 108 cm^2 ; k = 0.765; range of economic injury levels = 120 to 180 larvae per m^2).

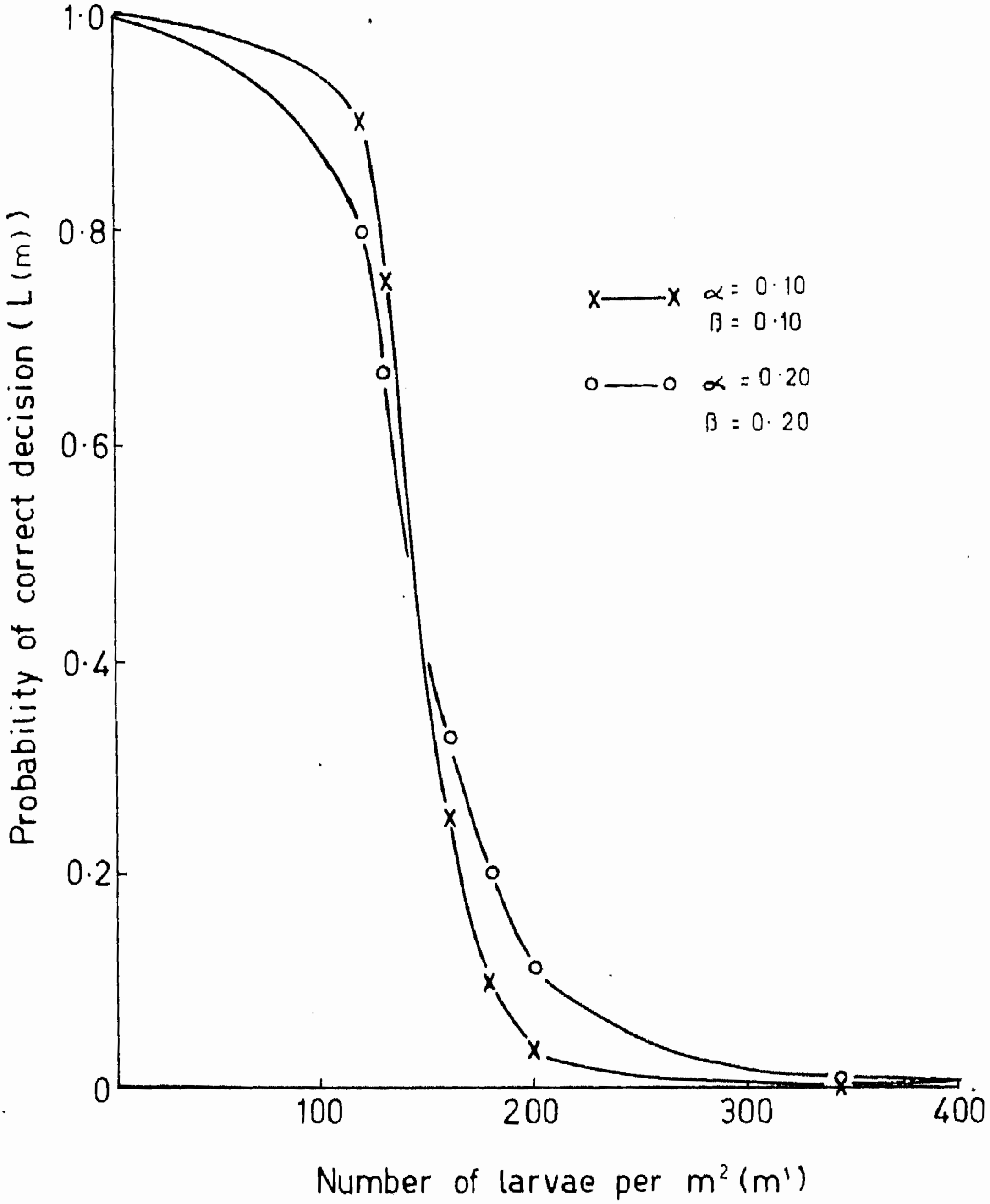


Figure 10: Operating characteristic curves for simulated sequential plans in Figure 9.

6.2 Average Sample Number Curve

The average sample number curve shows the expected average number of sample units required to make a decision at different population levels. For sequential plans based on negative binomial distributions, the curve is described by Waters (1955):

$$E(n) = \frac{h_2 + (h_1 - h_2)\ L(m)}{kp - b} \qquad \text{where } L(m) = \frac{A^x - 1}{A^x - B^x}$$

(see Section 6.1).

and p - as for the operating characteristic curve (see section 6.1).

The values of E(n) and p for the two sequential plans were computed for given values of the dummy variable, x (Table 15).

Table 15. Computed values for the average sample number curves of the simulated sequential plans for *A. tasmaniae*

x	p	m	$\acute{m}^*$	E(n) (α =0.10, β =0.10)	E(n) (α=0.20, β =0.20)
∞	0	0	0	10.52	6.64
1	1.69	1.29	120	47.14	22.32
$\frac{1}{2}$	1.86	1.42	132	56.33	23.69
$-\frac{1}{2}$	2.28	1.74	162	46.60	20.04
-1	2.53	1.94	180	36.40	17.24
-3/12	2.81	2.15	200	26.54	14.04
-4	4.82	3.69	343	7.82	4.90
$-\infty$	∞	∞	∞	0.00	0.00

$\acute{m}^*$ - mean number of larvae per m^2.

The average sample number curves are shown in Figure 11.

7. CONCLUSION

The development of a sequential plan to determine whether an infestation of *A. tasmaniae* in pasture is economic to treat with insecticides appeared to be feasible because the frequency distributions of larval populations in pasture could be described by negative binomial distributions and a technique to estimate the economic injury level of larvae in pasture showed promise.

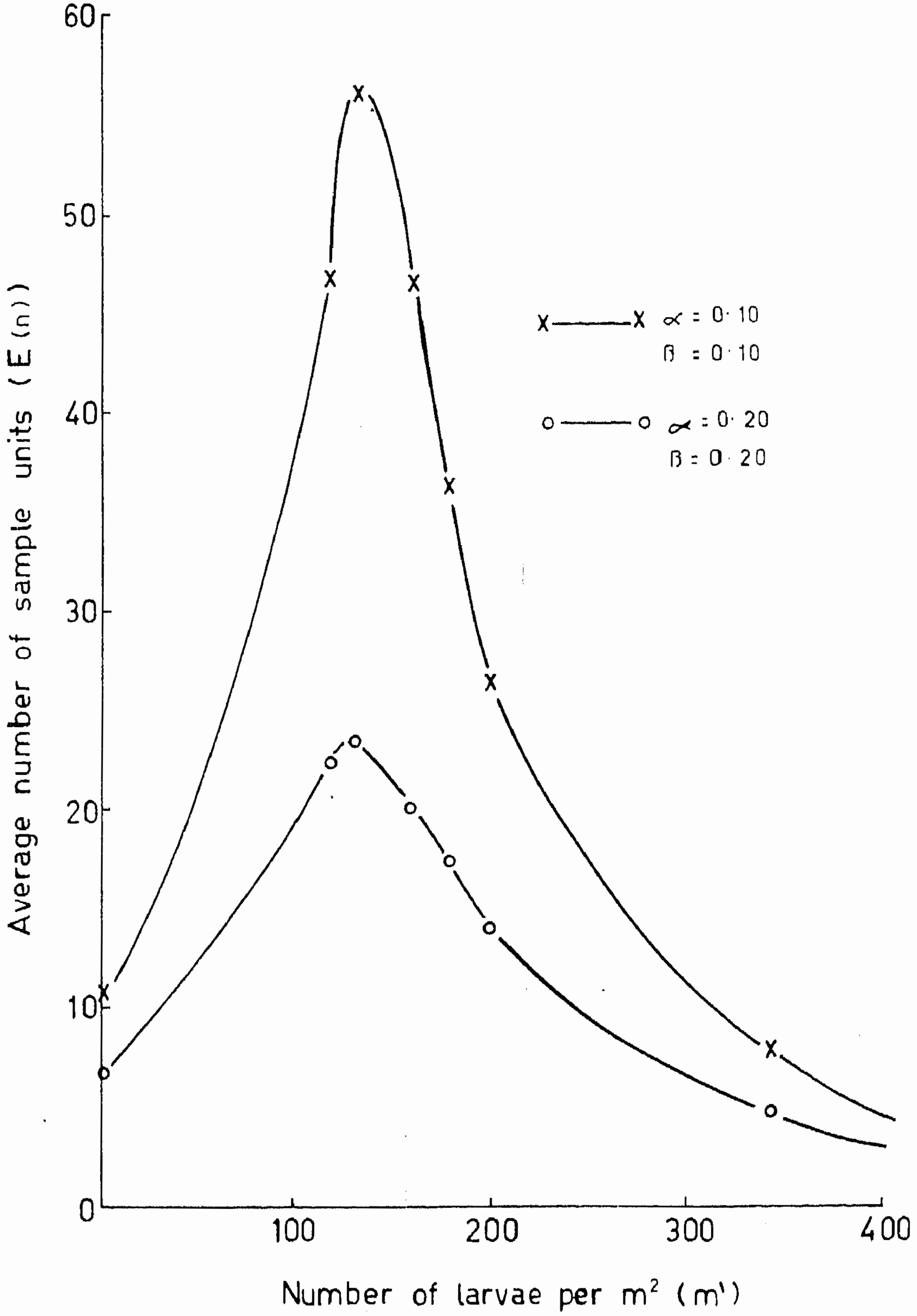


Figure 11: Average sample number curves for simulated sequential plans in Figure 9.

Frequency distribution of larvae

The computation of a sequential plan for A. tasmaniae larvae depended on being able to define the dispersion of the larvae in pasture by any one of a number of described distributions, including the negative binomial distribution. Because the dispersion of larval populations could be described by negative binomial distributions (Section 4), the value of the dispersion parameter of the negative binomial, k, was used to calculate the decision lines of the plan. The value of k can be influenced by changes in different ecological factors and, because the value of k differed between the different populations of <u>A. tasmaniae</u> a search was made for factors that could influence k, e.g. topography, presence of trees and other factors (Section 2.2). However, the only ecological factor which appeared to be correlated with the value of k was mean larval density, m (Figure 6). For the purpose of the sequential plan it was necessary to assume that there was a causal relation between the two parameters of the distribution and it was found that a significant linear regression of k on m could be obtained if log k was plotted against m (Figure 7). The slope of the regression could then be used to estimate the value of k for the value of m that was chosen as the economic injury level in a particular sequential plan. The range of mean larval densities in the regression included the expected economic injury levels of <u>A. tasmaniae</u> in pastures in most years.

Damage assessment

The first trials to assess the economic injury level were unreplicated and compared the pasture dry matter (D.M.) production from naturally infested pastures, either treated or not treated with lindane, respectively (Section 5.1). The trials were not grazed with livestock and there were no differences in pasture D.M. which could be attributed to <u>A. tasmaniae</u> activity at any of the sites. The results suggested that the apparent damage caused by <u>A. tasmaniae</u> to pastures was a combined effect of grazing livestock and larval feeding and indicated the need for trials with grazing livestock in future damage assessment studies.

Because trials with grazing livestock are expensive, an unrelicated trial was set up at one site only the following year. This trial was similar to each of the ungrazed trials above except that both treatments were evenly grazed by wethers (Section 5.2). The trial was designed mainly to test a technique involving grazing livestock which might be used in more intensive trials in future years. The trial showed significant differences in the available pasture D.M. after the winter and spring periods between the lindane treated and untreated pastures. These differences could be attributed mainly to the difference in <u>A. tasmaniae</u> activity between the treatments and the differences appeared to be meaningful when they were compared visually with the available pasture on damaged and undamaged areas in the adjacent, grazed pasture. This technique could be expanded for future trials to measure losses in available pasture D.M. caused by different densities of larvae compared to an insecticidally treated area. Because of the contagious distribution of larvae in naturally infested pastures, it is difficult to replicate the mean larval density in experimental plots. For this reason, the comparisons between available pasture D.M. and larval density would rely on single available pasture D.M. estimates at different times of the year for each density, indicating that trials would need to involve as many plots as possible to give a reasonable regression for the comparison. A problem with a design having no replication is no provision to estimate the variability of pasture growth between treatments. In the above trial with grazing livestock, the magnitude of the differences in available pasture D.M. between the treatments precluded the chance that it was due only to variability between the pastures. However, in future trials more emphasis should be placed on estimating the pasture variability between treatments, especially where the effects of lower mean densities of larvae are being tested. The use of closed pasture quadrats in each treatment area may be a method to give an estimate of pasture variability across the trial site.

The economic injury level of *A. tasmaniae* damaging pastures would vary with different climatic conditions and trials would be necessary over a number of years to evaluate this effect. The effect of climatic conditions during autumn and early winter would be the most important because this would be the time when the sequential plan should be used to assess whether a population is worth treating.

Delaying treatment until mid to late-winter is an effort to assess better the climatic conditions of that year is not advocated because irreparable pasture losses could occur and older larvae can be more difficult to control with some of the recommended insecticides. Experience with *A. tasmaniae* damage has indicated that pastures can tolerate higher densities of larvae in years with good growing conditions during autumn and early winter compared to years when the growing conditions were poor.

The composition and quality of pastures can also influence the economic injury level of *A. tasmaniae*. For this reason, the damage assessment trials were carried out in subterranean clover and annual or perennial ryegrass pastures with a low component of winter annual weeds. Results obtained with this type of pasture provide a better estimate of the economic injury level for extrapolation to other similar areas than do estimates from poor quality pasture.

The economic injury level may also vary from year to year with changes in agricultural markets due to the influence of the markets on the cost of treatment/potential benefit ratio. Also, different economic injury levels may be needed for different properties in any one year depending on the main commodities produced by the property (e.g. beef, wool, dairy products). If different economic injury levels are required for the different types of production, then a different sequential plan for A. tasmaniae could be easily developed for each situation.

Application of the sequential plan for A. tasmaniae

The acceptance of any new plan or method for the control of A. tasmaniae by farmers will depend, to a large extent, on its practicability and ease of use. The practicability of the simulated plans for A. tasmaniae in pasture is demonstrated by the average sample number curves (Figure 11) where the expected number of sample units to make a decision are shown for the different population levels. The number of sample units is directly related to the predetermined accuracy of the plan (selection of the levels of probability of Type I and Type II errors). The effect of the accuracy on the number of sample units is shown in Figure 11. With the higher level of accuracy (i.e. the probability of Type I and Type II errors being 0.10), the expected number of sample units to make a decision was too high to expect other than probably a few landowners to take the expected 35 to 55 sample units necessary to make a decision when infestations had a density about the economic injury level. However, if this level of accuracy is chosen, and if we add the constraint that no more than 30 sample units be taken, decisions to treat or not treat infestations of A. tasmaniae would be made with a greater than 90% probability of a correct decision (Figure 10). If a decision was not made within the 30 sample units, then the economics of treating the infestation would be so marginal that other managerial decisions (e.g. present or intended stocking rates) probably would be more important in making a decision. The risk of erosion and invasion of winter annual weeds into a pasture due to damage by this density of A. tasmaniae would be minimal.

If a plan with the lower level of accuracy, (i.e. the probability of Type I and Type II errors being 0.20) was used, then the maximum number of sample units required to make a decision is about 25 (Figure 11). This relatively low maximum number of sample units, together with the lower number of sample units required to make a decision at all infestation levels, makes this plan appear more practical for general use. Even though the accuracy of the plan is lower than the plan with the probability of the Type I and Type II errors set at 0.10, there is still more than an 80% probability of a correct decision for all infestations with densities above or below the range of economic injury levels used in the plan (Figure 10).

The accuracy of a sequential plan and the range of the economic injury level both change the width between the decision lines in the sequential plan; the lines are wider apart with a higher accuracy and with a smaller range of the economic injury level. Narrowing the range of the economic injury levels will, therefore, increase the average amount of sampling required.

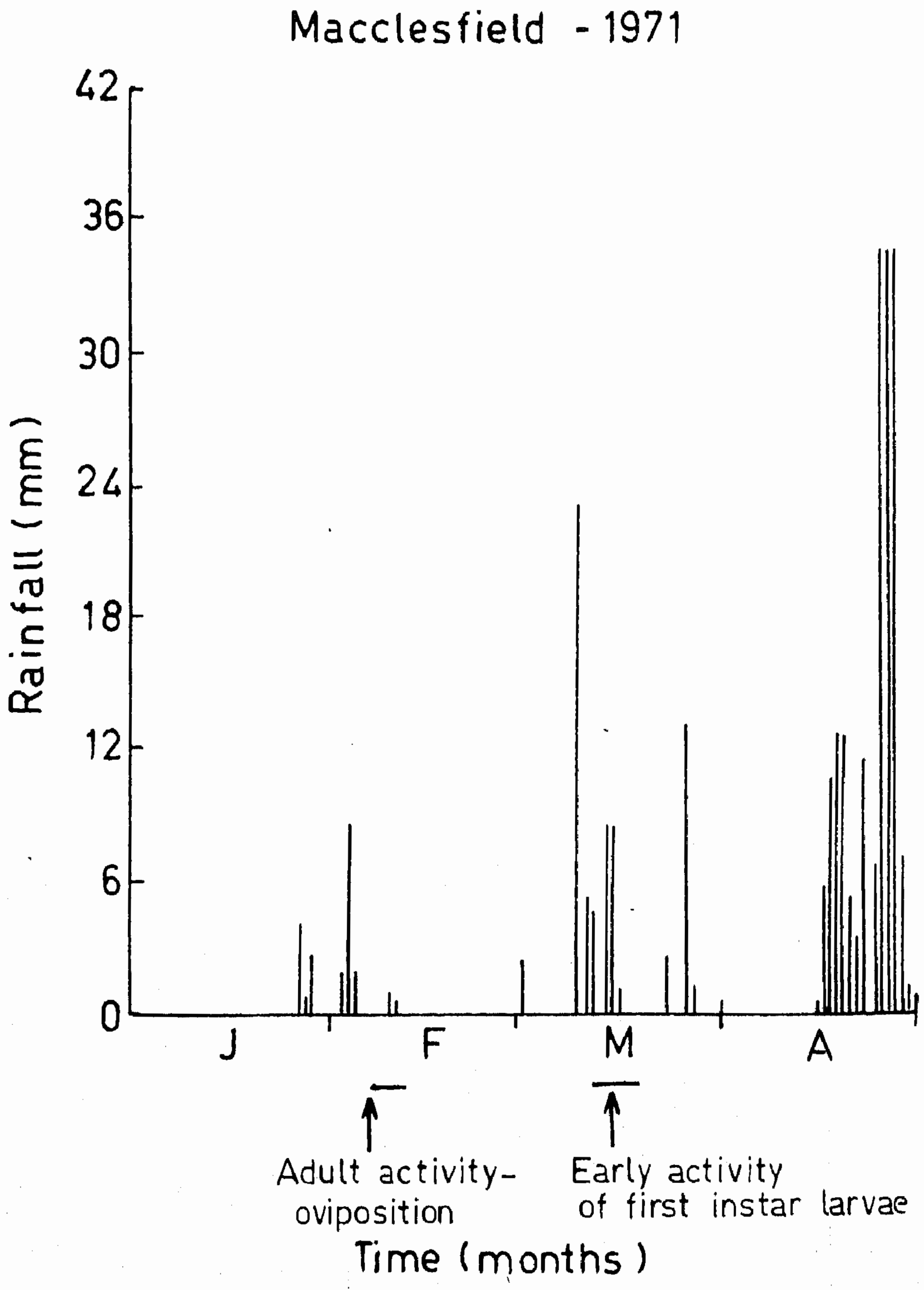
With some infestations of A. tasmaniae, the relationship between larval density and the value of the dispersion parameter does not agree with the relationship in Figure 7 (e.g. the infestation sampled at Macclesfield in Section 4.3). These infestations have isolated patches of very dense larvae. A sequential plan based on the relationship in Figure 7 may be misleading if it is used to classify this type of infestation. However, a decision on the need to treat the heavily infested areas does not require a sequential plan and the plan should be retricted to make a decision on the remainder of the paddock where the need for treatment may not be as obvious. If the remainder of the paddock does not require treatment, then the patches of high larval densities can be "spot-sprayed", a practice which is used already.

Occasionally, the expected damage forecasted by a sequential plan may not eventuate, e.g. in very wet winters when excessive soil moisture may cause mortaility of third instar larvae due to drowning and promotion of infections by pathogenic organisms, especially Cordyceps aphodii Mathieson (Maelzer 1964). However, in most areas there is only a small probability of such a high larval mortality during winter and because the cost of treatment/potential benefit ratio is usually relatively low, the error that may be caused by treating a pasture in which there is a consequent high natural mortality of larvae is small. This type of error can be tolerated in a prediction scheme, especially when the scheme is practised over a number of years. Similar reasoning could be applied to errors in years when the expected damage to pasture is reduced because the growing conditions for the pasture during winter are better than expected and allow the pasture to compensate for larval feeding.

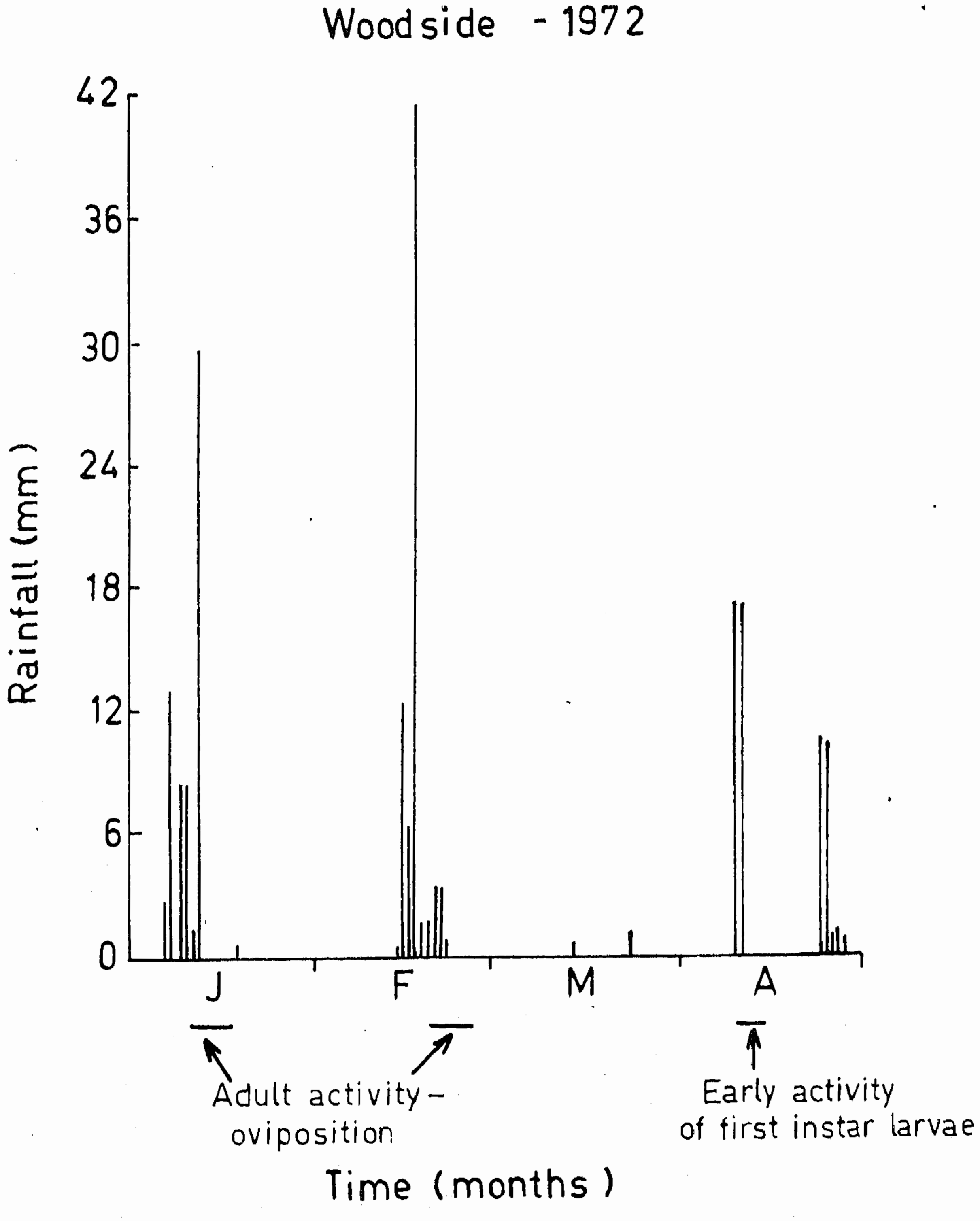
Use of sequential plans for other pests

Although this thesis was concerned with developing a sequential plan for A. tasmaniae in pasture, there is now no apparent reason why this technique cannot be used with other insect pests of pasture and crops. There are many insect pests of pastures and crops in South Australia where there is no information on the economic injury levels, let alone how to estimate the densities of the pests in the field. The information contained within a sequential plan provides the rationale necessary for discriminate insect pest control with insecticides.

8. APPENDIX I - Daily rainfalls (mm) for Macclesfield, 1971, and Woodside, 1972, which were used to detect early activity of first-instar larvae in the field.



8. APPENDIX I (cont'd.) - Daily rainfalls (mm) for Macclesfield, 1971, and Woodside, 1972, which were used to detect early activity of first-instar larvae in the field.



8. APPENDIX II - Estimating D.M. yields of annual ryegrass/subterranean clover pastures with an electronic pasture probe.

The efficiency of an electronic pasture probe to estimate D.M. yields of annual ryegrass/subterranean clover pasture with a low annual weed component was tested in a pasture which had a similar species composition to the pasture in the ungrazed trials (Section 5.1).

The probe, which estimated the quantity of pasture in an area, 0.6 m x 0.6 m, was calibrated in the following way.

First, the probe was corrected for atmospheric moisture at the time of sampling by placing the probe on an area of ground cleared of pasture and adjusting the meter to zero.

Then, readings of the meter were taken in ten different areas of the pasture to give a range of readings, including the highest and lowest readings which appeared to be possible from the pasture. After each meter reading, the pasture in the 0.6 m x 0.6 m quadrat was hand-cut to ground level and put into a plastic bag which was then sealed. The pasture was taken to the laboratory and the D.M. yield for each quadrat was estimated by drying the pasture to a constant weight in an oven at 90°C.

The meter readings and pasture D.M. yields per quadrat were -

Meter Reading	2.8	2.8	3.0	3.0	3.3	3.6	4.0	4.0	4.1	4.3
Pasture D.M. (g per 0.36 m^2)	97	107	99	104	120	126	131	137	144	127

The regression equation between the pasture D.M. yields (y) and the meter readings (x) was:

$$y = 26.7 + 26.4x \quad (r = 0.90)$$

The satisfactory correlation between pasture D.M. yields and meter readings indicated that an electronic pasture probe could be used to estimate the D.M. yields of pastures having a mixture of grass, subterranean clover and a low component of annual weeds, as in the trials.

In the trials, the electronic pasture probe was calibrated for each treatment at the time of the pasture estimates by comparing the pasture D.M. yields and the meter readings from six quadrats instead of ten. The lower number of quadrats still gave significant regressions for the calibrations.

8. APPENDIX III - Stratification of wethers to initially stock the grazing trial at Meadows, 1972.

Before the first wethers were put on the trial at Meadows (Section 5.2), they were stratified into two groups with equal numbers of wethers and having similar mean liveweights and mean greasy wool weights. The liveweights of the wethers were estimated after the wethers had been without food for two days and the greasy wool weight of each wether was a relative estimate using the midside-patch technique.

The two similar groups of wethers were obtained by plotting the weight of wool from the mid-side patch against the liveweight for each wether and then grouping them into similar pairs (Figure 12). The wethers in each pair were allotted to different groups. The main emphasis was to have two groups with similar liveweights; the two groups were then assumed to exert similar grazing pressures on the pasture.

The mean liveweights (kg) of each group were 37.6 ± 0.8 and 37.6 ± 0.7 and the mean greasy wool weights (g per 100 cm^2) were 5.1 ± 0.2 and 5.2 ± 0.3 respectively.

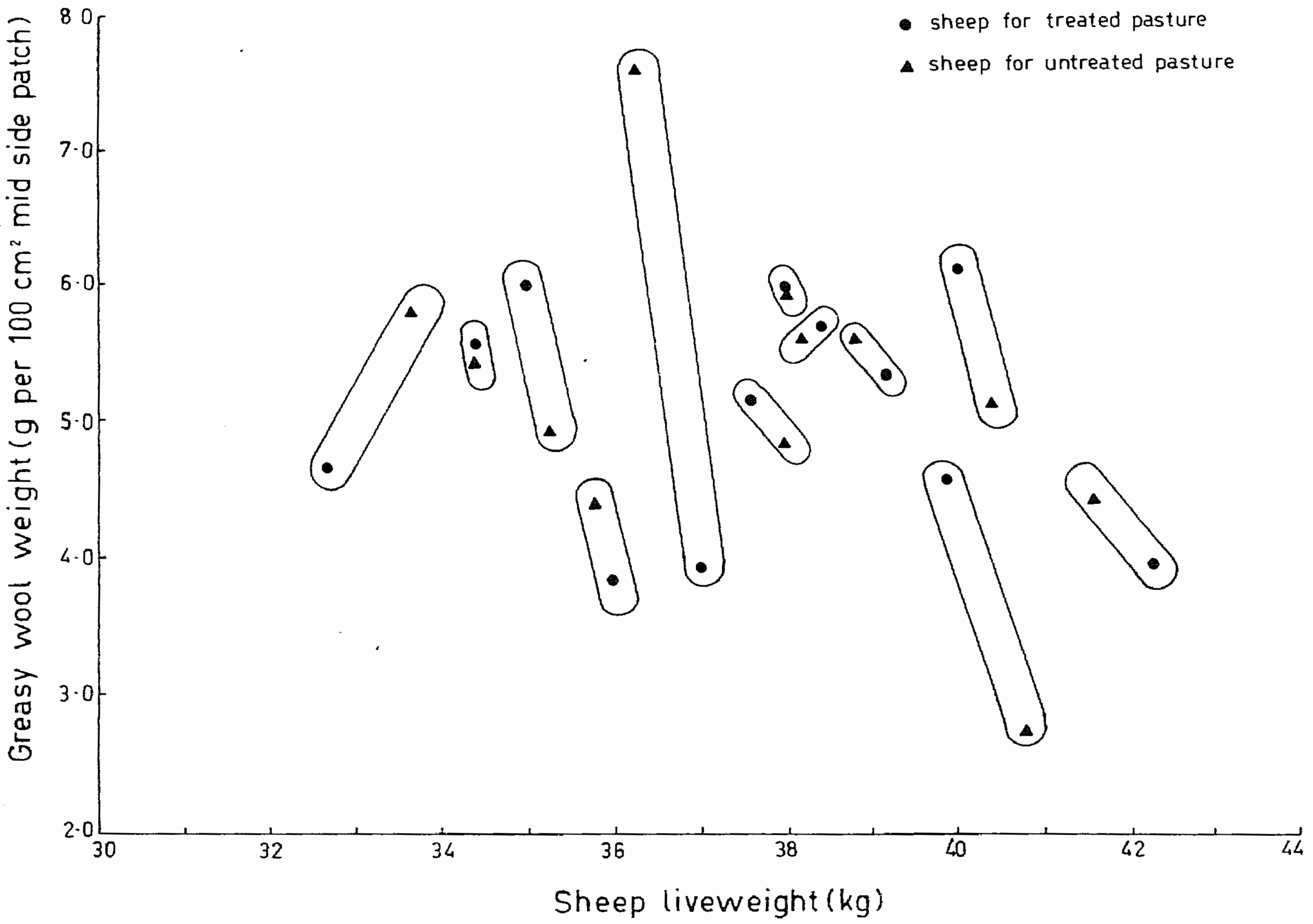


Figure 12: Stratification of wethers into two groups having equal numbers of wethers and similar mean liveweights and mean greasy wool weights.

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