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ECOLOGY OF LICE ON SHEEP

VI.* THE INFLUENCE OF SHEARING AND SOLAR RADIATION ON POPULATIONS AND TRANSMISSION OF *DAMALINIA OVIS*

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Summary

Many *D. ovis* are found more than $\frac{1}{4}$ in. from the skin of the sheep, and 30–50% of a louse population may be lost when the sheep is shorn. The lice near the tip of the fleece come to the tip quickly when it is shaded and warmed, particularly when the fleece is short, and consequently lice, mainly adults and stage III nymphs, spread rapidly from sheep to sheep which are in close contact.

All nymphal and adult stages of *D. ovis* were killed when exposed to 48°C for 60 min, 50°C for 30 min, or to 55 or 60°C for 5 min. Some lice died when exposed to 45°C for 4 hr but the main effect was on oviposition, and females exposed for only 2 hr laid fewer eggs. Most eggs were killed when exposed to 45°C for 4 hr, 47°C for 2–4 hr, or 49°C for $\frac{1}{2}$–1 hr.

The intensity of solar radiation during the summer in Australia can result in a temperature gradient within the fleece of sheep from *c.* 45°C near to the skin to 65–70°C at the tip of the fleece within 5–10 min of exposure. Many lice in the distal parts of the fleece are killed as lethal temperatures develop, and the number of eggs laid by survivors may be reduced. On newly shorn sheep even lice and eggs near the skin may be killed, as the temperature near the skin can rise to 45–52°C. Reasonably heavy infestations may be maintained on sheep kept permanently in the shade, and it appears that the cumulative effect of repeated mortalities due to solar radiation prevents an increase in numbers of *D. ovis* during the summer.

I. INTRODUCTION

Infestations of *Damalinia ovis* spread rapidly through a flock of sheep, and once populations are established the number of lice on each sheep increases during the winter months and declines during the spring to remain at a low level during the summer until the autumn (Scott 1952). It is customary in many parts of Australia to shear in the spring, and any lice within the shorn fleece are lost from the louse population. Shearing suddenly alters the habitat, the physical features of which gradually return to those found in the winter as the fleece grows. A feature of the Australian environment is sunshine, and the intensity of solar radiation during the summer can increase the temperature near the tip of the fleece of a sheep to 70–80°C (Murray 1957*c*; McFarlane, Morris, and Howard 1958). Spring and summer therefore are periods when the physical features of the habitat of *D. ovis* change, causing the microclimate within the habitat to become less stable. Some of the effects of these changes are reported in this paper.

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II. Methods

The techniques used to collect *D. ovis* from sheep, to age eggs, to determine the distribution of living eggs and lice in the fleece, to expose lice in cells on a temperature gradient, and to control and determine temperature and humidity have been described previously (Murray 1957*a*, 1957*b*, 1957*c*, 1960). The temperatures in the fleeces of sheep were recorded to an accuracy of $\pm 0{\cdot}25$°C using fine thermocouples connected to a multipoint recording potentiometer. A 240 V, 375 W frosted drying lamp was used as a source of infrared radiation.

III. Distribution of D. ovis in the Fleece

Samples of fleece of different lengths were dry-shaven from the skin of lousy sheep, immersed immediately in ether to kill the lice *in situ*, and stored separately in a refrigerator until examined. The staple of fleece of each sample was cut parallel to the skin at $\frac{1}{4}$-in. intervals, and the number of living lice in each $\frac{1}{4}$-in. zone was counted.

Table 1

Distribution of *D. ovis* in fleeces of length* 1–3 in.

Instar of Louse	No. of Lice in Fleeces at Distances (in.) from Skin to Tip of:											
	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3
Fleece 1												
Males	4	0	0	0	—	—	—	—	—	—	—	—
Females	6	0	0	0	—	—	—	—	—	—	—	—
Nymphs	25	6	3	0	—	—	—	—	—	—	—	—
Fleece 2												
Males	2	0	0	0	0	1	—	—	—	—	—	—
Females	6	1	1	0	0	0	—	—	—	—	—	—
Nymphs	30	0	2	0	0	0	—	—	—	—	—	—
Fleece 3												
Males	33	11	7	2	2	4	2	—	—	—	—	—
Females	17	5	4	5	3	1	2	—	—	—	—	—
Nymphs	358	61	24	19	14	8	18	—	—	—	—	—
Fleece 4												
Males	3	1	1	0	0	0	0	0	—	—	—	—
Females	1	0	0	0	0	0	1	0	—	—	—	—
Nymphs	18	4	0	1	0	1	0	0	—	—	—	—
Fleece 5												
Males	7	4	2	0	0	1	0	0	1	0	—	—
Females	19	9	1	0	0	0	0	0	0	0	—	—
Nymphs	148	34	16	5	1	2	1	0	0	0	—	—
Fleece 6												
Males	61	18	11	1	0	1	0	0	0	0	0	0
Females	78	37	10	9	1	1	0	1	0	0	1	0
Nymphs	227	51	22	5	1	2	2	0	0	1	0	0

* Temperature gradients in fleeces were from 38°C near to the skin to 15°C near the tip of the fleece.

Table 1 shows that, although most lice were found in the zone next to the skin, many lice were found more than $\frac{1}{4}$ in. from the skin. It has been observed repeatedly that lice are present throughout the depth and on the tip of the fleece of heavily infested sheep.

IV. Effect of Shearing on Numbers of D. ovis

Areas 3 in. square of the 2-in. fleece of a Lincoln × Merino sheep were machine-shorn to within ¼ in. of the skin. The wool remaining on the skin was then removed by dry-shaving. The number of living lice and eggs in the shorn fleece and in the wool which remained on the skin was determined. Table 2 shows that 30–50% of the eggs, nymphs, and adults present were removed with the shorn wool.

Table 2

Effect of Shearing on the Number of *D. ovis* on Sheep

The fleece was 2 in. long and was shorn to within ¼ in. of the skin. The size of each sample area was 3 in. square. The temperature near to the tip of the fleece at the time of shearing was 15–20°C

Sample No.	No. of Lice Removed in Shorn Fleece				No. of Lice Remaining in Wool on Sheep			
	Eggs	Nymphs	Males	Females	Eggs	Nymphs	Males	Females
1	8	50	20	11	27	117	16	4
2	64	39	17	21	102	163	5	14
3	85	6	2	6	107	80	9	25
4	48	4	1	2	143	73	7	18
5	100	13	4	10	92	47	5	20
Total	305	112	44	50	471	480	42	81

V. Transmission

When a cloth is placed over the tip of a fleece, lice move from the fleece onto the cloth, from which they may be removed by suction (Scott 1952; Murray 1957*a*). Proportionately more lice may be collected from heavily infested sheep than from those which are lightly infested, and more lice when the fleece is short rather than long. The number of lice collected may be further increased by warming the cloth, particularly in cold weather. For these reasons it has become the practice to use only heavily infested sheep for louse collection, to keep the fleece trimmed to 1–1½ in., and to warm the cloth with a drying lamp or one's hands.

If lice on a collection cloth are placed on a bench by a window, all lice walk away from the light because they are strongly negatively phototactic. If the cloth is folded at right angles to the direction of the light, the lice walk under the fold and congregate because they will not walk towards the light to escape, so when large collections are being removed from a cloth, two or three small folds are made in the cloth to prevent their escape.

The fleece of a heavily infested sheep was trimmed to 1 in. and a drying lamp switched on to warm the tip of the fleece. The number of lice visible on the tip in the bright light of the lamp was counted on five areas, each of which was 2 in. square. The areas were then shaded from the light, and the number of lice visible was counted ½ min later. The numbers of lice seen on the tip in bright light were 15, *c.* 40, *c.* 60, 6, and 20, and after being shaded for ½ min *c.* 50, *c.* 100, *c.* 100, *c.* 50, and *c.* 60, respectively.

Thermocouples were placed on the tip, midway, and near the skin of a 1-in. fleece, and the temperatures recorded continuously. The range of the temperature gradient within the fleece was 21–23°C at the tip to 34–36·5°C near the skin, and the gradient remained at these values throughout each of three experiments. A cloth was placed lightly on the tip of the fleece over an area of *c.* 1 sq ft. After 2 min the number of lice on the cloth was counted. A fresh cloth was then placed firmly on the

TABLE 3

TRANSMISSION OF *D. OVIS* FROM SHEEP TO CLOTH PLACED ON TIP OF FLEECE

Instar	Collection No.	No. of Lice*	Percentage of Population		
			On Cloth	In ¼-in. Tip of Fleece	In Remainder of Fleece
Males	1	163	16·0	40·5	43·5
	2	190	18·5	48·9	32·6
	3	176	5·1	45·5	49·4
	4	176	11·4	47·1	41·5
	5	121	16·5	42·2	41·3
Females	1	236	10·2	42·8	47·0
	2	117	19·7	44·4	35·9
	3	105	6·6	46·7	46·7
	4	98	15·3	37·8	46·9
	5	190	14·2	31·6	54·2
Stage 3 nymph	1	166	5·5	36·7	57·8
	2	176	6·8	33·0	60·2
	3	241	5·8	30·7	63·5
	4	221	10·8	29·0	60·2
Stage 2 nymph	1	121	8·3	27·3	64·5
	2	179	8·4	26·3	65·4
	3	156	3·2	13·5	83·3
	4	192	4·7	22·9	72·4
Stage 1 nymph	1	75	0	18·7	81·3
	2	129	2·6	14·7	82·7
	3	101	0	8·9	91·1
	4	83	0	7·2	92·8
	5	65	0	7·7	92·3

* Total number from each collection area of 2 in. square.

tip, and after 2 min the number of lice on the cloth counted. The results in each experiment were similar in that after 2 min, 20–30 lice were counted on the cloth placed lightly on the tip whereas 200–300 lice were present on the firmly applied cloth which was in closer contact with the fleece.

A lousy sheep was restrained on a table; a collection cloth marked in 2 in. squares was placed firmly on the tip of the fleece and warmed. After 5 min, a 2-in. square of material was cut from the cloth, and removed together with the attached

lice. The top $\frac{1}{4}$ in. of the fleece, which was beneath the cloth, was quickly removed with scissors, and then the remainder of the fleece of the 2-in. square area was immediately dry-shaved from the skin. The number of each instar of *D. ovis* on the cloth, in the tip of the fleece, and the remainder of the fleece was determined. Five such areas were examined, and Table 3 shows that adults and nymphs were found on the cloth. However, the proportion of the adult louse population which transferred to the cloth and was found in the tip of the fleece was greater than the proportion of the nymphal population. Moreover, the proportion of the population of stage 3 nymphs was greater than that of stage 2 nymphs, and the proportion of stage 2 nymphs was greater than that of stage 1 nymphs.

VI. Effects of Solar Radiation

(*a*) *Effect of Shading the Fleece on Populations of* D. ovis

During these studies methods have been developed to maintain heavy louse populations for as long as possible. Sheep are not shorn but the fleece is trimmed to about $1\frac{1}{2}$ in., a convenient length for collection of lice. Relatively heavy infestations are maintained during the summer months by keeping sheep shaded from the sun. Many of these sheep subsequently develop early in winter the heavy infestations required for repeated harvesting of lice.

(*b*) *Temperatures within Fleeces Exposed to Solar Radiation*

(i) *General.*—The temperature gradient within the fleece of a sheep in the shade is usually from *c.* 38°C at the skin to atmospheric temperature at the tip, provided the fleece structure maintains a blanket of stationary air between the wool fibres. When a sheep is exposed to the sun the temperature at the tip of the fleece may rise to 70–80°C (Murray 1957*c*; McFarlane, Morris, and Howard 1958), and the direction of the temperature gradient within the fleece is reversed.

(ii) *Rapidity of the Changes of Temperatures within the Fleece.*—A Merino sheep with a 2 in. fleece was restrained on a table. The temperatures within $\frac{1}{16}$ in. of the skin, midway between the skin and the tip of the fleece, and just beneath the tip of the fleece were measured continuously. The sheep was exposed alternately to sun and shade on a summer's day in Sydney, N.S.W., when the atmospheric temperature was 25–30°C. The range of the temperature gradient within the fleece when the sheep was in the shade was from *c.* 37°C next to the skin to 25–30°C just beneath the tip. When exposed to the sun, the direction of the temperature gradient reversed, and within 3–5 min the temperatures just beneath the tip of the fleece were *c.* 65°C, and those next to the skin were *c.* 45°C. The temperatures returned to their original values within 15 min of shading the fleece from the sun. Similar high temperatures in the fleece were established as rapidly whenever the sheep was exposed to the sun.

It was found in other sheep exposed to the sun that the direction of the temperature gradient also reversed rapidly. Once, temperatures as high as 75°C just beneath the tip of the fleece and 50°C near the skin were recorded after an exposure of only 5–10 min. Cobalt thiocyanate papers inserted in the fleece showed that relative humidity within the distal parts was less than 60%.

(iii) *Temperatures within the Fleece of a Shorn Sheep.*—A Merino and a Merino crossbred sheep with fleeces $\frac{3}{4}$ and 1 in. long respectively were restrained on a table, and exposed to a drying lamp placed so that the temperatures just beneath the tip of the fleece were 60–65°C and near the skin 43–45°C. An area of the fleece was shorn to leave $\frac{1}{8}$–$\frac{3}{8}$ in. of wool on the skin, the usual length of fleece left after shearing. The temperatures within $\frac{1}{16}$ in. of the skin of the shorn area rose rapidly to 45–52°C, and remained in this range during the $\frac{3}{4}$-hr period of observation. The temperatures within the unshorn fleece remained in the ranges 60–65°C beneath the tip and 43–45°C near the skin.

TABLE 4

EFFECT OF VARIATIONS OF TEMPERATURES WITHIN THE FLEECE OF A SHEEP ON THE SURVIVAL OF *D. OVIS*

Conditions to which Lice Exposed for 4 Hr	No. of Males	Male Mortality (%)	No. of Females	Female Mortality (%)	No. of Eggs Laid
Temperature gradient 40°C at skin and 30°C near tip	78	23·1	107	18·7	10
	79	12·7	94	11·7	3
		—	60	5	0
Totals or means	157	17·5	261	13	13
Temperature gradient initially 40°C at skin to 30°C near tip of fleece. Changed to 45–70°C within 10 min and kept thus	96	31·3	137	27·7	0
	73	24·7	120	11·7	0
	—		94	3·2	1
Totals or means	169	27·7	351	15·7	1
Temperature gradient initially 40°C at skin to 30°C near to tip. Changed to 45–70°C within 10 min. Returned to 40–30°C over next 15 min and remained as such for 35 min. This cycle repeated hourly	64	21·9	111	25·2	3
	64	51·6	114	40·4	3
	81	17·3	88	25	5
Totals or means	209	29·2	313	30·7	11

The sheep were subsequently exposed to solar radiation on a day of average warmth (*c.* 28°C) for February in Sydney. Even though there was a slight cool breeze, the temperature near to the tip of unshorn fleece rose rapidly to 54–56°C, and the temperature within $\frac{1}{16}$ in. of the skin of the shorn area to 45–47°C.

(*c*) *Mortality of* D. ovis *when Temperatures in Fleece are High*

A Merino sheep with a 1 in. fleece which had a dark tip was tied on its side on a table. Adult lice, comprising males and females in approximately equal numbers, were divided into groups of *c.* 200 and placed in nine marked localities in the upper side of the fleece. The lice were allowed to disperse within the fleece for 1 hr before a drying lamp, placed above, was switched on. Three of the localities were shaded with

aluminium foil, and the temperature gradient was 40°C next to the skin to 30°C near to the tip throughout the experiment. Another three localities were exposed to the lamp throughout the experiment. The temperature gradient changed to 45°C at *c.* $\frac{1}{16}$ in. from the skin to 70°C near the tip within 10 min, and remained at these temperatures. The remaining three localities were exposed to the lamp for 10 min, and then were shaded for 50 min. The temperature gradient returned from 45°C near the skin to 70°C near the tip to 40°C near the skin and 30°C near the tip within 15 min of the area being shaded. This cycle of exposure and shade was repeated three times. After 4 hr the fleece was dry-shaven from each area and its surroundings, and the number of dead and living lice counted.

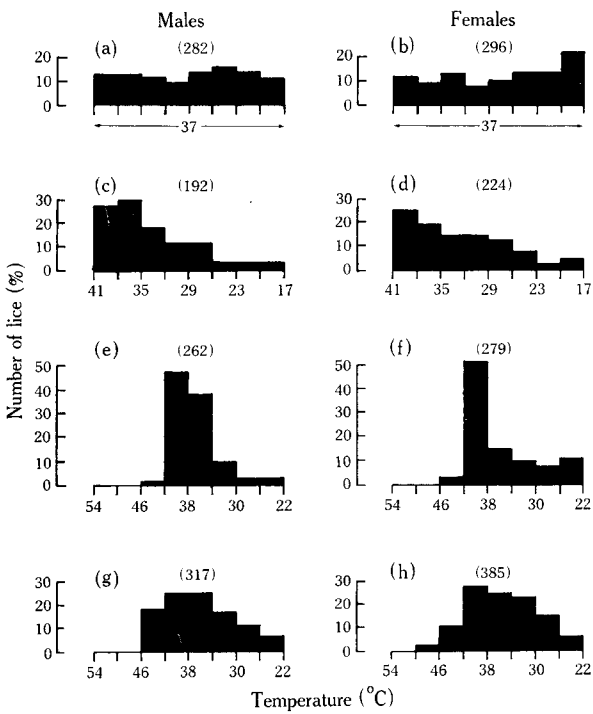

Fig. 1.—(*a*)–(*h*) Distribution of male and female *D. ovis* on filter paper [(*a*)–(*f*)] and on glass wool fibres [(*g*) and (*h*)] when exposed to various temperature gradients. Total number of lice exposed shown in parenthesis on the figure. Cells in which the lice were placed were 2 in. long.

Table 4 shows that, although lice died in the groups which were shaded through the experiment, more died in those exposed to alternate shade and heat. Furthermore, although females exposed to shaded conditions laid eggs at a normal rate, only one egg was laid in the fleece exposed to heat continuously.

(*d*) *Behaviour of* D. ovis *on a Temperature Gradient*

Groups of 70–80 male, female, and nymphal *D. ovis* were placed in separate cells on filter paper, and were kept at 37°C for 1 hr when the distribution of the lice was determined. The cells were then placed on a copper plate along which a temperature gradient was established, and the distribution of the lice was again determined 30 min later. Lice were exposed to temperature gradients from 41 to 17°C or from 54 to 22°C. Lice dispersed throughout the cell when exposed to a constant temperature of 37°C [Figs. 1(*a*) and 1(*b*)]; on the temperature gradient from 41 to

TABLE 5

MORTALITY OF *D. OVIS* WHEN EXPOSED TO A CHANGE IN TEMPERATURE GRADIENT FROM 38–12°C TO 38–68°C

Conditions to which Lice were Exposed	No. of Dead Lice																	
	Experiment 1			Control			Experiment 2			Control			Experiment 3			Control		
	♂	♀	N*	♂	♀	N	♂	♀	N	♂	♀	N	♂	♀	N	♂	♀	N
Initial temperature gradient of 38–12°C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature gradient change to 38–68°C in 1 hr	†	13	—	—	0	—	12	38	11	2	0	1	8	21	3	0	3	6
New temperature gradient established for:																		
1 hr	36	32‡	33	2	4	2	12	38	16	4	0	1	10	21	3	1	3	8
2 hr	42	32	48	—	—	—	13	49‡	27‡	4	0	1	10	21	3	3	3	8
3 hr	42	32	48	3	4	5	17	50	31	9	1	1	—	—	—	—	—	—
4 hr	—	—	—	—	—	—	19	50	31	9	1	2	—	—	—	—	—	—
Total No. of lice	81	79	80	54	83	97	71	68	89	98	63	142	96	111	97	111	85	123

* N, nymphs. † Dead lice not counted. ‡ Lice disturbed when counted.

17°C most lice were found between the 41–35°C gradient, and many were in the zones of cooler temperatures [Figs. 1(*c*) and 1(*d*)]; on the gradient from 54 to 22°C most were in the 44–34°C zone but a few were in the 46–44°C zone and in the cooler zones [Figs. 1(*e*) and 1(*f*)]. The distribution of nymphs was similar.

Other groups of males and females were exposed to the temperature gradient 54–22°C and glass wool or wool fibres were placed in the cell so as to lie longitudinally along the gradient as do the wool fibres in the fleece of a sheep. Figures 1(*g*) and 1(*h*) show that the lice were more dispersed and that many were found in the cooler zones.

TABLE 6

SURVIVAL OF *D. OVIS* AFTER SHORT EXPOSURE TO HIGH TEMPERATURE

Temp. (°C)	Length of Exposure* (min)	No. of Males	Male Mortality (%)	No. of Females	Female Mortality (%)	No. of Nymphs	Nymph Mortality (%)
37†	24 hr	387	39·5	173	25·4	504	3·4
45	2 hr	286	62·9	321	20·6	251	1·6
	4 hr	317	77·9	323	8·7	582	1·5
48	5	314	5·1	335	1·0	914	0
	15	353	19·8	361	3·0	910	1·2
	30	294	32·7	304	21·3	574	24·2
	60	339	100	356	100	926	100
50	5	317	54·3	294	23·1	309	4·2
	15	300	62	286	40·2	278	12·2
	30	283	100	310	100	300	100
55	5	300	100	318	100	350	100
	15	294	100	324	100	337	100
	30	91	100	98	100	98	100
60	5	92	100	104	100	94	100
	15	93	100	101	100	99	100
	30	91	100	97	100	89	100

* After exposure to a high temperature the lice were placed at 37°C for the remainder of the 24-hr period.

† Control.

Groups of males, females, and nymphs were placed in separate cells of 2 in. in length containing glass wool aligned longitudinally. The lice were kept in the dark except when dull vertical illumination was used for counting. A temperature gradient from 38 to 12°C was established along the cell. After 1 hr the number of dead lice was counted. The direction of the gradient was then reversed slowly over 1 hr by raising the temperature of the cool end to 68°C. The number of dead lice was again counted after the new gradient had become established and hourly subsequently. Table 5 shows that many lice died during the period of change of temperature gradient, but once the new gradient had become established the number of deaths was fewer, unless the lice were disturbed when examined.

(*e*) *Effect of Constant High Temperatures on* D. ovis

(i) *Time Required to Kill Adults and Nymphs.*—Lice were divided into groups of 90–110 males, females, or nymphs. The nymphs comprised all three instars, and each group contained approximately the same proportions of each instar. The groups of

males, females and nymphs were exposed to either 45, 48, 50, 55, or 60°C for periods of 5, 15, 30, 60, 120, or 240 min. Three groups of males, females and nymphs were exposed to all but 55°C for 60 min and 60°C for 5, 15, and 30 min. No attempt was made to control the R.H. which was less than 60%. After exposure to these temperatures, the lice were placed at 37°C and 54% R.H. until 24 hr had elapsed from the commencement of the experiment after which the percentage of lice which had died in each group was determined. Control groups of lice were exposed to 37°C and 54% R.H. for 24 hr. The number of lice which died in the groups exposed for the same period to a particular temperature was similar, and the results are presented in Table 6. All lice were killed when exposed to 48°C for 60 min, 50°C for 50 min, or to 55 or 60°C for only 5 min, and they appeared to be dead when examined immediately after the exposure. There was a greater mortality of males in all conditions above 37°C which were not completely lethal to the whole group.

TABLE 7

EFFECT OF SHORT EXPOSURE TO HIGH TEMPERATURE AT 54% R.H. ON EGGS OF *D. OVIS*

Temp. (°C)	Time (hr)	No. of Eggs	Mortality (%)
37	4*	29	24·1
45	1	29	27·6
	2	41	68·3
	4	42	83·3
47	½	31	58·1
	1	32	75
	2	39	82·1
	4	39	100
49	½	41	70
	1	42	100
	2	31	100

* Control.

(ii) *Time Required to Kill Eggs.*—Lice were placed in tubes with glass wool for oviposition, and exposed to 37°C at 54% R.H. The eggs laid were examined 5 days later, and all those in which an embryo was developing were divided into groups of 9–11. Three or four groups were each exposed to 45, 47, or 49°C for ½, 1, 2, or 4 hr at 54% R.H., and then returned to 37°C at 54% R.H. Control groups were kept at 37°C at 54% R.H. The percentage of eggs which died following these treatments was determined 14 days later when all living eggs would have hatched. The mortalities in the groups exposed for the same length of time to each temperature were similar so the results were combined. Table 7 shows that exposure to 45°C for 1 hr had no adverse effect. Deaths rose with increase in length of exposure and temperature, and over 50% were killed when eggs were exposed to 45°C for 4 hr, 47°C for 2 hr, and 49°C for ½–1 hr. All eggs were killed when exposed to 47°C for 4 hr and 49°C for 1 hr.

TABLE 8

INFLUENCE OF SHORT EXPOSURE TO 45°C ON THE NUMBER AND VIABILITY OF EGGS LAID BY *D. OVIS* WHEN SUBSEQUENTLY EXPOSED TO 37°C AT 54% R.H.

Temp. (°C)	R.H. (%)	Duration of Exposure (hr)	State of Lice after Exposure	No. of Lice	No. of Eggs Laid	Eggs per 100 Females (%)	Percentage Hatch
37	54	48	Vigorously active after 4 hr	152	19	12·5	78·9
				102	6	5·8	66·6
				159	10	6·3	60·0
				114	8	7·0	56·2
				129	12	9·3	75·0
				99	16	16·2	75·0
				93	16	17·2	61·5
				171	31	18·1	73·1
				97	26	26·8	45·5
				119	15	12·6	86·6
Totals				1235	159	12·9	68·2
45	54	1	Vigorously active	94	4	4·3	75
				110	8	7·3	37·5
				115	7	6·1	71·4
Totals				319	19	6·0	57·9
45	54	2	Several sluggish	86	2	2·3	0
				89	5	5·6	40·0
				93	1	1·1	0
Totals				268	8	3·0	25·0
45	54	4	In heat stupor many dead	95	1	1·1	0
				103	0	0	—
				94	0	0	—
Totals				292	1	0·3	0
45	88	1	Vigorously active	105	9	8·6	77·8
				122	6	4·9	66·6
				99	7	7·1	42·9
Totals				326	22	6·8	63·6
45	88	2	Active	64	6	9·4	16·7
				94	7	7·5	28·6
				86	6	7·0	33·3
Totals				244	19	7·8	26·3
45	88	4	In heat stupor, rapid recovery	98	5	5·1	0
				114	4	3·5	0
				97	2	2·1	0
Totals				309	11	3·6	0

(iii) *Effect on Oviposition.*—Collections of females were divided into groups, placed in empty test tubes, and exposed to 45°C at 54 or 88% R.H. for 1, 2, or 4 hr after which their condition was assessed as previously for *D. equi* (Denny) (Murray 1963). They were then placed in other test tubes containing glass wool for oviposition, and kept at 37°C at 54% R.H. Control groups were exposed to 37°C and 54% R.H. The number of eggs laid after 48 hr was counted, and the eggs were left at 37°C at 54% R.H. for 14 days when the number of eggs which had hatched was counted. Table 8 shows that exposures to 45°C for 2 and 4 hr had an adverse influence both on oviposition and on the viability of the eggs laid.

VII. Discussion

Although most *D. ovis* were found near the skin of sheep, many lice of all instars were found further than $\frac{1}{4}$ in. from the skin, and these were removed with the shorn fleece. The percentage of the population which may be lost is variable, as it is influenced by factors such as the length of the fleece and the temperature gradient within the fleece which affect the distribution of the lice, and the breed of the sheep and the skill of the shearer which affect the efficiency of shearing, but it was shown that as much as 30–50% can be lost.

D. ovis is an active louse, and is adapted to crawl along fibres rather than flat surfaces. Thus, their distribution on a temperature gradient was less restricted when fibres were present, and lice moved readily into the cooler zones. The preferred temperature of *D. ovis* depends on its physiological state. In oviposition they are attracted to warmth (Murray 1957*b*), and it is likely that attraction to warmth is also an initial feature of a behaviour pattern when lice are hungry. At other times it appears that they wander readily throughout a temperature gradient from *c.* 40 to 20°C, and for this reason many are found near the tip of the fleece but do not remain on the tip because they are negatively phototactic. When the tip was shaded from light lice came rapidly to the surface of the fleece. Thus, when sheep come into contact lice transfer to other sheep, and, if the sheep are in close contact, many lice may transfer to other sheep even before the temperature gradient has changed; more will transfer if the sheep remain in contact long enough for the temperature gradient to change and for the temperature at the tip of the fleece to rise; even more will transfer if the fleece is short. All instars transfer from one sheep to another but in the main they comprise adults and stage III nymphs. At all times lice are in the distal parts of the fleece, and their presence accounts for the rapid spread of *D. ovis* from sheep to sheep. These lice, however, are vulnerable, not only to loss by shearing, but to the sudden development of lethal temperatures in the fleece when sheep are exposed to solar radiation.

Males, females, and nymphs of *D. ovis* died when exposed to 48°C for 60 min, to 50°C for 30 min, or to 55–60°C for only 5 min. A 4-hr exposure to 45°C killed some lice but the main effect was on oviposition. Even lice exposed for only 2 hr at 45°C at 54% R.H. laid fewer eggs than those exposed to 37°C at 54% R.H. There was also an indication of an adverse effect on the subsequent development of the eggs as there was a reduction in the percentage hatch of eggs laid by females exposed for 2 hr at

45°C at both 54 and 88% R.H. The majority of eggs died when exposed to 45°C for 4 hr, 47°C for 2–4 hr, or 49°C for only ½–1 hr.

The range of the temperature gradient within the fleeces of sheep not exposed to solar radiation is usually from 35 to 40°C at the skin to atmospheric temperature at the tip. When sheep were exposed to the sun, the temperature gradient changed to *c.* 45°C near the skin to 60–70°C and even higher near the tip of the fleece, and the temperatures in much of the fleece became lethal to *D. ovis*. The direction of the temperature gradient within the fleece reversed rapidly, and lethal temperatures were established within 5 min. Lice died during the transition of a temperature gradient as they were apparently unable to orientate themselves when the direction of the temperature gradient was reversing, even when this took 1 hr, and were killed as lethal temperatures developed. Once the reverse gradient was established the lice were able to orientate themselves, and remained where temperatures were coolest, which on sheep would have been near the skin. The temperatures near the skin of sheep exposed to the summer's sun are usually not lethal but may be sufficiently high to reduce the number and viability of the eggs laid. When the fleece is less than 1½ in. (4 cm) in depth, however, radiation energy from the sun can penetrate the fleece to the skin with a resultant rise in skin temperature (McFarlane, Morris, and Howard 1958; Parer 1963). Thus, high temperatures may persist near the skin of newly shorn sheep sufficiently long to be lethal to both lice and eggs. The severity of these mortalities may be expected to lessen as the fleece grows, and as the intensity of solar radiation decreases during late summer. The skin temperature of a sheep exposed to solar radiation decreases as the length of the fleece increases to 1½ in. (4 cm) (Parer 1963), thus there is also an increase in the depth of the zone near the skin with non-lethal temperatures.

Solar radiation can lower the reproductive potential of *D. ovis* on sheep in two ways. The temperatures near the skin may become high enough and persist sufficiently long to reduce the number of eggs which females lay, and even kill both eggs and lice when the fleece is short. Males, females, and nymphs may be killed whenever the direction of temperature gradient in the fleece reverses rapidly and lethal temperatures become established in the distal parts of the fleece, as when a sheep leaves the shade of a tree or when a cloud ceases to obscure the sun. At any one time the mortality of lice on a sheep may not be great but it can occur daily in much of Australia for 4–5 months, and the resultant cumulative effect is apparently sufficient to prevent an increase in the numbers of *D. ovis* during the summer.

VIII. References

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