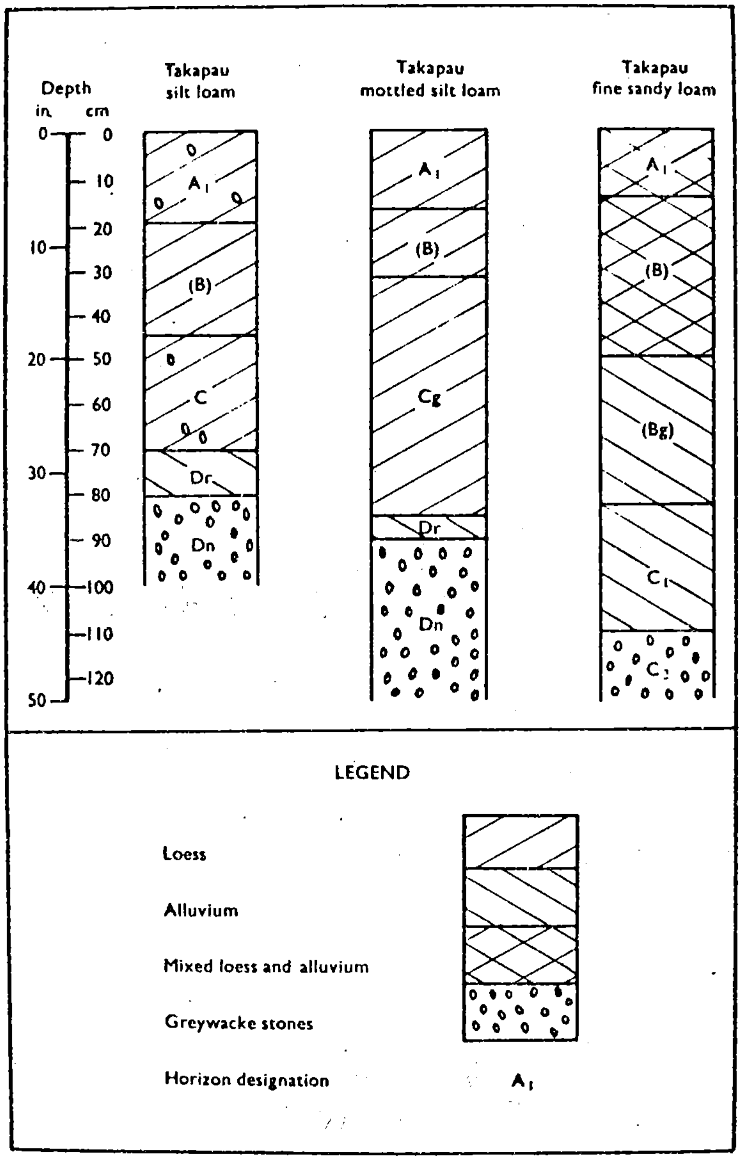
POPULATION DYNAMICS AND PEST ASSESSMENT STUDIES OF GRASS GRUB (COSTELYTRA ZEALANDICA (WHITE), MELOLONTHINAE) IN THE NORTH ISLAND OF NEW ZEALAND

APPENDICES



Appendix 4-1 Profiles of the different soil types found on the Takapau research area.

Appendix 4-2 Particulars of the improved and unimproved Takapau life table plots in terms of, soil fertility, pasture productivity and botanical composition*

	Soil test values+		Pasture production (Kg/ha)		
	Improved	Unimproved		Improved	Unimproved
pH	6.0	6.1	Summer	1,598	1,110
Ca	12.5	12.5	Autumn	2,926	1,336
K	7.0	6.5	Winter	628	260
P	8.0	8.0	Spring	5,378	3,646
			Total	10,530	6,346

Botanical composition of pasture (%)

		Lolium perenne	Other grasses	Clovers	Broad leaved weeds and litter
Summer	Improved	18.57 ± 4.72	36.83 ± 4.57	37.17 ± 1.89	7.50 ± 1.34
	Unimproved	9.17 ± 1.54	44.83 ± 3.94	19.67 ± 4.70	26.33 ± 4.84
Autumn	Improved	42.05 ± 8.27	18.01 ± 1.05	27.5 ±16.51	7.52 ± 7.50
	Unimproved	14.61 ± 6.35	52.00 ± 5.27	18.05 ± 3.01	16.0 ± 14.0
Winter	Improved	37.01 ± 5.21	56.09 ± 5.40	6.01 ± 1.02	1.0 ± 7.0
	Unimproved	34.62 ±13.41	60.0 ± 9.17	2.07 ± 0.24	4.0 ± 4.0
Spring	Improved	28.75 ± 2.53	46.75 ± 3.41	22.25 ± 2.66	2.13 ± 0.77
	Unimproved	26.01 ± 5.05	47.02 ± 4.71	18.75 ± 3.05	8.25 ± 2.26

* Assessed by herbage dissection

\+ Methods and units as per Mountier *et al.* (1966)

Appendix 4-3 Design of sampler used in population studies of *C. zealandica*

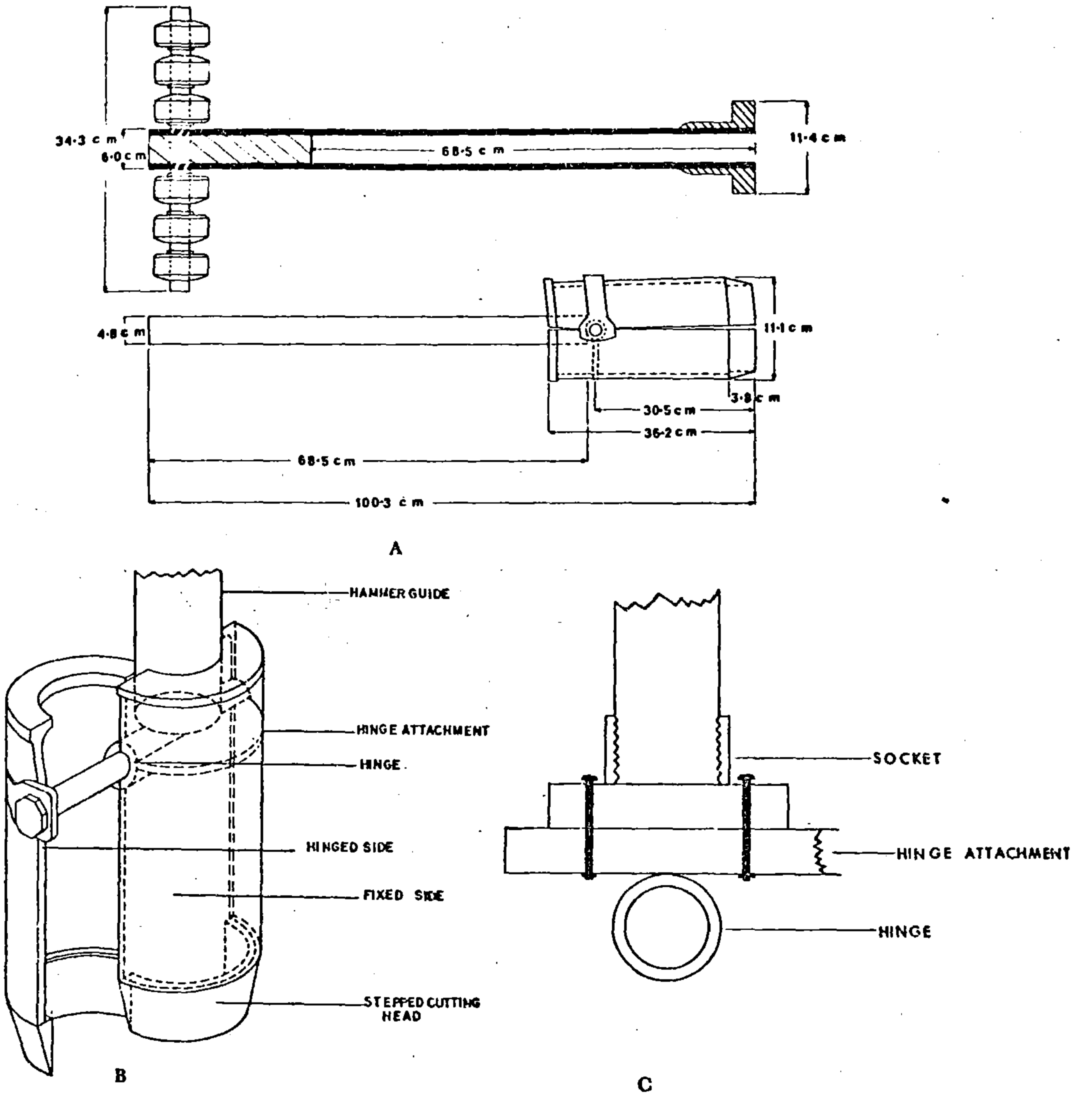
The components of the sampler are shown in A, B and C of Appendix 4-4 Basically, the sampler consists of two parts, the hammer and the corer (A, Appendix 4-4). The hammer consists of a 5 cm diameter pipe weighted at the top and flanged at the striking end. Located at the weighted end are two well braced handles equipped with rubber grips to minimise shock. The weight of the hammers used varied depending on the soil type and the season. In the winter when soils were moist lighter hammers (12 kg) were adequate, while in the summer the use of heavier hammers (16.5 kg) was necessary.

The corer consists of the hammer guide and the barrel (B, Appendix 4-4). The hammer guide is a 3.75 cm diameter 1.0 m long tube attached to the top of the corer. The function of this tube which fits inside the hammer is to direct the stroke of the hammer on to the upper part of the barrel.

The point of attachment of the guide is shown in C, Appendix 4-4. The guide tube screws into a socket which, in turn, is held by four bolts extending upward through a plate attached to the fixed half of the corer. The socket hinge pin on which the hinge articulates and guide handle are all separate components which can be removed to dismantle the corer and allow access to parts requiring replacement or repair.

The barrel is split longitudinally and consists of a hinged and fixed half (B, Appendix 4-4). The hinged half of the corer is cut back on an angle above the hinge which allows it to open, at the cutting head, from the fixed side. Internally the cutting edge has a diameter which is 3.0 mm smaller than the barrel. Because of this stepped cutting edge, the sample is retained loosely within the barrel which enables it to be released easily and quickly. Externally the cutting head tapers towards the cutting edge.

The corer is constructed of mild steel, and the barrel is case hardened. Apart from the guide tube the complete corer after construction is re-tempered, and the barrel is polished both internally and externally to reduce soil adhesion.



Appendix 4-4 Design of hammer (upper, A) and corer (lower, A) used for sampling C. zealandica populations; (B) construction of corer barrel (C) attachment of the hammer guide to the corer barrel.

Appendix 5-1 Statistical parameters of frequency distributions of *C. zealandica* recorded from the improved Takapau life table plot

			DAMAGED STRATA					
					Skewness		Kurtosis	
Generation	Stage	No. samples	s^2	$\bar{x}$	G1	SD	G2	SD
68/69	Eggs	500	33.701	1.588	4.352	0.109	20.771	0.218
	3rd M*	400	1.968	0.677	2.497	0.122	6.237	0.243
	3rd A**	364	2.240	0.829	2.428	0.127	7.316	0.255
	P	400	1.717	0.585	3.313	0.122	15.124	0.243
	B	Spade spit sample unit used						
69/70	Eggs	545	232.723	8.418	2.919	0.104	11.188	0.208
	1st	535	33.501	4.745	1.708	0.105	3.155	0.210
	2nd	420	12.414	2.914	1.425	0.119	1.601	0.237
	3rd M	445	3.337	1.748	0.986	0.115	0.246	0.230
	3rd A	400	1.959	1.015	2.226	0.122	7.666	0.243
	P	401	1.571	0.845	2.269	0.121	8.618	0.243
	B	400	1.195	0.665	2.185	0.122	5.611	0.243

* 3rd M = Third instar May

** 3rd A = Third instar August

No. = number of samples

s^2 = variance

$\bar{x}$ = mean

Skewness (G1) see Snedecor and Cochran (1959)

Kurtosis (G2) see Snedecor and Cochran (1959)

SD = Standard deviation

Appendix 5-1 cont.

DAMAGED STRATA

Generation	Stage	No. samples	s^2	$\bar{x}$	Skewness G1	Skewness SD	Kurtosis G2	Kurtosis SD
70/71	Eggs	603	144.691	4.963	3.170	0.099	11.365	0.198
	2nd	406	11.902	2.689	1.447	0.121	1.475	0.241
	3rd M	395	2.902	1.615	1.121	0.122	1.125	0.244
	3rd A	350	1.954	1.011	2.226	0.130	6.903	0.260
	P	350	1.396	0.751	2.021	0.130	4.601	0.260
	B	350	0.737	0.480	2.287	0.130	6.277	0.260
71/72	Eggs	601	36.243	1.865	5.257	0.099	39.450	0.199
	2nd	500	5.204	1.160	2.900	0.109	10.413	0.218
	3rd M	517	0.728	0.419	2.419	0.107	6.305	0.214
	3rd A	500	0.341	0.230	3.174	0.109	11.908	0.218
	P	500	0.233	0.164	3.287	0.109	11.333	0.218
	B	501	0.188	0.133	3.792	0.109	16.122	0.217
72/73	Eggs	600	15.854	0.878	5.987	0.099	42.442	0.199

Appendix 5-1 cont.

UNDAMAGED STRATA									
					Skewness		Kurtosis		
Generation		No.	s^2	$\bar{x}$	G1	SD	G2	SD	
69/70	Eggs	255	36.231	1.450	5.813	0.152	38.299	0.303	
	1st	260	7.021	0.965	4.470	0.151	23.871	0.300	
	2nd	160	2.177	0.583	3.923	0.181	21.434	0.360	
	3rd M	255	2.056	0.850	1.991	0.152	3.830	0.303	
	3rd A	200	0.436	0.160	5.093	0.171	27.976	0.342	
	P	200	0.378	0.135	5.532	6.171	33.132	0.342	
	B	200	0.108	0.085	4.183	0.171	18.214	0.342	
70/71	Eggs	200	12.116	0.535	7.553	0.171	59.492	0.342	
	2nd	94	0.627	0.265	3.463	0.248	12.146	0.492	
	3rd M	200	0.572	0.255	4.313	0.171	23.001	0.342	
	3rd A	50	1.152	0.520	2.522	0.336	6.946	0.661	
	P	50	0.107	0.120	2.411	0.336	4.675	0.661	
	B	50	0.039	0.040	4.841	0.336	22.585	0.661	
71/72	Eggs	180	3.300	0.261	7.430	0.181	57.573	0.360	
	2nd	100	0.972	0.240	4.853	0.241	24.607	0.478	
	3rd M	83	0.106	0.060	5.573	0.264	30.954	0.522	
	3rd A	100	0.143	0.090	4.386	0.241	18.987	0.478	
	P	100	0.323	0.200	3.028	0.241	8.936	0.478	
	B	99	0.068	0.050	5.744	0.242	35.578	0.480	
72/73	Eggs	200	4.250	4.250	0.275	0.171	65.713	0.342	

Appendix 5-2 Statistical parameters of frequency distributions of *C. zealandica* recorded from the unimproved Takapau life table plot

DAMAGED STRATA								
					Skewness		Kurtosis	
Generation	Stage	No. samples	s^2	$\bar{x}$	G1	SD	G2	SD
68/69	Eggs	500	34.303	1.838	3.960	0.109	17.782	0.218
	3rd M	400	3.230	1.150	2.033	0.122	4.575	0.243
	3rd A	400	2.090	1.010	1.823	0.122	4.094	0.243
	P	400	2.142	0.972	2.144	0.122	5.564	0.243
	B		Spade split sample unit used					
69/70	Eggs	550	190.646	8.303	2.592	0.104	8.404	0.207
	1st	550	30.467	5.850	1.663	0.104	4.770	0.207
	2nd	400	14.062	4.797	0.796	0.122	0.417	0.243
	3rd M	410	5.121	2.787	0.781	0.120	0.290	0.240
	3rd A	500	2.439	1.256	1.385	0.109	1.805	0.218
	P	500	2.373	1.158	2.001	0.109	5.458	0.218
	B	500	1.889	0.890	2.462	0.109	9.849	0.218

No. = Number of samples

s^2 = Variance

$\bar{x}$ = mean

Skewness (G1) see Snedecor and Cochran (1959)

Kurtosis (G2) see Snedecor and Cochran (1959)

SD = standard deviation

Appendix 5-2 cont.

Generation	Stage	No. samples	s^2	$\bar{x}$	Skewness G1	Skewness SD	Kurtosis G2	Kurtosis SD
DAMAGED STRATA								
70/71	Eggs	598	130.524	4.525	4.087	0.099	24.001	0.199
	2nd	500	16.226	3.060	1.894	0.109	4.121	0.218
	3rd M	498	2.222	1.196	1.547	0.109	2.372	0.218
	3rd A	400	1.595	0.967	1.643	0.122	3.095	0.243
	P	400	1.069	0.652	1.978	0.122	4.531	0.243
	B	427	0.816	0.454	3.943	0.118	29.933	0.235
71/72	Eggs	610	21.492	1.221	4.992	0.098	28.320	0.197
	2nd	500	2.362	0.738	3.651	0.109	22.414	0.218
	3rd M	500	0.775	0.488	2.184	0.109	5.083	0.218
	3rd A	500	0.483	0.348	2.563	0.109	8.645	0.218
	P	500	0.436	0.250	3.824	0.109	20.392	0.218
	B	500	0.277	0.222	2.582	0.109	6.867	0.218
72/73	Eggs	600	34.547	1.691	4.304	0.099	20.874	0.199
UNDAMAGED STRATA								
69/70	Eggs	250	62.593	2.616	4.613	0.154	24.681	0.306
	1st	250	18.059	2.316	4.895	0.154	41.005	0.306
	2nd	200	4.672	1.395	2.214	0.171	6.837	0.342
	3rd M	300	3.420	1.470	1.666	0.140	3.132	0.280

Appendix 5-3 Tests for the adequacy of fit of the negative binomial (NB) for counts of C. zealandica recorded from the improved life table plot at Takapau

(* signified appropriate test of NB for $\bar{x}/k$)

Stage	SINGLE SAMPLE UNITS - DAMAGED STRATA									
	$\bar{x}$	s^2	k	x^2	df	T	SET	U	SEU	$\bar{x}/k$
1968-69 Eggs	1.59	33.70	0.0310	67.24	7	- 550.40	4928.88	- 49.07*	27.75	51.22
3rd (May)	0.68	1.96	0.2571	9.67	7	- 2.62	3.70	- 0.49*	0.30	2.64
3rd (Aug)	0.83	2.24	0.3720	13.65	8	- 1.78	3.22	- 0.44*	0.29	2.23
Pupae	0.59	1.71	0.2414	7.30	7	- 0.96	2.86	- 0.29*	0.24	2.42
1969-70 Eggs	8.41	233.78	0.2052	63.98	29	-2329.93	6987.35	-120.84*	49.12	40.90
2nd	2.91	12.41	0.6700	21.49	13	- 31.46	27.49	- 3.17*	1.56	4.34
3rd (May)	1.74	3.33	1.4796	21.12	9	- 3.43*	1.89	- 0.48*	0.28	1.17
3rd (Aug)	1.01	1.95	1.1022	10.63	7	0.45	0.85	0.01*	0.14	0.92
Pupae	0.84	1.57	0.9526	3.53	7	0.17	0.68	- 0.02*	0.11	0.88
Beetles	0.66	1.19	0.7979	1.96	6	- 0.27	0.51	- 0.02*	0.09	0.83
1970-71 Eggs	4.95	143.72	0.0722	105.52	13	-2801.59	16903.77	-201.05*	71.60	68.50
2nd	2.68	11.90	0.5490	31.11	13	- 34.44	33.29	- 3.96*	1.68	4.90
3rd (May)	1.61	2.90	1.6251	13.05	8	- 2.02*	1.47	- 0.32*	0.24	0.99
3rd (Aug)	1.01	1.95	1.2149	2.35	7	0.43	0.79	0.10*	0.14	0.83
Pupae	0.75	1.39	0.8109	2.14	6	- 0.49	0.70	- 0.05*	0.11	0.92
Beetles	0.48	0.73	0.8704	1.18	5	- 0.09	0.24	- 0.007*	0.04	0.55
1971-72 Eggs	1.86	36.24	0.0523	42.92	13	- 230.76	2021.07	- 32.04*	16.13	35.64
2nd	1.16	5.20	0.2788	11.69	11	- 7.26	11.92	- 0.78*	0.67	4.16
3rd (May)	0.42	0.72	0.4660	4.13	5	- 0.30	0.35	- 0.07*	0.06	0.90
3rd (Aug)	0.23	0.34	0.4572	1.10	4	- 0.04	0.10	- 0.004*	0.02	0.50
Pupae	0.16	0.23	0.3044	3.26	4	- 0.06	0.09	- 0.018*	0.01	0.53
Beetles	0.13	0.18	0.2892	1.27	4	- 0.03	0.06	- 0.007*	0.01	0.45
1972-73 Eggs	0.87	15.85	0.0291	15.43	7	- 180.35	904.48	- 11.46*	8.47	29.90

$\bar{x}$ = mean

s^2 = variance

k = dispersion parameter of NB

x^2 = chisquare test

df = degrees of freedom in x^2

T = test of NB

SET = SE of T

U = test of NB

SEU = SE of U

Appendix 5-3 cont Tests for the adequacy of fit of the negative binomial (NB) for counts of C. zealandica recorded from the improved life table plot at Takapau

(* signified appropriate test of NB for $\bar{x}/k$)

Stage		SINGLE SAMPLE UNITS - UNDAMAGED STRATA									
		$\bar{x}$	s^2	k	x^2	df	T	SET	U	SEU	$\bar{x}/k$
1969-70	Eggs	1.45	36.23	0.0379	9.44	6	-520.31	3233.58	-20.71*	24.09	38.26
	2nd	0.58	2.17	0.1718	5.86	5	- 1.68	8.45	- 0.39*	0.56	3.38
	3rd (May)	0.85	2.05	0.4554	5.84	6	- 2.08	2.82	- 0.38*	0.29	1.87
	3rd (Aug)	0.16	0.43	0.0706	0.82	3	- 0.50	1.66	- 0.09*	0.15	2.27
	Pupae	0.13	0.37	0.0535	0.83	3	- 0.48	1.88	- 0.10*	0.15	2.43
	Beetles	0.08	0.10	0.2444	1.17	3	- 0.02	0.05	- 0.006*	0.011	0.33
1970-71	Eggs	0.53	12.11	0.0103	1.05	2	-223.05	4603.36	-16.11*	25.61	51.46
	2nd	0.27	0.62	0.1424	1.20	3	- 0.67	2.19	- 0.13*	0.22	1.90
	3rd (May)	0.25	0.57	0.2128	0.73	4	- 0.16	0.64	0.01*	0.09	1.17
	3rd (Aug)	0.70	1.59	0.3236	2.33	3	- 1.02	3.45	- 0.20*	0.39	2.16
	Pupae	0.12	0.10	8.1200	0.48	2	- 0.0055	0.0174	- 0.014*	0.0057	0.015
	Beetles	0.04	0.03	3.2253	0.06	2	- 0.0022	0.0041	- 0.0013*	0.0013	0.012
1971-72	Eggs	0.26	3.30	0.0059	0.93	2	- 36.31	2254.25	- 8.44*	14.69	44.07
	2nd	0.24	0.97	0.0461	0.91	2	- 2.39	17.55	- 0.52*	0.81	5.21
	3rd (May)	0.06	0.10	0.0411	0.54	2	- 0.08	0.64	- 0.04*	0.08	1.46
	3rd (Aug)	0.09	0.14	0.0905	0.73	2	- 0.08	0.36	- 0.04*	0.05	0.99
	Pupae	0.20	0.32	0.2165	2.72	3	- 0.18	0.50	- 0.06*	0.08	0.92
	Beetles	0.05	0.06	0.1072	0.18	2	- 0.01	0.08	- 0.005*	0.02	0.47
1972-73	Eggs	0.27	4.25	0.0050	0.93	2	- 58.12	3709.72	-10.97*	19.69	54.00

Appendix 5-4 Tests for the adequacy of fit of the negative binomial (NB) for counts of *C. zealandica*

recorded from the unimproved life table plot at Takapau

(* signifies appropriate test of NB for $\bar{x}/k$)

Stage	$\bar{x}$	s^2	k	x^2	df	T	SET	U	SEU	$\bar{x}/k$
	+SINGLE SAMPLE UNITS - DAMAGED STRATA									
1968-69 Eggs	1.84	34.30	0.0442	48.00	10	- 455.07	3196.49	- 43.86*	22.01	41.63
3rd (May)	1.15	3.23	0.5115	9.47	9	- 3.20	3.94	- 0.50*	0.36	2.25
3rd (Aug)	1.01	2.09	0.7797	10.73	7	- 1.09	1.39	- 0.23*	0.19	1.30
Pupae	0.97	2.14	0.7887	4.32	7	- 0.62	1.25	- 0.03*	0.17	1.23
1969-70 Eggs	8.30	190.66	0.2697	38.22	31	-1776.69	3530.38	- 73.26*	32.87	30.78
2nd	4.79	14.06	1.9672	27.68	16	- 26.70*	15.93	- 2.43*	1.72	2.43
3rd (May)	2.78	5.12	2.7592	14.63	10	- 4.70*	2.63	- 0.48*	0.49	1.01
3rd (Aug)	1.25	2.43	1.0562	12.54	8	- 1.79	1.32	- 0.31*	0.19	1.18
Pupae	1.15	2.37	1.1038	5.56	8	- 0.08*	1.02	0.00*	0.16	1.04
Beetles	0.89	1.88	0.7856	5.86	7	- 0.22	0.91	- 0.01*	0.13	1.13
1970-71 Eggs	4.52	130.08	0.0737	85.96	18	-1315.29	12247.90	-152.02*	57.88	61.33
2nd	3.06	16.22	0.5855	11.71	16	- 32.78	37.70	- 2.82*	1.82	5.23
3rd (May)	1.19	2.22	1.2740	5.41	8	- 0.94*	0.91	- 0.10*	0.15	0.93
3rd (Aug)	0.96	1.59	1.3810	4.18	6	- 0.38*	0.57	- 0.05*	0.11	0.70
Pupae	0.65	1.06	0.9238	3.92	6	- 0.26	0.40	- 0.044*	0.07	0.70
Beetles	0.45	0.81	0.6902	7.00	6	0.27	0.26	0.06*	0.05	0.65
1971-72 Eggs	1.22	21.49	0.0379	22.02	10	- 239.97	1256.68	- 19.07*	11.04	32.19
2nd	0.74	2.36	0.2946	9.18	8	0.42	3.17	- 0.22*	0.26	2.51
3rd (May)	0.49	0.77	0.7537	3.81	5	- 0.21	0.25	- 0.03*	0.05	0.65
3rd (Aug)	0.35	0.48	0.8927	5.85	5	- 0.004	0.10	0.0002*	0.02	0.39
Pupae	0.25	0.43	0.3356	3.02	5	0.009	0.185	0.0001*	0.032	0.74
Beetles	0.22	0.27	0.7697	1.52	4	- 0.04	0.05	- 0.0087*	0.013	0.29
1972-73 Eggs	1.69	34.54	0.0361	40.04	10	506.91	3730.02	- 46.20*	22.91	46.81
	SINGLE SAMPLE UNITS - UNDAMAGED STRATA									
1969-70 Eggs	2.62	62.59	0.0984	7.96	10	- 675.44	1857.78	- 9.52*	19.64	26.63
2nd	1.39	4.67	0.4361	14.97	8	- 4.59	12.53	- 1.18*	0.88	3.19
3rd (May)	1.47	3.42	0.9751	7.48	8	- 2.06	2.80	- 0.26*	0.35	1.51

+ Notations defined in Appendix 5-3

Appendix 5-5 Tests for the adequacy of fit of the negative binomial (NB) for counts of *C. zealandica* recorded from the improved lifetable plot at Takapau in 1969-70 season

(* signifies appropriate test of NB for $\bar{x}/k$)

Stage	$\bar{x}$	s^2	k	x^2	df	T	SET	U	SEU	$\bar{x}/k$
	SINGLE SAMPLE UNITS - DAMAGED STRATA									
Eggs	8.41	233.78	0.2052	63.98	29	-2329.93	6987.35	-120.84*	49.12	40.97
2nd instar	2.91	12.41	0.6700	21.49	13	-31.46*	27.49	-3.17*	1.56	4.34
3rd instar (May)	1.74	3.33	1.4796	21.12	9	-3.43*	1.89	-0.48*	0.28	1.17
3rd instar (Aug)	1.01	1.95	1.1022	10.63	7	0.45*	0.85	-0.01*	0.14	0.92
Pupae	0.84	1.57	0.9526	3.53	7	0.17*	0.68	-0.02*	0.11	0.88
Beetles	0.66	1.19	0.7979	1.96	6	-0.27*	0.51	-0.02*	0.09	0.83
	TWO SAMPLE UNITS POOLED DAMAGED STRATA									
Eggs	16.29	2351.48	0.5658	44.96	30	-4803.7*	6870.52	-133.93	71.93	28.85
2nd instar	9.59	29.3	4.0889	25.24	19	-67.3*	46.08	-2.81	8.97	2.34
3rd instar (May)	5.57	10.34	5.7183	12.46	13	-12.88*	8.22	-0.67	2.34	0.97
3rd instar (Aug)	2.03	3.15	3.6990	3.22	8	0.0561*	1.41	0.0108	0.34	0.55
Pupae	2.31	4.67	2.2859	3.00	9	-0.33*	2.75	0.01	0.48	1.01
Beetles	1.78	3.76	1.7492	5.02	9	1.52*	2.14	0.17	0.35	1.02
	THREE SAMPLE UNITS POOLED DAMAGED STRATA									
Eggs	24.95	559.25	0.9189	32.31	28	-8192.18*	10418.46	-143.11	131.06	27.15
2nd instar	14.35	53.06	4.8106	20.62	21	-143.12*	128.59	-4.12	33.87	2.98
3rd instar (May)	8.36	15.41	10.0841	7.83	14	-5.31*	14.77	0.13	8.08	0.83
3rd instar (Aug)	3.77	7.53	3.4540	5.02	11	-5.47*	6.38	-0.35	1.26	1.09
Pupae	3.46	7.47	3.0656	5.07	11	1.27*	6.04	0.83	1.12	1.13
Beetles	2.67	5.10	3.0247	4.99	8	0.03*	3.39	0.07	0.68	0.88

$\bar{x}$ = mean

s^2 = variance

k = dispersion parameter of NB

x^2 = chisquare test

df = degrees of freedom in x^2

T = test of NB

SET = SE of T

U = test of NB

SEU = SE of U

Appendix 5-6 Skewness and kurtosis of the frequency distributions of independently pooled sample units taken over different developmental stages of C. zealandica and transformed using Taylor's power law.

Stage		SKEWNESS 1 unit	SKEWNESS 2 units Pooled	SKEWNESS 3 units Pooled	KURTOSIS 1 unit	KURTOSIS 2 units Pooled	KURTOSIS 3 units Pooled
Eggs	Low	** 3.17 ± 0.109	** 1.88 ± 0.154	** 1.34 ± 0.188	** 9.09 ± 0.218	** 2.06 ± 0.307	NS 0.33 ± 0.375
	Med	** 1.78 ± 0.100	** 0.77 ± 0.140	NS 0.30 ± 0.172	** 2.00 ± 0.199	**-0.83 ± 0.279	**-1.36 ± 0.341
	High	** 1.02 ± 0.105	NS 0.01 ± 0.148	NS-0.10 ± 0.181	NS 0.14 ± 0.209	**-0.90 ± 0.294	NS-0.53 ± 0.359
1st	Low	** 2.00 ± 0.099	not calculated	not calculated	** 2.95 ± 0.198	not calculated	not calculated
	Med	* 1.22 ± 0.107			NS 0.25 ± 0.214		
	High	NS-0.28 ± 0.104			NS-0.37 ± 0.201		
2nd	Low	** 1.33 ± 0.109	** 0.55 ± 0.154	NS-0.10 ± 0.178	** 0.66 ± 0.218	**-0.81 ± 0.307	**-1.01 ± 0.355
	Med	** 0.33 ± 0.121	NS-0.30 ± 0.171	**-0.69 ± 0.209	**-1.18 ± 0.242	NS-0.58 ± 0.340	NS 0.66 ± 0.414
	High	**-0.54 ± 0.122	**-0.61 ± 0.172	NS-0.18 ± 0.202	NS-0.26 ± 0.243	* 0.84 ± 0.342	NS 0.00 ± 0.401
3rd (May)	Low	** 1.09 ± 0.109	NS 0.28 ± 0.154	NS-0.09 ± 0.188	NS-0.35 ± 0.218	**-1.15 ± 0.307	**-1.01 ± 0.375
	Med	**-0.07 ± 0.123	**-0.54 ± 0.173	**-0.97 ± 0.212	**-1.35 ± 0.245	NS-0.33 ± 0.345	NS 0.77 ± 0.420
	High	**-0.56 ± 0.121	**-0.93 ± 0.170	NS 0.30 ± 0.208	**-0.54 ± 0.240	** 1.39 ± 0.338	NS-0.38 ± 0.413
3rd (Aug)	Low	** 1.41 ± 0.109	** 0.72 ± 0.154	** 0.56 ± 0.188	** 0.61 ± 0.218	* -0.63 ± 0.307	NS-0.45 ± 0.375
	Med	** 0.46 ± 0.122	NS-0.03 ± 0.172	NS-0.03 ± 0.210	**-1.05 ± 0.243	NS-0.67 ± 0.342	NS-0.44 ± 0.417
	High	** 0.35 ± 0.109	NS 0.08 ± 0.154	NS 0.08 ± 0.188	**-1.26 ± 0.218	* -0.60 ± 0.307	NS-0.25 ± 0.375
Pupae	Low	** 1.94 ± 0.109	** 1.06 ± 0.154	** 0.61 ± 0.188	** 2.21 ± 0.218	NS-0.54 ± 0.307	**-1.16 ± 0.375
	Med	** 0.47 ± 0.122	* -0.36 ± 0.172	NS-0.40 ± 0.210	**-1.38 ± 0.243	* -1.11 ± 0.342	NS-0.12 ± 0.417
	High	NS 0.18 ± 0.109	**-0.58 ± 0.154	**-0.62 ± 0.188	**-1.44 ± 0.218	NS-0.56 ± 0.307	NS 0.38 ± 0.375
Beetles	Low	** 1.74 ± 0.109	** 0.80 ± 0.154	NS 0.26 ± 0.188	** 1.11 ± 0.218	**-1.31 ± 0.307	**-1.85 ± 0.375
	Med	** 0.58 ± 0.122	NS-0.31 ± 0.172	**-0.94 ± 0.210	**-1.54 ± 0.243	**-1.72 ± 0.342	NS-0.54 ± 0.417
	High	** 0.33 ± 0.109	**-0.71 ± 0.154	**-1.40 ± 0.188	**-1.72 ± 0.218	**-1.19 ± 0.307	* 0.96 ± 0.375

NS = not significant * and ** = P > .05 and P > .01 respectively

Appendix 5-7 Proportion of the Takapau life table plots in each stratum and the proportion of the damaged and undamaged strata in each subplot.

	IMPROVED PLOT					UNIMPROVED PLOT				
Stage	E 1968 – B 1969	E 1969–3rd M 1970		3rd A 1970–2nd 1970		E 1968 – B 1969	E 1969–3rd M 1970		3rd A 1970–2nd 1973	
Sub-plots		Damaged	Undamaged	Damaged	Undamaged		Damaged	Undamaged	Damaged	Undamaged
1	Not stratified on damage	0.066	0.040	0.063		Not stratified on damage	0.054	0.047	0.05	
2		0.066	0.040	0.063			0.008	0.083	0.05	
3		0.091	0.024	0.063			0.055	0.046	0.05	
4		0.081	0.031	0.063			0.046	0.053	0.05	
5		0.030	0.062	0.063			0.064	0.039	0.05	
6		0.033	0.061	0.063			0.094	0.016	0.05	
7		0.044	0.053	0.063			0.090	0.017	0.05	
8		0.083	0.029	0.063			0.039	0.059	0.05	
9		0.089	0.026	0.063			0.022	0.072	0.05	
10		0.009	0.075	0.017	0.177		0.054	0.047	0.05	
11		0	0.081	0	0.243		0.008	0.083	0.05	
12		0.019	0.069	0.016	0.180		0.011	0.080	0.05	
13		0.035	0.059	0.063			0.035	0.061	0.05	
14		0.050	0.050	0.063			0.049	0.051	0.05	
15		0.055	0.047	0.063			0.047	0.052	0.05	
16		0.070	0.037	0.063			0.058	0.043	0.05	
17		0.078	0.032	0.063			0.080	0.027	0.05	
18		0.070	0.037	0.063			0.078	0.028	0.05	
19		0.027	0.064	0.022	0.158		0.078	0.028	0.05	
20		0	0.081	0	0.243		0.032	0.064	0.05	
Proportion of the plot in each stratum		0.383	0.617	0.794	0.206		0.438	0.562	1.00	0.00

Appendix 5-7 cont. Proportion of the Rukuhia and Smith's life table plots in each stratum and the proportion of the damaged and undamaged strata in each subplot.

	RUKUHIA PLOT					SMITH'S PLOT	
Stage	3rd A 1969 - P 1969	E 1969 - 3rd M 1970		3rd A 1970 - 2nd 1973		E 1970 - 2nd 1971	
Sub Plots		Damaged	Undamaged	Damaged	Undamaged	Damaged	Undamaged
1	Not stratified on damage	0.033	0.078	0.05		0	0.050
2		0.075	0	0.05		0.004	0.046
3		0.073	0.007	0.05		0.011	0.039
4		0.027	0.051	0.05		0.003	0.047
5		0.033	0.089	0.05		0.003	0.047
6		0.027	0.078	0.05		0.003	0.047
7		0.020	0.089	0.05		0.008	0.042
8		0.062	0.100	0.05		0.006	0.044
9		0.040	0.030	0.05		0.007	0.043
10		0.058	0.067	0.05		0	0.050
11		0.080	0	0.05		0.002	0.048
12		0.058	0.037	0.05		0.015	0.035
13		0.062	0.037	0.05		0.010	0.040
14		0.080	0	0.05		0.004	0.046
15		0.058	0.030	0.05		0.002	0.048
16		0.053	0.037	0.05		0.002	0.048
17		0.027	0.045	0.05		0.001	0.049
18		0.027	0.089	0.05		0.003	0.047
19		0.053	0.089	0.05		0.003	0.047
20		0.055	0.045	0.05		0.004	0.046
Proportion of the plot in each stratum		0.627	0.373	1.00	0.00	0.091	0.909

E = Egg 2nd = Second instar larvae 3rd M = Third instar larvae in May
3rd A = Third instar larvae in August P = Pupae B = Beetles

Appendix 5-8 Total number of sample units taken from the undamaged and damaged strata of the Takapau life table plots

IMPROVED PLOT

Generation	Stage	No. samples	Damaged	Undamaged
1968-69	Eggs	500	not stratified on damage	
	1st instar	-		
	2nd instar	-		
	3rd instar (May)	400		
	3rd instar (Aug)	406		
	Pupae	400		
	Beetles	*100		
1969-70	Eggs	800	500	300
	1st instar	795	535	260
	2nd instar	600	420	180
	3rd instar (May)	700	445	255
	3rd instar (Aug)	600	400	200
	Pupae	600	400	200
	Beetles	600	400	200
1970-71	Eggs	783	583	200
	1st instar	not sampled		
	2nd instar	500	406	94
	3rd instar (May)	595	395	200
	3rd instar (Aug)	400	350	50
	Pupae	400	350	50
	Beetles	400	350	50
1971-72	Eggs	781	601	180
	1st instar	not sampled		
	2nd instar	597	497	100
	3rd instar (May)	600	500	100
	3rd instar (Aug)	600	500	100
	Pupae	600	500	100
	Beetles	600	501	99
1972-73	Eggs	800	600	200
	2nd instar	600	500	100

UNIMPROVED PLOT

Generation	Stage	No. samples	Damaged	Undamaged
1968-69	Eggs	500	not stratified on damage	
	1st instar	-		
	2nd instar	-		
	3rd instar (May)	400		
	3rd instar (Aug)	400		
	Pupae	400		
	*Beetles	100		
1969-70	Eggs	800	550	250
	1st instar	800	550	250
	2nd instar	600	400	200
	3rd instar (May)	710	410	300
	3rd instar (Aug)	500	500	-
	Pupae	500	500	-
	Beetles	500	500	-
1970-71	Eggs	598	598	-
	1st instar	not sampled		
	2nd instar	500	500	-
	3rd instar (May)	498	498	-
	3rd instar (Aug)	400	400	
	Pupae	400	400	
	Beetles	427	427	-
1971-72	Eggs	608	608	-
	1st instar	not sampled		
	2nd instar	500	500	-
	3rd instar (May)	500	500	-
	3rd instar (Aug)	500	500	-
	Pupae	500	500	-
	Beetles	500	500	-
1972-73	Eggs	600	600	-
	2nd instar	500	500	-

* sampling unit 15^2 cm spade spit

Appendix 5-8 cont. Total number of sample units taken from the undamaged and damaged strata of the Rukuhia life table plot and Smiths plots

Rukuhia Plots					Smiths Plots				
Generation	Stage	No. samples	Damaged	Undamaged	Generation	Stage	No. samples	Damaged	Undamaged
1968-69	3rd instar (Aug)	400	not stratified on damage		1970-71	Eggs	454	54	400
	Pupae	200				2nd instar	434	78	350
						3rd instar (May)	160	10	150
1969-70	Eggs	800	600	200					
	2nd instar	600	400	200					
	3rd instar (May)	600	400	200					
	3rd instar (Aug)	500	500	-					
	Pupae	400	400	-					
1970-71	Eggs	430	430	-					
	Pupae	360	360	-					

Appendix 5-9

Statistical Notation

A list of notations and formulae used in the ensuring discussion on stratified sampling are listed below. Without exception the formulae have been taken from Cochran (1963) or derived from formulae given by Cochran.

In stratified sampling the population of N units is first divided into sub-populations $N_1, N_2 \ldots N_l$. The sample sizes within each stratum are $n_1, n_2 \ldots n_l$, respectively.

In the following the suffix h denotes the stratum and i the unit within the stratum.

N_h total number of sample units

n_h total number of units in the sample

x_{hi} value obtained in the i th unit

$$W_h = \frac{N_h}{N} \quad \text{stratum weight}$$

$$f_h = \frac{n_h}{N_h} \quad \text{sampling fraction}$$

$$\bar{x}_h = \sum_{i=1}^{n_h} \frac{x_{hi}}{n_h} \quad \text{sample mean of h stratum}$$

Statistics calculated from stratified sampling are denoted by the suffix st.

$$\bar{X}_{st} = \sum W_h \bar{x}_h \quad \text{sample mean}$$

$$V_{st}\bar{x} = \sum \frac{W_h^2 s_h^2}{n_h} \sum \frac{W_h s_h^2}{N} \quad \text{variance of sample mean}$$

Where the sampling fraction is negligible in all strata the right hand portion of the equation for $V_{st}\bar{x}$ can be deleted giving,

$$V_{st}\bar{x} = \sum \frac{W_h^2 s_h^2}{n_h}$$

$$S_{\bar{x}} = \sqrt{V_{st}\bar{x}} \quad \text{standard error of the mean}$$

In the cases where samples are proportionately allocated the sampling fraction is the same for each stratum. The mean is calculated as for sample random and the variance:

$$Vst = \sum Wh\ sh^2$$

If sampling is proportional and the strata variance homogeneous (Sw^2).

$$Vstx = \frac{Sw^2}{n} \quad \text{variance of the mean}$$

An unbiased estimate of the variance of the mean for simple random sampling (Vran x) where sampling was stratified is calculated by:

$$Vran\ \bar{x} = \frac{N - n}{nN} \left[\sum Wh\ sh^2 - \frac{Wh\ sh^2}{nh} + \frac{Wh^2 sh^2}{nh} + \sum Wh\ (\bar{x}\ h^2) - (\sum Wh\ \bar{x}\ h)^2 \right]$$

It should be noted that in the text and the appendices that follow, the terms Vran and Vst are used to denote the variance of simple random sampling and stratified sampling rather than the respective variances of the mean.

Estimate of the sample size for optimal allocation of sample units to each stratum, where n is a fixed sample size, is given by:

$$nh^i = n \frac{(Whsh)}{Whsh}$$

Estimate of the number of samples for a 10% relative standard error with optimum allocation

$$\bar{nh} = \frac{Whsh \cdot \sum Whsh}{(0.1\ \bar{x})^2}$$

Appendix 5-10 Variance components of the damaged and undamaged strata of the Takapau life table study plots

Variance components		Unimproved 1969-70	Unimproved 1970-71	Unimproved 1971-72	Improved 1969-70	Improved 1970-71	Improved 1971-72
Eggs							
Damaged	Between subplots	5.39 **	0.19	0.34	9.79 **	0.95	0.46
	Within subplots	187.48	130.29	21.23	240.92	138.25	35.81
	$\bar{x}$	8.30	4.52	1.22	8.42	4.96	1.86
	* Wh	0.44	1.00	1.00	0.38	0.80	0.79
Undamaged	Between subplots	-1.66	All classified as damaged		1.91	0.39	-0.02
	Within subplots	63.44			34.50	11.80	3.32
	$\bar{X}$	2.61			1.45	0.53	0.26
	Wh	0.56			0.61	0.20	0.21
First instar							
Damaged	Between subplots	2.12	Not sampled		4.35	Not sampled	
	Within subplots	28.79			30.95		
	$\bar{X}$	5.85			4.74		
	Wh	0.44			0.38		
Undamaged	Between subplots	2.86	Not sampled		0.84	Not sampled	
	Within subplots	15.34			6.60		
	$\bar{X}$	2.32			0.96		
	Wh	0.56			0.62		

* Wh = stratum weight, $\bar{x}$ = stratum mean

Tests of the level of significance * = P>.05

** = P>.01

Appendix 5-10 cont.

Variance components		Unimproved 1969-70	Unimproved 1970-71	Unimproved 1971-72	Improved 1969-70	Improved 1970-71	Improved 1971-72
Third instar (Aug)							
Damaged	Between subplots	0.27	0.09	0.05	-0.01	0.08	0.00
	Within subplots	2.18	1.50	2.45	1.96	1.93	0.34
	$\bar{X}$	1.25	0.97	0.35	1.01	1.01	0.23
	Wh	1.00	1.00	1.00	0.79	0.79	0.79
Undamaged	Between subplots				0.00	0.06	0.02
	Within subplots				0.43	0.18	0.13
	$\bar{X}$				0.16	0.52	0.09
	Wh				0.21	0.20	0.20
Pupae							
Damaged	Between subplots	0.11	0.01	0.01	0.02	0.03	0.00
	Within subplots	2.26	1.06	0.42	1.55	1.38	0.23
	$\bar{X}$	1.16	0.65	0.25	0.84	0.75	0.16
	Wh	1.00	1.00	1.00	0.79	0.79	0.79
Undamaged	Between subplots				0.02	0.01	0.02
	Within subplots				0.36	0.10	0.30
	$\bar{X}$				0.13	0.12	0.20
	Wh				0.21	0.21	0.20

Appendix5 - 10 cont.

Variance components		Unimproved			Improved		
		1969-70	1970-71	1971-72	1969-70	1970-71	1971-72
Second instar							
Damaged	Between subplots	1.48 **	2.54 **	0.14 **	1.15 **	0.19	0.11
	Within subplots	12.66	13.81	1.76	11.54	11.72	5.14
	$\bar{X}$	4.79	3.06	0.74	2.91	2.69	1.16
	Wh	0.44	1.00	1.00	0.38	0.79	0.79
Undamaged	Between subplots	0.39			0.30	-0.01	0.01
	Within subplots	4.29			2.12	0.63	0.06
	$\bar{X}$	1.39			0.58	0.26	0.24
	Wh	0.56			0.62	0.20	0.20
Third instar (May)							
Damaged	Between subplots	0.44 **	0.13 **	0.05 **	0.07	0.03	0.01
	Within subplots	4.71	2.11	0.72	3.19	2.88	0.72
	$\bar{X}$	2.78	1.20	0.49	1.74	1.61	0.42
	Wh	0.44	1.00	1.00	0.38	0.79	0.79
Undamaged	Between subplots	0.52			0.47	0.02	0.00
	Within subplots	2.93			2.01	0.56	0.10
	$\bar{X}$	1.47			0.85	0.25	0.06
	Wh	0.56			0.62	0.20	0.21

Appendix 5 - 10 cont.

Variance components		Unimproved			Improved		
		1969-70	1970-71	1971-72	1969-70	1970-71	1971-72
Beetles							
Damaged	Between subplots	0.07	0.01	0.01	0.03	0.01	0.00
	Within subplots	1.82	0.59	0.26	1.16	0.69	0.18
	$\bar{X}$	0.89	0.45	0.22	0.66	0.48	0.13
	Wh	1.00	1.00	1.00	0.79	0.79	0.79
Undamaged	Between subplots				0.01	0.00	0.00
	Within subplots				0.10	0.04	0.07
	$\bar{X}$				0.08	0.04	0.05
	Wh				0.21	0.21	0.21

Appendix 5-11 (a) Statistics* of stratified sampling of the improved Takapau life table plot for the egg stage of the 1969-1970 generation

Geostrata of damaged area

nh	sh^2	Wh	Whsh	$Whsh^2$	$Whsh^2/nh$	Wh^2sh^2/nh	$Wh\bar{x}h$	$Wh(\bar{x}h^2)$
20	12.0421	0.0665	0.2310	0.8017	0.0400	0.0026	0.1731	0.4500
30	9.0160	0.0665	0.1999	0.6003	0.0200	0.0013	0.1642	0.4051
35	7.0806	0.0913	0.2431	0.6470	0.0184	0.0016	0.2297	0.5777
30	15.4310	0.0809	0.3178	1.2486	0.0416	0.0033	0.2832	0.9912
15	4.9809	0.0300	0.0670	0.1495	0.0099	0.0002	0.0560	0.1046
15	13.6666	0.0326	0.1206	0.4460	0.0297	0.0009	0.0761	0.1776
20	13.6736	0.0443	0.1641	0.6069	0.0303	0.0013	0.1731	0.6751
30	15.0758	0.0835	0.3244	1.2596	0.0419	0.0035	0.2840	0.9658
30	23.2138	0.0887	0.4277	2.0808	0.0686	0.0060	0.5681	3.6362
5	0.2000	0.0091	0.0040	0.0018	0.0003	0.0000	0.0018	0.0003
10	17.1111	0.0195	0.0810	0.3350	0.0335	0.0006	0.0391	0.0783
15	28.5523	0.0352	0.1883	1.0064	0.0670	0.0023	0.1715	0.8348
20	6.8315	0.0496	0.1296	0.3389	0.0169	0.0008	0.1537	0.4767
30	4.7868	0.0548	0.1199	0.2624	0.0131	0.0007	0.1069	0.2084
30	9.9724	0.0704	0.2226	0.7030	0.0234	0.0016	0.1691	0.4060
30	2.5988	0.0783	0.1262	0.2035	0.0067	0.0005	0.1227	0.1922
30	10.6678	0.0704	0.2302	0.7520	0.0250	0.0017	0.1715	0.4174
15	10.6952	0.0274	0.0896	0.2932	0.0195	0.0005	0.0676	0.1668
Σ 400		1.0000	3.2878	11.7173	0.5068	0.0303	3.0122	10.7650

* For definition see Appendix 5-9

Geostrata of undamaged area

nh	sh^2	Wh	Whsh	$Whsh^2$	$Whsh^2/nh$	Wh^2sh^2/nh	$Wh\bar{x}h$	$(Wh(\bar{x}h^2)$
5	3.2000	0.0397	0.0710	0.1270	0.0254	0.0010	0.0476	0.0571
5	3.8000	0.0397	0.0774	0.1508	0.0301	0.0011	0.0555	0.0778
5	0.3000	0.0243	0.0133	0.0072	0.0014	0.0000	0.0097	0.0038
5	4.7000	0.0307	0.0667	0.1447	0.0289	0.0008	0.0369	0.0443
15	2.5523	0.0623	0.0996	0.1592	0.0106	0.0006	0.0707	0.0801
15	2.9809	0.0607	0.1049	0.1811	0.0120	0.0007	0.0688	0.0780
10	0.0000	0.0534	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	5.3000	0.0291	0.0671	0.1546	0.0309	0.0009	0.0466	0.0746
5	1.8000	0.0259	0.0347	0.0466	0.0093	0.0002	0.0155	0.0093
15	9.4952	0.0753	0.2322	0.7156	0.0477	0.0035	0.0703	0.0656
20	0.0499	0.0810	0.0181	0.0040	0.0002	0.0000	0.0040	0.0002
15	1.0666	0.0688	0.0711	0.0734	0.0048	0.0003	0.0183	0.0048
10	0.1000	0.0591	0.0187	0.0059	0.0005	0.0000	0.0059	0.0005
10	0.4888	0.0502	0.0351	0.0245	0.0024	0.0001	0.0301	0.0180
10	10.4000	0.0470	0.1515	0.4888	0.0488	0.0022	0.1316	0.3684
5	9.8000	0.0372	0.1166	0.3653	0.0730	0.0027	0.0969	0.2519
5	3.0000	0.0324	0.0561	0.0972	0.0194	0.0006	0.0324	0.0324
5	0.0000	0.0372	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	2.6000	0.0640	0.1032	0.1664	0.0110	0.0007	0.0512	0.0409
20	0.0499	0.0810	0.0181	0.0040	0.0002	0.0000	0.0040	0.0002
Σ 200		1.0000	1.3561	2.9172	0.3574	0.0161	0.7967	1.2089

Appendix 5-11(b)

Statistics of stratified sampling for damage - geostratification

Damaged stratum

	nh	sh^2	Wh	Whsh	$Whsh^2$	$Whsh^2/nh$	Wh^2sh^2/nh	$Wh\bar{x}h$	$Wh(\bar{x}h^2)$
	20	12.0421	0.0255	0.0884	0.3070	0.0153	0.0003	0.0663	0.1723
	30	9.0160	0.0255	0.0765	0.2299	0.0076	0.0001	0.0629	0.1551
	35	7.0806	0.0350	0.0931	0.2478	0.0070	0.0002	0.0880	0.2212
	30	15.4310	0.0309	0.1217	0.4782	0.0159	0.0004	0.1084	0.3796
	15	4.9809	0.0115	0.0256	0.0572	0.0038	0.0000	0.0214	0.0400
	15	13.6666	0.0124	0.0462	0.1708	0.0113	0.0001	0.0291	0.0680
	20	13.6736	0.0170	0.0628	0.2324	0.0116	0.0001	0.0663	0.2585
	30	15.0758	0.0320	0.1242	0.4824	0.0160	0.0005	0.1088	0.3699
	30	23.2138	0.0340	0.1638	0.7892	0.0263	0.0008	0.2176	1.3926
	5	0.2000	0.0034	0.0015	0.0006	0.0001	0.0000	0.0006	0.0001
	10	17.1111	0.0074	0.0310	0.1283	0.0128	0.0000	0.0149	0.0299
	15	28.5523	0.0134	0.0721	0.3854	0.0256	0.0003	0.0656	0.3197
	20	6.8315	0.0190	0.0496	0.1298	0.0064	0.0001	0.0589	0.1825
	20	4.7868	0.0210	0.0459	0.1005	0.0050	0.0001	0.0409	0.0798
	30	9.9724	0.0270	0.0852	0.2692	0.0089	0.0002	0.0648	0.1555
	30	2.5988	0.0300	0.0483	0.0779	0.0025	0.0000	0.0470	0.0736
	30	10.6678	0.0270	0.0881	0.2880	0.0096	0.0002	0.0657	0.1598
	15	10.6952	0.0105	0.0343	0.1123	0.0074	0.0000	0.0259	0.0638
Σ	400		0.3829	1.2592	4.4876	0.1941	0.0044	1.1536	4.1229

Appendix 5-11(b) cont.

Undamaged Stratum

nh	sh^2	Wh	Whsh	Whsh^2	Whsh^2/nh	Wh^{2}sh^2/nh	Wh$\bar{x}$h	Wh($\bar{x}$h^2)
5	3.2000	0.0245	0.0438	0.0784	0.0156	0.0003	0.0294	0.0352
5	3.8000	0.0245	0.0477	0.0931	0.0186	0.0004	0.0343	0.0480
5	0.3000	0.0150	0.0082	0.0045	0.0009	0.0000	0.0000	0.0024
5	4.7000	0.0190	0.0411	0.0893	0.0178	0.0003	0.0228	0.0273
15	2.5523	0.0384	0.0615	0.0982	0.0065	0.0002	0.0436	0.0494
15	2.9809	0.0375	0.0647	0.1117	0.0074	0.0002	0.0425	0.0481
10	0.0000	0.0330	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	5.3000	0.0179	0.0414	0.0953	0.0190	0.0003	0.0287	0.0460
5	1.8000	0.0159	0.0214	0.0287	0.0057	0.0000	0.0095	0.0057
15	9.4952	0.0465	0.1432	0.4415	0.0294	0.0013	0.0434	0.0405
20	0.0499	0.0500	0.0111	0.0025	0.0001	0.0000	0.0025	0.0001
15	1.0666	0.0425	0.0438	0.0453	0.0030	0.0001	0.0113	0.0000
10	0.1000	0.0365	0.0115	0.0036	0.0003	0.0000	0.0036	0.0003
10	0.4888	0.0310	0.0216	0.0151	0.0015	0.0000	0.0186	0.0111
10	10.4000	0.0290	0.0935	0.3016	0.0301	0.0008	0.0812	0.2273
5	9.8000	0.0230	0.0720	0.2254	0.0450	0.0010	0.0598	0.1554
5	3.0000	0.0199	0.0346	0.0599	0.0119	0.0002	0.0199	0.0199
5	0.0000	0.0230	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	2.6000	0.0395	0.0635	0.1027	0.0068	0.0002	0.0316	0.0252
20	0.0499	0.0500	0.0111	0.0025	0.0001	0.0000	0.0025	0.0001
Σ 200		0.6170	0.8367	1.7999	0.2205	0.0061	0.4916	0.7459
$\Sigma\Sigma$ 600		1.0000	2.0959	6.2875	0.4146	0.0105	1.6486	4.8688

Random variance estimates for each subplot and estimates of the variance of the mean assuming geostratification

	Damaged Stratum				Undamaged Stratum				Random variance estimates		
Subplot	nh	$\bar{x}h$	Wh	sh^2	nh	$\bar{x}h$	Wh	sh^2	+ sh^2 (Vran)	Wh sh	$Wh^2 sh^2/nh$
1	20	2.6000	0.51	12.0421	5	1.2000	0.49	3.2000	7.888	0.140	0.00079
2	30	2.4666	0.51	9.0160	5	1.4000	0.49	3.8000	6.479	0.127	0.00046
3	35	2.5142	0.70	7.0806	5	0.4000	0.30	0.3000	5.930	0.122	0.00037
4	30	3.5000	0.62	15.4310	5	1.2000	0.38	4.7000	12.256	0.175	0.00088
5	15	1.8666	0.23	4.9809	15	1.1333	0.77	2.5523	3.117	0.088	0.00026
6	15	2.3333	0.25	13.6666	15	1.1333	0.75	2.9809	5.714	0.119	0.00047
7	20	3.9000	0.34	13.6736	10	0.0000	0.66	0.0000	7.908	0.141	0.00066
8	30	3.4000	0.64	15.0758	5	1.6000	0.36	5.3000	11.943	0.172	0.00085
9	30	6.4000	0.68	23.2138	5	0.6000	0.32	1.8000	23.434	0.242	0.00167
10	5	0.2000	0.07	0.2000	15	0.9333	0.93	9.4952	8.835	0.148	0.00110
11	0	-	0.0	-	20	0.0500	1.00	0.0499	0.050	0.011	0.00001
12	10	2.0000	0.15	17.1111	15	0.2666	0.85	1.0666	3.6291	0.095	0.00036
13	15	4.8666	0.27	28.5523	10	0.1000	0.73	0.1000	11.883	0.172	0.00119
14	20	3.1000	0.38	6.8315	10	0.6000	0.62	0.4888	4.279	0.103	0.00036
15	20	1.9500	0.42	4.7868	10	2.8000	0.58	10.4000	7.907	0.140	0.00066
16	30	2.4000	0.54	9.9724	5	2.6000	0.46	9.8000	9.333	0.153	0.00067
17	30	1.5666	0.60	2.5988	5	1.0000	0.40	3.0000	2.671	0.081	0.00020
18	30	2.4333	0.54	10.6678	5	0.0000	0.46	0.0000	7.143	0.134	0.00051
19	15	2.4666	0.21	10.6952	15	0.8000	0.79	2.6000	4.613	0.107	0.00038
20	0	-	0.0	-	20	0.0500	1.00	0.0499	0.050	0.011	0.00001
	400				200				145.068	2.485	0.01136

+ Estimate of random variance for subplot 1 is given in appendix 11 (d)

Estimate of random variance for subplot 1

	$W_h s_h^2$	$W_h s_h^2/n_h$	$W_h^2 s_h^2/n_h$	$W_h(\bar{x}_h^2)$	$W_h\bar{x}_h$
Damaged	6.1415	0.3071	0.1566	3.4476	1.3260
Undamaged	1.5680	0.3136	0.1537	0.7056	0.5880
	7.7095	0.6207	0.3103	4.1532	1.9140

$$V_{ran}\,(\text{subplot}_1) = \sum W_h s_h^2 - \sum W_h^2 s_h^2 + \sum W_h^2 s_h^2/n_h + \sum W_h(\bar{x}_h^2) - \left(\sum W_h\bar{x}_h\right)^2$$

$$= 7.888$$

I. Variance estimates

1 Estimates of the variance of mean assuming damage stratification.

Since sample allocation to geo-strata in the damaged and undamaged areas was made for this particular sampling proportionately in batches of five samples, in the strictest sense samples cannot be considered to be proportionally allocated. In these studies it is unlikely that this will markedly alter the results. To assess the efficiency of damage stratification in estimating variance, estimates of random variances for each stratum were required. From the bottom of appendices 11(a) and 11(b) the following statistics are given for the damaged and undamaged areas.

	$\sum Whsh^2$	$\sum Whsh^2/nh$	$\sum Wh^2sh^2/nh$	$\sum Wh\bar{x}h$	$\sum Wh(\bar{x}h^2)$
Damaged	11.7173	0.5068	0.0303	3.0122	10.7650
Undamaged	2.9172	0.3574	0.0161	0.7967	1.2089

Random variance (Vran) $= \sum Whsh^2 - \sum Whsh^2 + \sum Wh^2sh^2/nh + \sum Wh(\bar{x}h^2) - (\sum Wh\bar{x}h)^2$

Damaged Vran = 12.9325

Undamaged Vran = 3.1501

Appendix 5-11(e) cont.

From the random variances calculated for the damaged and undamaged strata.

Strata	n_h	$\bar{x}_h$	s_h^2	W_h	$W_h s_h^2$	$W_h s_h$	$W_h s_h^2/n_h$	$W_h^2 s_h^2/n_h$	$W_h(\bar{x}_h^2)$	$(\sum W_h \bar{x}_h)^2$
Damaged	400	3.01	12.9325	0.384	4.9661	1.3809	0.01242	0.00476	1.1558	3.4790
Undamaged	200	0.80	3.1501	0.616	1.9404	1.0933	0.00971	0.00597	0.4928	0.3942
$\sum$	600			1.000	6.9065	2.4742	0.03454	0.01073	1.6486	3.8732

Estimate of damage stratification variance of the mean from above

$V_{st}\,\bar{x}\,(d) = \sum \frac{W_h^2 s_h^2}{n_h} = 0.01073$ $\quad$ % SE = $(\sqrt{.01073}/1.648) \cdot 100 = 6.28\%$

2 Estimate of simple random variance of the mean from V_{ran} of damaged undamaged strata 5-11(e).

$$V_{ran}\,\bar{x} = \sum \frac{1}{n_h} \cdot \left(\sum W_h s_h^2 - \sum W_h s_h^2/n_h + \sum W_h^2 s_h^2/n_h + \sum W_h (\bar{x}_h^2) - \sum (W_h \bar{x}_h)^2 \right)$$

$V_{ran}\,\bar{x} = 0.013397$ $\quad$ % SE $(\sqrt{.013397}/1.648 \cdot 100 = 7.02\%$

3 Estimate of damage - geostratified (d-g) variance of mean from appendix 5-11(a)

$V_{st}\,\bar{x}\,(d\text{-}g) = \sum \frac{W_h^2 s_h^2}{n_h} = 0.010499$ $\quad$ % SE = $(\sqrt{.0105}/1.648) \cdot 100 = 6.21\%$

4 Estimate of geostratified variance of mean as per appendix 5-11(c) and (d)

$V_{st}\,\bar{x}\,(g) = \sum \frac{W_h^2 s_h^2}{n_h} = 0.01131$ $\quad$ % SE = $(\sqrt{.01131}/1.648) \cdot 100 = 6.45\%$

II Comparison of efficiencies of different patterns of sampling assuming proportional allocation between stratum

Relative efficiency (RE) = $\left(\frac{Vran\ \bar{x} - Vst\ \bar{x}}{Vran\ \bar{x}} \right) \cdot 100$

From variances of the mean estimated above

RE Vst(d) = 19.90%

RE Vst (d-g) = 24.98%

RE Vst (g) = 15.57%

III Number of samples (ns) required for a relative level of precision 10% SE assuming proportional and optimal allocation

1 Simple random $ns = \frac{Vran\ \bar{x}\ .n}{(0.1\ \bar{x})^2} = \frac{0.013397 \times 600}{(0.1 \times 1.648)^2} = 297$

n = number of samples which Vran $\bar{x}$ is estimated

2 Stratified on damage

(a) proportional allocation (pa)

$ns = \frac{Vst\ \bar{x} \cdot n}{(0.1 \times 1.648)^2} = 236$

	Wh	nh
Damage	0.384	91
Undamage	0.616	145
		236

(b) Optimal allocation (op.a.)

Number of samples (nh') required from each stratum for a relative level of precision of ± 10% S.E.

$$nh' = \frac{Whsh \times \sum Whsh}{(0.1\ \bar{x})^2}$$

	Whsh	nh'
Damage	1.3809	126
Undamage	1.0933	100
	2.4742	226

Whsh and $\sum$Whsh were calculated above with Vst $\bar{x}$ (d) calculations

3 Damage - geostratification

Proportional allocation and optimal allocation calculated from statistics of damage - geostratification given previously in appendix 5-11(a)

Strata	nh' for p.a.	nh' for op.a.	Strata	nh' for p.a.	nh' for op.a.	Strata	nh' for p.a.	nh' for op.a.
1	6	7	14	5	5	27	4	2
2	6	6	15	6	6	28	11	11
3	8	7	16	7	7	29	12	1
4	7	9	17	6	6	30	9	3
5	3	2	18	2	2	31	8	1
6	3	3	19	6	3	32	7	2
7	4	5	20	6	4	33	7	7
8	7	10	21	3	1	34	5	5
9	8	13	22	4	3	35	4	3
10	1	0	23	9	5	36	5	0
11	2	2	24	9	5	37	9	5
12	3	3	25	8	0	38	12	1
13	4	4	26	4	3	$\sum$	230	162

4 Geostratification

Proportional allocation and optimal allocation calculated from statistics of geostratification given in appendix 5-11(c)

Strata	nh' for p.a.	nh' for op.a.	Strata	nh' for p.a.	nh' for op.a.	Strata	nh' for p.a.	nh' for op.a.
1	13	13	8	13	16	15	13	16
2	13	12	9	13	22	16	13	14
3	13	11	10	13	14	17	13	7
4	13	16	11	13	1	18	13	15
5	13	8	12	13	9	19	13	10
6	13	11	13	13	16	20	13	1
7	13	13	14	13	9	Σ	260	234

IV Summary

	Variance of means	Efficiency of Variance estimates		Number of samples for a relative level of precision $\pm$ 10% S.E.	p.a.	op.a.
Vran $\bar{x}$	0.013397			Vran	297	
Vst $\bar{x}$ (d)	0.010732	RE Vst $\bar{x}$ (d)	19.90%	Vst (d)	236	226
Vst $\bar{x}$ (d-g)	0.010499	RE Vst $\bar{x}$ (d-g)	21.62%	Vst (d-g)	230	162
Vst $\bar{x}$ (g)	0.011311	RE Vst $\bar{x}$ (g)		Vst (g)	260	234

Appendix 5-12

Statistics of the damaged and undamaged strata

Generation	Stage	+Vh DAM	+Vh UNDAM	sh^2 DAM	sh^2 UNDAM	$\bar{x}h$ DAM	$\bar{x}h$ UNDAM	$Vh\bar{x}$
		IMPROVED LIFE TABLE						
1969-70	Eggs	0.38	0.62	268.410	32.340	8.474	1.142	4.24
	1st	0.38	0.62	35.302	7.654	4.991	1.091	2.59
	2nd	0.38	0.62	12.933	3.150	3.010	0.800	1.64
	3rd (May)	0.38	0.62	3.264	2.093	1.753	0.851	1.19
	3rd (Aug)	0.79	0.21	1.903	0.399	1.008	0.153	0.83
	Pupae	0.79	0.21	1.639	0.341	0.856	0.119	0.70
	Beetles	0.79	0.21	1.175	0.101	0.644	0.079	0.53
1970-71	Eggs	0.79	0.21	142.490	10.510	4.894	0.492	3.98
	2nd	0.79	0.21	11.911	0.391	2.722	0.158	2.19
	3rd (May)	0.79	0.21	2.932	0.515	1.592	0.252	1.32
	3rd (Aug)	0.79	0.21	2.013	0.224	1.014	0.401	0.87
	Pupae	0.79	0.21	1.414	0.107	0.755	0.118	0.62
	Beetles	0.79	0.21	0.721	0.044	0.475	0.045	0.39
1971-72	Eggs	0.79	0.21	36.183	3.440	1.912	0.274	1.57
	2nd	0.79	0.21	5.081	0.062	1.159	0.047	0.93
	3rd (May)	0.79	0.21	0.705	0.085	0.422	0.047	0.34
	3rd (Aug)	0.79	0.21	0.343	0.141	0.230	0.089	0.20
	Pupae	0.79	0.21	0.234	0.324	0.164	0.200	0.17
	Beetles	0.79	0.21	0.190	0.069	0.135	0.051	0.12
1972-73	Eggs	0.79	0.21	16.145	4.302	0.888	0.278	0.76
		UNIMPROVED LIFE TABLE						
1969-70	Eggs	0.44	0.56	191.221	58.532	8.254	2.461	4.99
	1st	0.44	0.56	30.626	16.395	5.880	2.230	3.83
	2nd	0.44	0.56	13.890	5.110	4.775	1.408	2.88
	3rd (May)	0.44	0.56	5.059	3.307	2.133	1.433	1.73
		RUKUHIA LIFE TABLE						
1969-70	Eggs	0.63	0.37	36.570	8.479	3.061	1.140	2.340
	2nd	0.63	0.37	0.396	0.161	0.256	0.134	0.211
	3rd (May)	0.63	0.37	0.084	0.032	0.060	0.032	0.050
		SMITH'S PLOT						
1970-71	Eggs	0.091	0.909	244.30	0.0501	11.30	0.021	1.046
	2nd	0.091	0.909	11.94	0.0132	2.73	0.011	0.258

+ See appendix 5-9 for statistical notation

Appendix 5-13

Relative efficiencies (*RE) of estimating the variance and the level of precision obtained, with different sampling designs

TAKAPAU IMPROVED PLOT

SAMPLING DESIGN

Stratification Stage		Random $\bar{X}$	Random % S.E.	Damage RE	Damage % S.E.	Geostrata RE	Geostrata % S.E.	Damage – Geostrata RE	Damage – Geostrata % S.E.
1968-69	Egg	1.58	16.37	+NA		2.07	16.20	NA	
	3rd (May)	0.67	10.36	NA		11.84	9.27	NA	
	3rd (Aug)	0.63	10.48	NA		18.98	9.44	NA	
	Pupa	0.58	11.21	NA		0.72	11.48	NA	
1969-70	Egg	4.36	9.36	28.19	7.93	18.66	8.44	24.61	8.13
	1st	2.61	6.35	26.27	5.45	25.43	5.48	32.96	5.20
	2nd	1.64	7.02	19.90	6.28	15.57	6.45	24.98	6.21
	3rd (May)	1.18	5.27	1.33	5.23	22.10	4.65	20.52	4.70
	3rd (Aug)	0.85	6.30	- 7.99	6.55	25.67	5.43	1.82	6.25
	Pupa	0.70	7.01	- 9.13	7.33	-13.82	7.48	-10.98	7.39
	Beetle	0.53	7.77	-11.82	8.22	7.52	8.06	- 1.43	7.83
1970-71	Egg	4.15	9.37	- 3.28	9.52	- 7.03	9.69	- 7.32	9.70
	2nd	2.18	6.67	11.99	6.26	11.85	6.26	12.76	6.23
	3rd (May)	1.34	5.05	- 4.47	5.16	- 4.33	5.16	-13.57	5.38
	3rd (Aug)	0.87	7.82	18.87	7.04	18.93	7.04	25.25	6.76
	Pupa	0.62	8.85	12.87	8.26	16.02	8.11	20.62	7.89
	Beetle	0.38	10.34	12.69	9.66	7.59	9.94	14.98	9.53
1971-72	Egg	1.57	12.42	- 8.98	12.97	- 2.82	12.59	- 7.45	12.78
	2nd	0.93	9.03	18.49	8.15	8.25	8.65	9.49	8.59
	3rd (May)	0.34	9.16	9.71	8.71	12.51	8.57	19.92	8.20
	3rd (Aug)	0.20	11.00	3.16	10.83	4.55	10.75	20.95	9.78
	Pupa	0.17	11.97	4.76	11.68	2.62	11.81	30.00	10.02
	Beetle	0.12	14.27	2.91	14.06	-15.64	15.35	27.27	12.17
1972-73	Egg	0.76	17.20	- 4.12	17.55	5.64	16.71	- 3.61	17.51

* RE = (Vran-Vst)/Vran).100 (see text)

\+ NA = Not applicable - as plots in the early stage were not subdivided into damaged and undamaged strata and in the latter stages were classified as being completely damaged.

Appendix 5-13 cont.

Relative efficiencies (*RE) of estimating the variance and the level of precision obtained with different sampling designs

TAKAPAU UNIMPROVED PLOT

SAMPLING DESIGN

Stratification	Random		Damage		Geostrata		Damage x Geostrata	
Stage	$\bar{X}$	% S.E.	RE	% S.E.	RE	% S.E.	RE	% S.E.
1968-69 Egg	1.80	14.35	NA		0.30	14.33	NA	
3rd (May)	1.15	7.81	NA		12.21	7.32	NA	
3rd (Aug)	1.01	7.16	NA		8.52	6.84	NA	
Pupa	0.97	7.52	NA		10.88	7.10	NA	
1969-70 Egg	4.94	8.00	9.80	7.59	10.29	7.57	12.16	7.50
1st	3.84	4.68	31.00	3.89	24.46	4.07	16.50	4.28
2nd	2.88	4.85	24.74	4.21	14.20	4.50	23.82	4.24
3rd (May)	.94	3.96	0.63	3.95	9.84	3.76	23.71	3.46
3rd (Aug)	1.28	5.44	NA		2.70	5.36	NA	
Pupa	1.10	6.17	NA		3.23	6.07	NA	
Beetle	0.86	6.96	NA		2.35	6.88	NA	
1970-71 Egg	4.53	10.26	NA		- 2.68	10.40	NA	
2nd	3.10	5.82	NA		11.46	5.48	NA	

Appendix 5-13 cont.

Stratification Stage		$\bar{X}$	Random % S.E.	Damage RE	Damage % S.E.	Geostrata RE	Geostrata % S.E.	Damage x Geostrata RE	Damage x Geostrata % S.E.
TAKAPAU UNIMPROVED PLOT									
SAMPLING DESIGN									
1970-71	3rd (May)	1.55	4.34	NA		2.46	4.29	NA	
	3rd (Aug)	0.97	6.53	NA		5.85	6.34	NA	
	Pupa	0.65	7.99	NA		1.35	7.93	NA	
	Beetle	0.43	8.71	NA		- 2.44	8.82	NA	
1971-72	Egg	1.26	15.21	NA		- 8.03	15.82	NA	
	2nd	0.74	8.31	NA		4.93	8.10	NA	
	3rd (May)	0.49	7.98	NA		- 1.70	8.05	NA	
	3rd (Aug)	0.34	8.99	NA		7.24	8.66	NA	
	Pupa	0.25	11.82	NA		3.78	11.60	NA	
	Beetle	0.22	10.61	NA		7.40	10.21	NA	
1972-73	Egg	1.69	14.19	NA		- 4.16	15.02	NA	
RUKUHIA PLOT									
SAMPLING DESIGN									
1969-70	Egg	2.34	8.88	31.74	7.34	24.97	7.70	31.76	7.34
	2nd	0.21	10.83	4.45	10.58	9.86	10.28	22.63	9.52
	3rd (May)	0.05	20.69	5.61	20.10	3.74	20.30	8.41	19.80
SMITH'S PLOT									
SAMPLING DESIGN									
1970-71	Egg	1.00	24.62	66.2	14.31	60.2	15.52	77.7	11.62
	2nd	0.39	44.73	66.7	9.34	28.0	13.73	74.6	8.21

Appendix 5-14 **The effect of different methods of stratifying on the number of samples required to obtain an estimate of the mean population of *C. zealandica* with a precison of ± 10% S.E.**

Stage	Plot	Stratification	No samples taken	$\bar{X}$	Variance	No samples proportionally allocated	No samples optimally allocated
Egg	Complete study plot	Simple random	486	1.05	32.49	2953	2953
		Damage strata	486	1.05	10.98	998	240
		Geo-strata	486	1.05	12.94	1176	1033
		Damage – geo-strata	486	1.05	7.24	658	97
	Undamaged stratum deleted	Simple random	86	11.62	244.30	181	192
		Geo-strata	86	11.62	197.30	146	113
Second instar	Complete study plot	Simple random	434	0.38	1.69	1139	1139
		Damage strata	434	0.38	0.56	379	118
		Geo-strata	434	0.38	1.21	820	328
		Damage - geo-strata	434	0.38	0.43	293	127
	Undamaged stratum deleted	Simple random	78	2.73	11.95	160	160
		Geo-strata	78	2.73	9.72	130	75

Appendix 5-15 The total number of C. zealandica required in a given number of samples to obtain a relative level of precision of ± 10% S.E. and ± 20% S.E.

Stage	± 10% S.E.						± 20% S.E.					
N	10	50	100	250	500	1000	10	50	100	250	500	1000
Eggs	5692	4089	3501	2912	2493	2173	1059	757	637	539	464	402
1st instar	821	739	703	663	631	604	187	168	160	151	143	137
2nd instar	597	498	458	413	380	352	127	106	98	88	81	75
3rd instar (May)	232	217	210	203	196	191	55	51	50	48	46	45
3rd instar (Aug)	279	230	208	184	167	152	59	47	43	38	34	31
Pupae	259	258	222	184	159	138	67	48	42	34	30	26
Beetles	262	207	186	163	147	132	53	42	38	33	30	27

Calculated from the relationship between log variance and log mean (Table 4-6) per Green (1970).

N = number of sample units

Appendix 6-1

Technical apsects of photogrammetric methods used for recording and measuring grass grub damage in pasture.

1) Materials and methods. The cameras used for these studies were Canon FR QL 35 mm single lens reflex which have a through the lens metering system, fitted with a 50 mm J2 Canon lens.

Individual paddocks or plots at Smiths and the Takapau Research Farm were photographed as near vertically as possible from the open door of a fixed wing aeroplane (Piper cub), flown along markers set at each end of the areas, from a height of 200 m.

One camera was loaded with colour film (high speed ektachrome EH135) with an ASA rating of 160, the other with false colour film (ektachrome infra red aero film 8443, 135) rated as ASA 125. The shutter speed setting used for both films was 1/250 sec. Ultra violet filters were used on both cameras and a "Wratten 12" gelatin filter was used with the false colour film.

The photographs were interpreted in the following way. The transparencies were projected through an 8.5 cm, f2.5 lens and reflected by a mirror at right angles through a glass topped table and projected on high quality bond paper. Damaged areas were detected visually and traced out in pencil. These were then cut out, weighed and related to the total weight of the paddock. The distance the mirror was set from the projector was dependent on the requirements of the interpreter. Usually this was set so that the image was enlarged approximately 20 times. Allowances were not made for distortion caused by the photograph being taken off vertical, although for critical or comparative work photographs not near-vertical were discarded.

2) Results. Photographs taken in the manner described are shown in Appendix 6-2, A and B. Areas of grass grub damage appear as yellow to brown patches against a green background of healthy green pasture (A, Appendix 6-2). On the infra red photograph (B, Appendix 6-2) soil and dead tissue are reproduced as cyan while green healthy tissue strongly reflects infra red and appears as magenta.

In rank pasture a large amount of dead tissue from naturally senescing foliage canopying healthy young tissue was indistinguishable from grass grub damage photographed in colour but was detectable when photographed in false colour. This situation is illustrated in the oblique ground shots of grass grub damaged hillsides (C and D, Appendix 6-2) in which damage appears as rank pasture in colour but completely dead pasture in infra red. By comparison, rank pasture in the foreground which shows as undamaged in false colour appears as a pale pink, indicating that the foliage at the base of the pasture was alive.

Detection of damage in heavily grazed pastures was possible with false colour film but not successful with conventional colour film. With colour, unlike false colour, dead tissue and soil hues merged with the brown, yellow and green of short grazed pasture and were not clearly differentiated. The pattern of damage on the hill faces overlooking the road is indistinguishable in colour (E, Appendix 6-2) but detectable with infra red (F, Appendix 6-2)

Estimates of the percentages of plots damaged from the ground and aerial photography by false and colour film are given in Table 1.

Table 1 Percentage of plots damaged by _C. zealandica_ measured from the ground and from aerial colour and infra red photographs

Plots	Ground	Colour	Infra red
A	4.20	4.66	4.30
B	5.03	5.20	4.91
C	3.44	3.75	3.33

Estimates of damage from ground measurement, colour and infra red photographs were very similar and did not vary by more than 12%. In view of the low levels of damage in each plot and the relatively insensitive method of measurement, the range in percentage differences between ground measurement and infra red was surprisingly low.

An overall comparison of differences between colour and infra red estimates from 26 sets of photographs showed that the mean difference of 0.94% ± 0.75 in favour of colour was not significantly different from zero. A regression of colour on infra red gave a slope 1.108 (r^2 = .871) and a negative intercept not significantly different from the origin, suggesting that estimates of damage from both films were not influenced by the extent of damage.

The influences of pasture length, month and year were assessed from the ratio of colour/infra red (Table 2.)

Table 2

Mean ratio of the proportion of study areas damaged assessed from conventional colour films and infra red colour transparencies.

Month	Pasture length	
	Short (1 - 4 cm)	Long (4 - 8 cm)
April	1.048 ± .049 *(6)	.968 ± .041 (7)
May	.940 ± .091 (6)	1.108 ± .042 (7)
Year		
1970	.984 ± .057 (13)	
1971	1.01 ± .034 (13)	

* No of plots or paddocks

Differences in the colour/infra red ratios between pasture length, time of year, and years were not significant. As damage became more widespread, however, it became more diffuse and ill defined, and increasingly more difficult and time consuming to interpret. Although this trend is also true with infra red, interpretation was easier and therefore quicker than with colour film and was less influenced by pasture height.

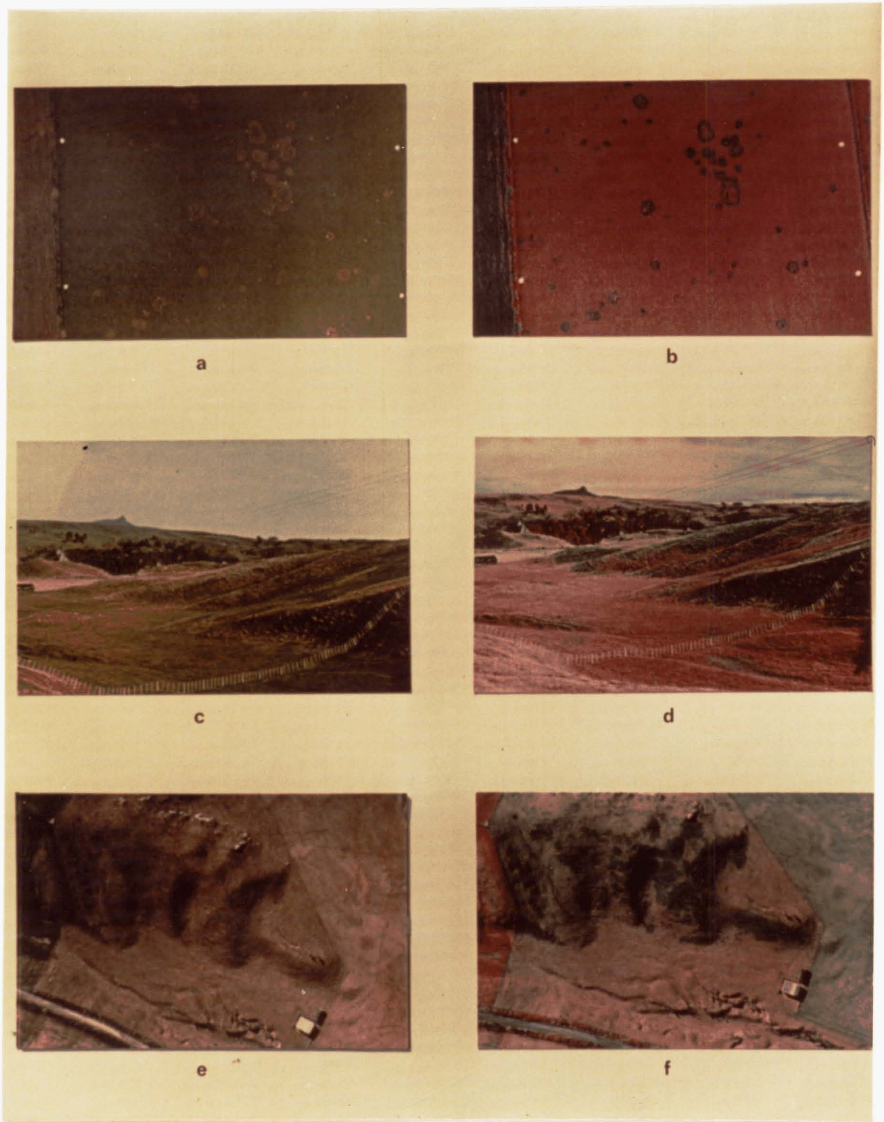
3) Conclusion. These studies showed that colour infra red film seems more versatile than colour film for detecting and measuring pasture damage. The ability of this film to differentiate between the merging hues of green, brown and yellow which are the dominant colours in vegetation, made interpretation easier since edge definition of damaged areas and healthy pasture was much more acute. Detection of grass grub damage in rank pasture where herbage is a mixture of living, senescing and dead plant tissue (C and D, Appendix 6-2) and in extremely grazed, short, brown coloured pasture (E and F, Appendix 6-2) is easier with infra red.

Ease of interpretation with colour compared with false colour is more dependent on pasture height and colour. With green, well grazed pasture in which rank and dry herbage is absent, the advantages of infra red film are less clear cut.

Under pasture conditions which are unfavourable for good definition of damaged pasture the characteristic circular pattern of grass grub damage aids in interpretation. This is well demonstrated in (F, Appendix 6-2) in which the outline of grass grub damage shows as a circular rather than an angular outline. For survey purposes, it is essential to inspect areas on the ground before photographic interpretation, as stock camps and areas spot sprayed with herbicides can be confused with grass grub damage.

Strategic use of filters to give a colour shift and enhance colour as outlined by Fritz (1967) may improve the results already obtained and is worthy of investigation.

Although relatively simple, compared with the methods for estimating insect damage outlined by Meyer, et al (1969) and Wallen, et al (1971), the tracing and weighing method for calculating the area of pasture damaged was remarkably accurate.



Appendix 6-2   Shows the ease with which grass grub damage in pasture can be detected under a wide range of conditions from colour infra red (B, D, F) compared with conventional colour (A, C, E).

A and B   Uniformly grazed flat land

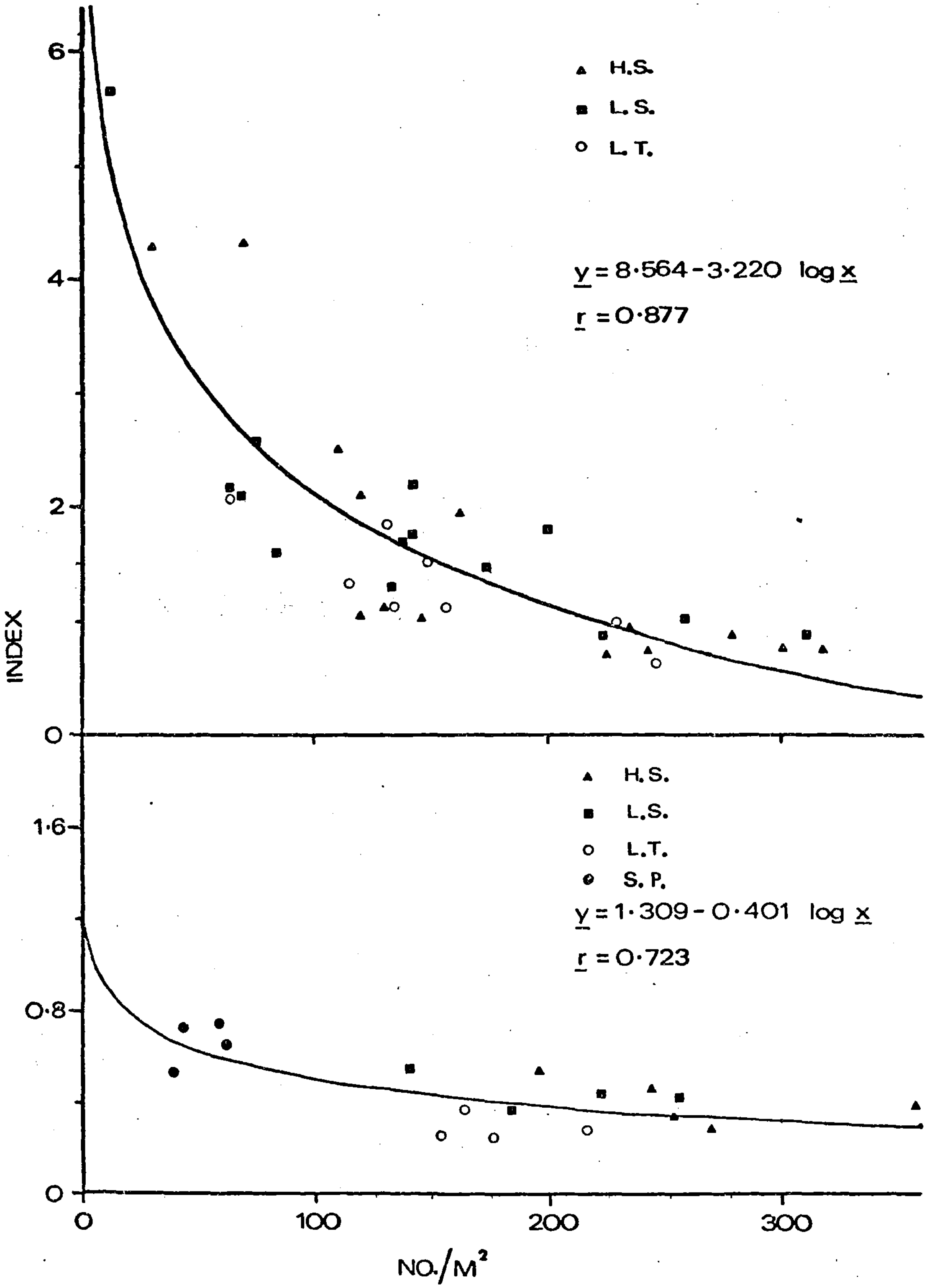
C and D   Rank hill country pasture

E and F   Heavily grazed hill country

Appendix 7-1 Population density of *C. zealandica* over four generations in the wet and dry areas of the improved life table plot at Takapau.

	1968-69				1969-70				1970-71				1971-72			
	Dry No./m^2	±95%	Wet No./m^2	±95%	Dry No./m^2	±95%	Wet No./m^2	±95%	Dry No./m^2	±95%	Wet No./m^2	±95%	Dry No./m^2	±95%	Wet No./m^2	±95%
Eggs	223	52	254	33	645	177	125	79	612	119	133	55	235	61	23	33
1st instar	-		-		392	64	52	39	-		-		-		-	
2nd instar	-		-		233	43	62	30	382	41	92	16	162	23	13	6
3rd instar May	105	14	10	1	170	22	33	20	288	21	38	12	53	9	10	8
3rd instar Aug	94	19	19	20	140	17	26	11	132	18	27	16	27	6	12	9
Pupae	93	13	9	1	105	15	19	10	102	15	17	11	21	5	19	14
Beetles	80	10	12	1	82	7	9	5	61	11	11	7	20	5	4	6

\- not sampled



Appendix 7-2 Relationship between the population trend index and May density of third instar *C. zealandica* larvae for the 1968-69, 1969-70, and 1970-71 (above) and 1971-72, 1972-73 (below) generations. (High stocked farmlet = H.S., low stocked farmlet = L.S., life table plots = L.T., and Smith's plots = S.P.).

Appendix 7-3 Population budgets for the Takapau life table study plots

Stage	Month	Year	Improved plot Paddock 1 $\bar{x}$ /m2	Diseased larvae (%)	Sex Ratio (♀♀)	Infert.+ (♀♀)	Adjusted* $\bar{x}$.2	Improved plot Paddock 2 $\bar{x}$ /m2	Diseased larvae (%)	Sex Ratio (♀♀)	Infert. (♀♀)	Adjusted $\bar{x}$.2
Egg	D	1968	213.83					240.46				
3rd instar	M	1969	115.85					51.14				
3rd instar	A	1969	96.43					59.05				
Pupae	O	1969	79.51	1.5				63.47	0.0			
Beetle	N	1969	60.21		.48	.133	50.11	56.83		.54	.133	53.2
Egg	D	1969	522.16					553.68				
1st instar	J	1970	358.63					284.07				
2nd instar	F	1970	253.85					151.54				
3rd instar	M	1970	157.36					134.88				
3rd instar	A	1970	113.54					95.35				
Pupae	O	1970	97.35	6.1				68.03	2.5			
Beetle	N	1970	75.62		.45	.024	66.42	48.27		.50	.024	47.12
Egg	N	1970	603.80					417.53				
2nd instar	F	1971	315.72					222.31				
3rd instar	M	1971	176.41					153.82				
3rd instar	A	1971	115.91					99.92				
Pupae	O	1971	69.11	7.6				65.44	16.6			
Beetle	N	1971	52.03		.33	.273	25.28	34.87		.45	.273	22.81
Egg	D	1971	156.62					201.54				
2nd instar	F	1972	142.33					87.36				
3rd instar	M	1972	43.83					39.27				
3rd instar	A	1972	29.98					20.41				
Pupae	O	1972	17.54	4.76				16.73	30.0			
Beetle	N	1972	16.03		.40	.105	11.47	8.39		.42	.105	6.31
Egg	N	1972	107.31					80.47				
2nd instar	F	1973	7.12					26.53				

+ Proportion of female beetles which were infertile

* Corrected for proportion of female beetles

Appendix 7-4 Population budgets for the Takapau life table study plots

Stage	Month	Year	Unimproved plot: Paddock 1 $\bar{x}$/m2	Diseased larvae (%)	Sex ratio (♀♀)	Infert.+ (♀♀)	Adjusted* $\bar{x}$.2	Unimproved plot: Paddock 2 $\bar{x}$/m2	Diseased larvae (%)	Sex ratio (♀♀)	Infert. (♀♀)	Adjusted $\bar{x}$.2
Egg	D	1968	260.30					183.39				
3rd instar	M	1969	151.59					131.87				
3rd instar	A	1969	139.27					109.64				
Pupae	O	1969	124.88	3.5				105.35	4.5			
Beetle	N	1969	108.56		.42	.133	79.27	90.45		.44	.133	69.01
Egg	D	1969	725.02					491.90				
1st instar	J	1970	523.91					421.93				
2nd instar	F	1970	372.20					337.51				
3rd instar	M	1970	229.31					247.97				
3rd instar	A	1970	148.84					168.14				
Pupae	O	1970	127.66	5.6				130.09	4.4			
Beetle	N	1970	94.07		.48	.024	88.14	123.87		.46	.024	111.22
Egg	N	1970	560.12					557.81				
2nd instar	F	1971	441.01					323.74				
3rd instar	M	1971	216.53					164.63				
3rd instar	A	1971	116.48					122.02				
Pupae	O	1971	67.03	12.6				70.72	15.0			
Beetle	N	1971	41.96		.45	.273	27.45	50.46		.46	.273	33.74
Egg	D	1971	145.97					164.89				
2nd instar	F	1972	91.54					90.83				
3rd instar	M	1972	61.88					59.09				
3rd instar	A	1972	45.37					39.94				
Pupae	O	1972	17.92	15.4				35.16	13.0			
Beetle	N	1972	19.17		.46	.105	15.78	27.87		.45	.105	22.45
Egg	N	1972	131.06					285.52				
2nd instar	F	1973	3.95					7.88				

+ Proportion of female beetles which were infertile

* Corrected for proportion of female beetles

Appendix 7-5 Estimates of sex ratios and percentage infertile female beetles of C. zealandica in the Takapau study plots

Generation	1969-70		1970-71		1971-72		1972-73	
	☆PDK.1	PDK.2	PDK.1	PDK.2	PDK.1	PDK.2	PDK.1	PDK.2
Unimproved plot								
Sex Ratio	0.42	0.44	0.48	0.46	0.45	0.46	0.46	0.45
(♀♀)	(160)	(149)	(120)	(182)	(62)	(75)	(31)	(41)
+Infertile	13.3%		2.4%		27.3%		10.5%	
	(120)		(84)		(29)		(36)	
Improved plot								
Sex Ratio	0.48	0.54	0.45	0.50	0.33	0.45	0.40	0.42
(♀♀)	(120)	(79)	(104)	(89)	(45)	(69)	(23)	(17)
+Infertile	13.3%		2.4%		27.3%		10.5%	
	(120)		(84)		(29)		(36)	

Footnote: data based on insectary studies

+ Pooled estimate of the unimproved and improved plots

( ) No of individuals observed

☆ Paddock (each life table plot consisted of two paddocks)

Appendix 7-6 Oviposition performance of beetles

from the Takapau improved life table plot

Generation	1969-70	1970-71	1971-72	1972-73
No. Females	62	41	14	19
No eggs				
+Mean eggs	25.05 ± 1.10	43.85 ± 3.63	21.80 ± 3.40	31.88 ± 2.68
1st cluster	23.17 ± 1.05	22.65 ± 0.84	18.80 ± 2.45	18.11 ± 1.59
2nd cluster	8.15 ± 1.00	10.76 ± 0.58	3.00 ± 0.57	8.58 ± 0.65
3rd cluster		7.57 ± 0.42	6.00	6.00 ± 1.51
4th cluster		6.04 ± 0.78		1.00
5th cluster		4.33 ± 0.53		
6th cluster		3.66 ± 1.35		
Ovipositions				
Mean cluster no.	1.24	3.66	1.80	2.06
% Laying				
0 clusters	12.90	2.44	28.57	10.53
1 cluster	66.10	5.00	28.57	26.32
2 clusters	20.97	12.20	28.57	36.84
3 clusters		24.39	14.28	21.05
4 clusters		34.15		5.26
5 clusters		14.63		
6 clusters		7.32		
Longevity	22.29 ± 2.90	51.02 ± 2.14	17.21 ± 3.32	21.05 ± 2.20

\+ Mean per fertile female

Appendix 7-7 Oviposition performance of beetles

from the Takapau unimproved life table plot

Generation	1969-70	1970-71	1971-72	1972-73
No. Females	59	42	15	19
No eggs				
+Mean eggs	18.49± 1.02	40.12 ± 2.44	22.91 ± 2.27	21.12 ± 2.58
1st cluster	17.37 ± 0.95	21.34 ± 1.10	17.63 ± 1.85	16.64 ± 1.70
2nd cluster	11.00 ± 1.58	10.92 ± 0.45	7.16 ± 3.34	7.22 ± 1.55
3rd cluster	2.00	7.55 ± 0.57	4.00 ± 1.00	5.5 ± 0.50
4th cluster		6.00 ± 0.63		
5th cluster		6.00 ± 0.89		
6th cluster		3.66 ± 0.91		
Ovipositions				
Mean cluster no	1.10	3.27	1.82	1.65
% Laying				
0 cluster	13.56	2.38	26.66	10.53
1 cluster	77.96	11.90	26.66	42.10
2 clusters	6.78	21.43	33.34	36.84
3 clusters	1.69	16.67	13.33	10.53
4 clusters		30.95		
5 clusters		9.50		
6 clusters		7.14		
Longevity				
Mean no. days	22.08 ± 2.60	42.50 ± 2.76	18.07 ± 2.25	22.15 ± 2.06

+ Mean per fertile beetle

A mechanical trap designed to study the flight behaviour of *Costelytra zealandica**

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Abstract

A rotary trap capable of sampling simultaneously at one location a range of heights has been developed to study the flight behaviour of *Costelytra zealandica* (White). The traps are designed so that entering beetles are swept back into a fluid-filled catching chamber and killed or prevented from mating. The trap may be controlled automatically and is cheap to construct.

Introduction

Mechanical traps for sampling airborne insects were first described by Williams & Milne in 1935. Since then they have been adapted for various purposes ranging from the study of attractants for scolytids in forest areas (Vite & Gara 1961) to more quantitative assessments of airborne fauna (Taylor 1962). Juliet (1963) reported trouble in sampling coleopterans, which tend to crawl out of the nets and escape while the trap is in motion.

The trap described below was designed especially for studies on *Costelytra zealandica* (White). Essentially the rotary trap consists of nets rotating in a horizontal plane around a central axis. This principle allows insects to be sampled independently of wind speed, since the increase in airflow over half a revolution is offset by the decrease in airflow over the other half.

Design

The components of this trap may be described in three parts: the framework, the traps, and the drive assembly. These are shown in Figs 1A, 1B, and 1C respectively.

Framework (Figs 1A and 1C)

The purpose of the framework is to support the components of the drive assembly. Constructed from 3.75 cm by 6.25 cm by 1.5 mm slotted angle iron and mounted on a plywood base (A), it consists of two distinct structures: a square pyramid (B) and a rectangular frame (Fig. 1C). The pyramidal-shaped frame has a 75 cm square base, is 90 cm high, with a 20 cm square top on which the upper bearing of the drive pole (L) is mounted. The rectangular frame, 30 cm high by 20 cm wide and 57.5 cm long, is fixed lengthwise to the plywood base and supports the gearbox (E) and lower drive bearing (M). Positioned diagonally across the base, it extends from one leg of the main frame to 3.75 cm past the centre point of the base.

Drive assembly (Fig. 1C)

The trap is driven either by a 2.5 horsepower four-stroke petrol engine running at 1530 r.p.m. or a small electric motor with a rating of 0.25 horsepower at 1425 r.p.m. Because of the voltage drop experienced over the length of cable used, this motor ran at 1378 r.p.m. The motors are seated on rubber mounts and are bolted through adjustment slots in the plywood base (A). Torque from the motor is transmitted from a 6.87 cm (7.5 cm)† diameter pulley (H) by a V-belt to a 35 cm (25 cm) diameter intake pulley (I) on a worm-drive reduction gearbox (E) with a ratio of 12 : 1 (16.5 : 1). From the 15 cm diameter outlet pulley (J) another V-belt drives a similar-sized pulley (K) fixed to the drive pole (L). This combination of pulleys and gearbox gives a reduction ratio from motor to drive pole of 61.2 : 1 (55.1 : 1).

The drive pole consists of 3.75 cm diameter exhaust tubing running in two ball-bearing races (C, M) and is supported on these bearings by collars clamped to the pole by grubscrews.

Each of the three traps (O) is supported on an arm (N) made from 1.8 cm square section hollow aluminium, which is rigid and light. The arms

* Part of post-graduate studies carried out in conjunction with Lincoln College, Canterbury.

† Dimensions of the electrically driven version in brackets.

are attached to the drive pole at three heights above the base of the trap and are spaced at 120° angles to one another, to ensure that the trap is balanced when in motion. The horizontal distance from the pole to the centre of the trap is 1.8 m, giving a trap speed of 16.1 km per hour at 25 r.p.m.

To the proximal end of each arm is bolted a 36 cm length of angle iron. This not only minimises flexing when the trap is in motion by giving added support to the arms, but serves as a point of attachment through which the arms are secured to the drive pole. The upper arm, which is fixed at a height of 2.4 m above the ground, is bolted to a collar clamped to the top of the drive pole, and the middle arm is positioned 1.35 m above the base and is secured by a double U bolt clamp. The lower arm is mounted above the upper bearing and extends downward at an angle of 28° from horizontal to a height of 10 cm above the ground. From this point the terminal 25 cm section of the arm on which the trap sits is bent to be parallel with the base. Thirty-seven cm from the proximal end of the lower arm the slotted angle iron to which it is bolted is braced back to the drive pole by a horizontal strut. This modification of the arm and its point of attachment allows the lower trap to sweep 10 cm above the ground without obstruction from the framework.

Trap heights may be changed by altering the position of the arms on the drive pole. For our studies of *C. zealandica,* traps were set at 10 cm, 1.29 m, and 2.5 m.

Traps (Fig. 1B)

The traps are attached to the upper side of the arms by two long bolts extending through the arms, up either side of each trap, and through two 3 mm-thick hardboard slats 5 cm wide and 30 cm long. These are glued to the upper and lower surfaces of the traps 15 cm back from the leading edge.

The design of the traps is such that beetles entering are unable to crawl out or mate.

Although a few beetles do manage to cling to the netted upper surface of the trap, those which strike the netting usually fall and are swept back into the catching chamber. Those that do cannot escape while the trap is in motion, as they are unable to crawl across the perspex mouth and invariably find their way into the chamber. Perspex, 1.5 mm thick, is used in the construction of the traps, as preliminary work had shown that, like glass, it neither attracts nor repels flying beetles.

The traps are 57.5 cm in length with a mouth 22.5 cm square and 20 cm deep which leads into a tapering rear section 37.5 cm long. Over the length of the rear section the outer edges of the floor converge from 22.5 cm to 7.5 cm, and the upper edges of the walls are cut back on such an angle that the wall height is reduced from 22.5 cm to 2.5 cm. The roof of this section is left open and is covered by fly netting (6.4 meshes per cm). Fitted lengthwise into the back of the trap is a V 7.5 cm wide, 5 cm long, and 2.5 cm high (R). The ends of the arms of the V are glued to the trap walls, which at this point are 2.5 cm high. The upper side of the V is covered by a triangular piece of perspex. Fly netting which covers the top side of the rear section is glued to the leading edge of this triangle. At the apex of the V a triangular tube leads into a catching chamber (S). The chamber is supported by an L-shaped bracket (T) and is held in position by an elastic band.

Insects entering the trap are swept to the back of the trap, into the V, and down the tube into the catching chamber. In flight studies it may be important that the physiological condition of the insect does not change from the time of capture to the clearing of the trap. Depending on requirements the chamber may be filled with water, which inhibits mating, but over a 10-h period does not impair their viability, or if live catches are not required, the chamber can be filled with a suitable killing fluid.

PERFORMANCE

Traps of this design have performed very satisfactorily, and there is no suggestion that flying *C. zealandica* beetles avoid or are attracted to this type of trap. Visual observations have shown that movement or air currents caused by the revolving traps appear to have little effect on the beetles' flight paths. Similarly, the effect of sound and vibrations arising from a petrol motor did not seem to disturb the beetle flight.

The trap design has a number of desirable features. It enables the flight of *C. zealandica* to be studied at different heights in one position in the paddock. The use of perspex and the design of the traps overcome the problem met by Juliet (1963), as beetles are prevented from clinging to the nets and crawling out of the trap, and mating is prevented. The electrically driven version may be worked automatically with an off-on time switch. With the petrol-motor-powered trap a simple switch-off device may be installed by raising the fuel intake above the bottom of the petrol tank to prevent dirt from entering and blocking the fuel system and by inserting a sight glass graduated in running time in the side of the petrol tank. The arrangement and

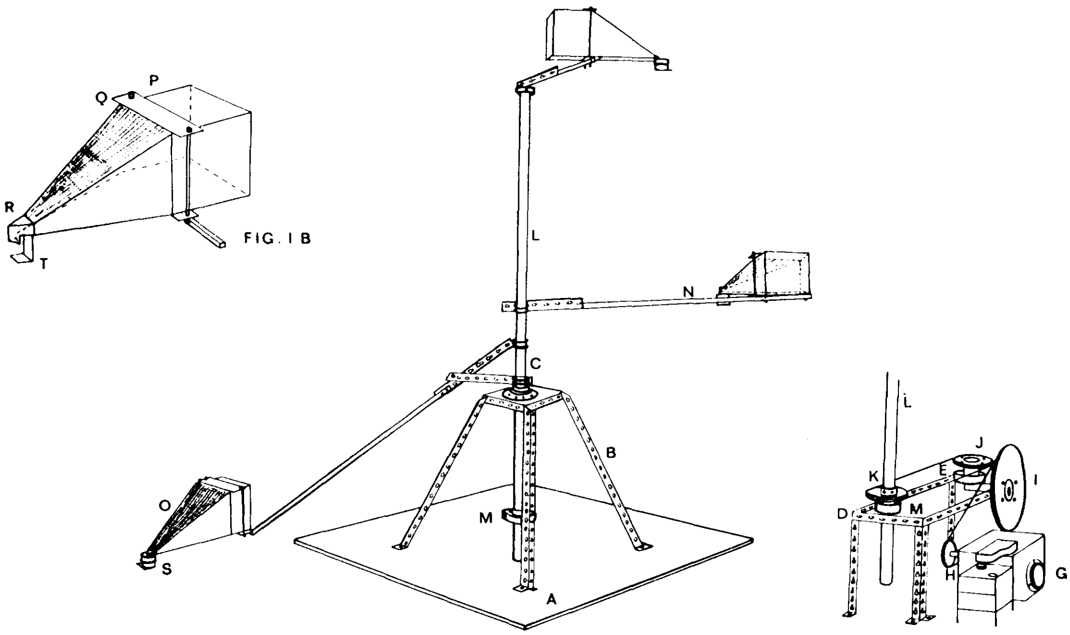

FIG. 1 A FIG. 1 C

Figs 1A, B, C — Construction and operational details of trap for sampling airborne insects.

number of traps may be varied by changing the position and number of arms. Trap speed may be altered by adjusting the governor on the petrol motor and by altering the length of the arms and/or pulley size.

The trap is extremely cheap to make. The electric version was constructed in part from a second-hand roller-wringer, agitator-type washing machine. This supplied a 0.25 horsepower motor and the wringer drive was used in the gear assembly, giving a total cost of materials of $62.00. The cost of the petrol-driven version was $112.00, which included the price of a new motor.

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"Pastures and Pasture Plants"

EDITOR R. H. M. LANGER

Students of pastures and pasture production in New Zealand have waited a long time for a comprehensive introductory textbook on the subject, and they will not be disappointed with this volume. The difficulty of dealing with a continually changing subject and of bringing forward a reasonably up-to-date account of the information available has deterred would-be authors, but Professor Langer has overcome this by calling on a team of experts to contribute sections of the book with which they are most familiar. This no doubt has reduced the writing time of the original manuscript and has allowed recent information and research results to be included. Even so, the fact that the preface was completed 18 months before publication indicates how slow the mechanics of this process are these days. The result is that very few data later than 1970 have been included.

However, the volume is one that will be most appreciated by students, as it provides a sound basis for understanding the application of plant science. It should be extensively used wherever agriculture is being taught at secondary or tertiary levels. Farmers will also appreciate having a reference volume on pasture production and management to provide background information to articles that appear in farming journals and newspapers.

The effort which has been made to link up pasture production with pasture utilisation and livestock production is to be commended, as they are inter-dependent in New Zealand, where the former is only a means to an end, viz, a high yield of animal products.

There are advantages and disadvantages in having a number of contributors to a book of this nature. On the one hand, the information on any particular topic is likely to be complete and well documented. On the other, there is the difficulty of integrating the subject matter of the different writers and of developing a logical progression of the main theme. Professor Langer has successfully achieved the best of both worlds and has avoided the contradictory statements that could so easily occur in such a publication.

The balance of space allotted to each subject has also required careful control to avoid over- or under-emphasis of a particular section. No two people would agree exactly on this matter, and the resultant product is a reflection of the individuality of the editor and his contributors. But there will be very few who will disagree violently with the result in this case.

Students will find the wide use of tables, which are largely adapted from research papers, helpful in illustrating statements in the text. Figures, mainly in the form of graphs and diagrams, are used profusely in preference to photographic material and should be very useful. A very full list of references is provided at the end of all chapters except one. Students who want to study any particular topic more fully will find these lists will save them time and unnecessary reading.

There is certain to be a widespread demand for this book, and before long a second edition may be required, when the authors will be able to correct the minor typographical errors which unfortunately are scattered through the pages. In addition, Chapter 8, which deals with livestock production from pasture, would be improved if a reference list were included. The next edition could also provide an opportunity for the further development of topics such as seed quality which are not dealt with very fully in the present volume.

— G.S.R.

"Pastures and Pasture Plants", Ed. R. H. M. Langer. A. H. and A. W. Reed, Wellington. $8.50 (limp); $10.95 (board).

Appendix 7-9 Anatomical condition of female *C. zealandica* beetles caught in flight at Takapau over three seasons*

Year	Weeks from beg. of flight	Total	Not laid Total	Not laid Mated	Not laid Fed	Laid Total	Laid Fed
1969	1	84	20	20	0	64	23
	2	145	18	18	9	127	93
	3	19	8	8	8	11	11
	4	25	7	7	7	18	6
	5	3	1	0	0	2	1
1970	1	5	5	4	0	0	0
	2	62	9	8	0	53	25
	3	249	6	5	0	243	83
	4	33	0	0	0	33	7
	5	50	0	0	0	50	16
	6	6	0	0	0	6	6
1971	1	45	5	4	0	39	23
	2	58	12	12	8	46	46
	3	48	3	3	2	45	45
	4	15	0	0	0	15	14
	5	6	0	0	0	6	3

* 1972 not included as few female beetles caught

Appendix 7-10 Tests of density dependence in mortality recorded over different age intervals at the Takapau life table plots.[+]

Age Interval	No. Obs.	Slope (b) b	± 95%	Intercept (a) a	± 95%
Eggs - 2nd instar	16	-0.596	0.806	2.576	0.244
2nd - 3rd instar (May)	12	-0.021	0.324	0.306	0.080
2nd - 3rd instar (Aug)	12	-0.060	0.502	0.636	0.124
3rd (May) - 3rd (Aug)	16	0.0003	0.145	0.152	0.037
3rd (Aug) - Pupae	16	0.028	0.223	0.070	0.058
Pupae - Beetles	16	0.057	0.240	0.137	0.066
Eggs - Beetles	16	0.347	0.533	-0.449	0.125

\+ In these tests grass grubs within each of the two paddocks within each life table plot were treated as independent populations

Appendix 7-11 The numbers ($/m^2$) of potentially predacious invertebrate species and diseased larvae recorded from the Takapau study plots.

Development stage of grass grub		UNIMPROVED LIFETABLE: Predators: Asilidae	Carabidae	Elateridae	Staphylinidae	Myriopoda	UNIMPROVED LIFETABLE: Diseases: Bacterial	Fungus	IMPROVED LIFETABLE: Predators: Asilidae	Carabidae	Elateridae	Staphylinidae	Myriopoda	IMPROVED LIFETABLE: Diseases: Bacterial	Fungus
1968-69	Eggs		0.75	1.17			0.25				2.71				
	3 m			0.93	0.31							0.31		1.24	
	3 A			0.93	0.62										
	P						0.31								
	B			1.23											2.46
1969-70	Eggs	0.15	0.15	2.40	2.60		0.30					3.12		0.60	0.30
	1st		0.30	2.85	2.55		4.50	0.30			1.71	1.71		1.55	
	2nd		0.41	0.82	2.66		5.33	0.41		0.82	0.41	3.28	0.82	0.82	0.20
	3 m			0.68	0.85		6.12					0.36	0.36	6.16	
	3 A		0.50	1.75	1.00		1.25			0.20	0.41	0.41		1.02	0.20
	P													0.82	
	B		0.25	0.25			1.25	0.25			0.20			1.43	
1970-71	Eggs	0.21	0.21	1.05	1.05	0.63		0.63	0.16	0.32	2.21				0.16
	2nd	2.25	1.25	2.00	2.25	0.25	0.75	0.75	7.25	0.75	1.00	2.50	0.25	1.00	1.00
	3m	0.25	0.25				6.75	0.25					0.40	3.20	0.20
	3 A													0.62	
	P			0.31							0.31				0.31
	B			0.29			2.02							1.24	1.55
1971-72	Eggs	0.20	0.20	2.60	0.60	0.20		0.40	0.32		3.95	0.82		0.16	0.64
	2nd	1.25	0.25	2.25	0.75				0.20	6.76	0.41	2.46	0.61	0.20	0.20
	3 m			0.25			0.50							0.20	
	3 A										0.41				
	P			0.50			0.50				0.61				
	B														
1972-73	Eggs	0.20	1.02	5.52	3.28	0.61	0.20	0.41	0.30	1.30	2.85	2.25	0.75	0.45	0.30
	2nd		1.75	1.00	0.25		0.25				0.41	0.20			

Appendix 7-12 Effect of density on the survival of first instar larvae of C. zealandica in the presence and absence of food

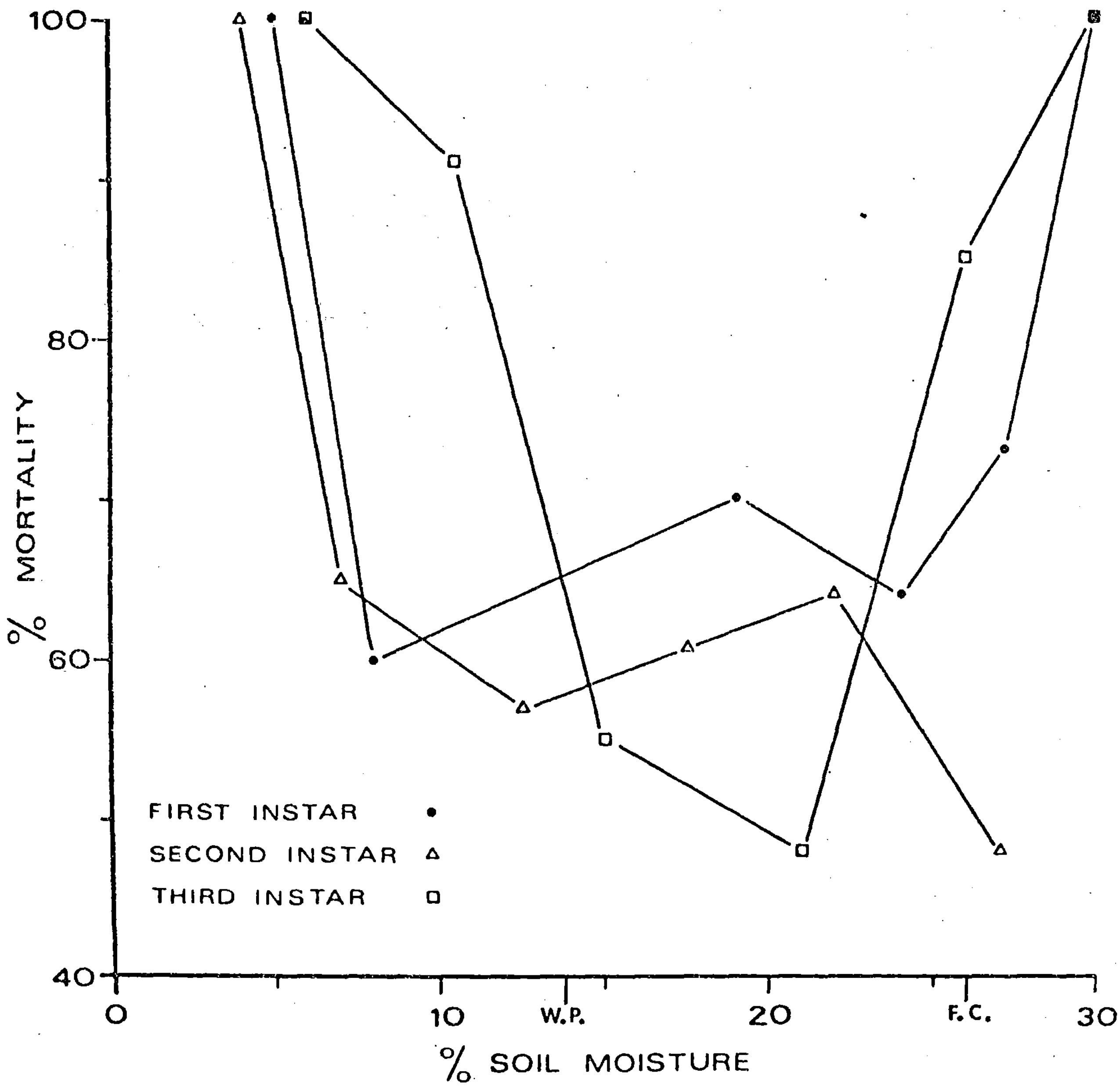
Treatment	Density per pot	No. pots.	No./Density	No. surviving 14 days	Mean survival /pot 14 days	% survival 14 days
Soil	5	6	30	6	1.0	20.0
(without food)	10	6	60	10	1.7	16.7
	15	6	90	9	1.5	10.0
	20	6	120	16	2.7	13.3
	25	6	150	5	0.8	3.3
	30	6	180	16	2.7	9.0
Barley	5	10	50	23	2.3	46.0
(with food)	10	10	100	30	3.0	30.0
	15	10	150	36	3.6	24.0
	20	10	200	36	3.6	18.0
	25	10	250	30	3.0	12.0
	30	10	300	36	3.6	12.0

Appendix 7-13 Effect of density on the survival of second instar larvae of *C. zealandica* in the presence and absence of food.

Treatment	Density per pot	No. pots	No./ density	No. surviving 14 days	Mean survival 14 days	% survival 14 days	No. surviving 28 days	Mean survival 28 days	% survival 28 days
Soil (without food)	2	16	32	24	1.5	75.0	12	0.75	37.5
	5	10	50	33	3.3	66.0	10	1.00	20.0
	8	8	64	37	4.6	57.8	6	0.75	9.4
	10	6	60	42	7.0	70.0	6	1.00	10.0
	15	6	90	41	6.8	45.6	6	1.00	6.7
	20	6	120	43	7.2	35.8	5	0.83	4.2
Barley (with food)	2	16	32	28	1.75	87.5	25	1.56	78.1
	5	10	50	39	3.9	78.0	26	2.6	52.0
	8	8	64	43	5.4	67.2	20	2.5	31.3
	10	6	60	39	6.5	65.0	14	2.3	23.3
	15	6	90	48	8.0	53.3	8	1.3	8.9
	20	6	120	71	11.8	59.2	18	3.0	15.0

Appendix 7-14 Effect of density on the survival of third instar larvae of C. *zealandica* in the presence and absence of food

Treatment	Density per pot	No. pots	No./density	No. surviving 7 days	Mean survival 7 days	% survival 7 days	No. surviving 14 days	Mean survival 14 days	% survival 14 days
Soil (without food)	1	32	32	27	0.84	84.5	26	0.81	81.3
	2	16	32	28	1.75	87.5	28	1.75	87.5
	5	10	50	39	3.9	78.0	32	3.2	64.0
	8	8	64	41	5.1	64.1	35	4.4	54.7
	10	6	60	38	6.3	63.3	26	4.3	43.3
	12	6	72	40	6.7	55.6	27	4.5	37.5
	15	6	90	38	6.3	42.2	10	1.7	11.1
	20	6	120	35	5.8	29.2	9	1.5	7.5
Barley (with food)	1	32	32	29	0.91	90.6	20	0.63	62.5
	2	16	32	22	1.4	68.8	15	0.94	46.9
	5	10	50	35	3.5	70.0	24	2.4	48.0
	8	8	64	49	6.1	76.6	31	3.9	48.4
	10	6	60	45	7.5	75.0	24	4.0	40.0
	12	6	72	48	8.0	66.7	37	6.3	51.8
	15	6	90	73	12.2	81.1	54	9.0	60.0
	20	6	120	88	14.7	73.8	63	10.5	52.5



Appendix 7-15 Relationship between soil moisture level and larval mortality as per Wightman (unpub.)

Appendix 7-16 Spring rainfall and spring mortality of *C. zealandica* at Takapau

	Rainfall (mm)	Mortality (%) 3rd Aug-Beetles
1968-69	91.7	37.8
1969-70	106.2	40.5
1970-71	299.0	75.9
1971-72	159.3	59.0

* Diseased larvae have been deleted in estimates of mortality

Appendix 7-17 Soil moisture profiles in the top 15 cm in wet and dry summers (February) at Takapau and Rukuhia

Depth cm	TAKAPAU		RUKUHIA	
	Wet	Dry	Wet	Dry
0- 5	24.4 ± 2.68	5.3 ± 0.41	36.0 ± 1.27	8.3 ± 0.65
5-10	28.7 ± 3.12	8.9 ± 1.26	37.0 ± 3.20	6.4 ± 0.64
10-15	29.3 ± 2.20	9.0 ± 1.26	41.9 ± 1.80	5.2 ± 0.38

Appendix 7-18 Effect of temperature on the larval stages of

C. zealandica following four, four-hour periods of exposure

Stage	1st Instar			2nd Instar				3rd Instar			
Temp (C^o)	% Mortality	*Corrected	Probit	Temp (C^o)	% Mortality	*Corrected	Probit	Temp (C^o)	% Mortality	*Corrected	Probit
21.0	27.1			23.9	8.33			23.9	26.0		
28.9	32.2	7.1	3.532	31.95	20.00	12.0	3.825	31.7	30.8	6.5	3.486
30.0	40.6	18.5	4.103	32.20	28.50	21.0	4.194	31.95	47.1	28.5	4.432
31.1	50.0	31.4	4.515	32.50	74.50	72.5	5.598	32.20	49.0	31.1	4.507
31.7	75.0	65.7	5.404	32.80	83.25	81.9	5.874	32.50	68.3	57.2	5.181
32.2	84.4	78.6	5.793	33.05	91.0	90.0	6.282	32.80	82.7	76.6	5.726
32.6	84.4	78.6	5.793	33.3	97.5	97.5	6.960	33.05	89.4	85.7	6.067
				33.9	100	100.0	8.719				

* Corrected for mortality in the control (run at 21°C).

Appendix 7-19 Variances and covariances among the components of log population index, based on eggs, expressed as a percentage of the total variance

age interval	log Ss	log Sa	log Sw	log Ssp	log f	* r^2
log Ss	21.35	-22.36	-1.77	-12.26	-19.70	0.0210
log Sa		20.3	5.59	21.96	- 4.00	0.0209
log Sw			3.42	9.07	- 2.80	0.2100
log Ssp				45.53	6.88	0.7410
log f					29.3	0.1297

* r^2 = coefficient of determination

Appendix 7-20 Variances and covariances among the components of log population index, based on second instar larvae, expressed as a percentage of the total variance.

(drought year omitted)

age interval	log Ss	log Sa	log Sw	log Ssp	log f	* r^2
log Ss	6.99	-5.15	-1.99	2.37	-6.47	0.0026
log Sa		6.93	2.63	18.37	9.46	0.5536
log Sw			1.73	6.83	2.25	0.2552
log Ssp				41.55	1.90	0.7638
log f					12.48	0.2069

* r^2 = coefficient of determination

Appendix 7-21 Variances and covariances among the components of log population index, based on second instar larvae, expressed as a percentage of the total variance

age interval	log Ss	log Sa	log Sw	log Ssp	log f	*r^2
log Ss	103.42	7.34	- 4.54	- 9.62	-29.98	0.6990
log Sa		5.03	1.38	5.37	- 1.00	0.2649
log Sw			0.85	2.25	- 0.60	0.0000
log Ssp				11.28	1.69	0.1094
log f					7.26	0.0821

*r^2 = coefficient of determination

Appendix 7-22 Variances and covariances among the components of log population index, based on third instar larvae in May, expressed as a percentage of the total variance

age interval	log Ss	log Sa	log Sw	log Ssp	log f	* r^2
log Ss	11.59	-12.14	-10.99	-13.39	-12.70	0.1472
log Sa		11.02	8.64	20.96	3.50	0.4202
log Sw			5.77	19.03	9.45	0.6157
log Ssp				34.74	13.32	0.8620
log f					11.18	0.2878

* r^2 = coefficient of determination

Appendix 7-23 Variances and covariances among the components of log population index based on third instar larvae, in August, expressed as a percentage of the total variance.

age interval	log Ss	log Sa	log Sw	log Ssp	log f	$*r^2$
log Ss	15.80	-16.54	-1.31	-18.26	-17.44	0.0762
log Sa		15.02	4.14	28.57	4.77	0.4327
log Sw			2.53	3.92	-2.01	0.0948
log Ssp				47.34	18.15	0.8533
log f					15.24	0.1895

$*r^2$ = coefficient of determination

Appendix 7-24 Estimates of population levels of <u>C. zealandica</u> at Takapau using different density dependent and density independent relationships

Year	Stage	A Actual	B Specific density dependent relationships, and relationships between survival, and soil moisture in summer and rainfall in winter.	* MSP ** MF	* MSP ++AF	+ASP **MF	+ASP ++AF	C Mean density dependent relationship for moist summers, mean slope of autumn-winter combat mortality with intercepts set from pasture production data and relationship between survival and soil moisture in summer and rainfall in winter.	
1969	Eggs	573		573	573	573	573		573
	Moist summer: assessment of combat mortality		$\log y = 0.130 \log x + 2.115$					$\log y = 0.142 \log x + 2.121$	
1970	2nd instar	279		297	297	297	297		327
	assessment of combat mortality		$\log y = 0.148 \log x + 1.792$					$\log y = \log x - (1.149(\log x - 2.102)$	
1970	3rd instar (August)	131		141	144	144	144		110
	assessment of density independent mortality based on rainfall		% mortality = 23.42+ 1.82 x rainfall cm rainfall = 10.62 cm					% mortality = 23.42+ 1.82 x rainfall cm rainfall = 10.62 cm	
1970	Beetles	79	Sex prop. 0.44♀ Mean fecundity / ♀ B 15.8 eggs	83	83	83	83	Sex prop. 0.44♀ Mean fecundity / ♀ B 15.8 eggs	63

* MSP = mean sex prop. 0.44 ♀

** MF = mean fecundity / ♀ beetle meaned over 3 years 15.8

\+ ASP = actual sex prop., 1970; 0.47 ♀: 1971; 0.42 ♀: 1972; 0.44 ♀.

++ AF = actual fecundity / ♀ beetle. 1970; 13.5: 1971; 12.5: 1972; 21.6.

Appendix 7-24 contd. Estimates of population levels of C. zealandica at Takapau using different density dependent and density independent relationships.

Year	Stage	A Actual	B	MSP MF	MSP AF	ASP MF	ASP AF	C	
1970	Eggs	535		577	494	616	528		438
	Moist summer: assessment of combat mortality		log y = 0.154 log x + 2.127					log y = 0.142 log x + 2.121	
1971	2nd instar	326		125	348	360	352		313
	Assessment of combat mortality		log y = -0.567 log x + 3.544					log y = log x -(1.149(log x - 2.260)	
1971	3rd instar (August)	114		125	127	124	126		168
	assessment of density independent mortality based on rainfall		% mortality = 23.42 + 1.82 x rainfall cm rainfall = 29.9 cm					% mortality = 23.42+ 1.82 x rainfall cm rainfall = 29.9 cm	
1971	Beetles	28		28	28	27	28		37
			Sex prop. 0.44♀ Mean fecundity / ♀ B 15.8 eggs					Sex prop. 0.44♀ Mean fecundity / ♀ B 15.8 eggs	

Appendix 7-24 contd. Estimates of population levels of *C. zealandica* at Takapau using different density dependent and density independent relationships.

Year	Stage	A Actual	B	MSP MF	MSP AF	ASR MF	ASP AF	C	
			Basic assumptions						
1971	Eggs	175		195	154	178	146		257
	Dry summer: assessment of density independent mortality based on soil moisture		% mortality = 142.41- 6.264 x % moisture % moisture = 16%					% mortality = 142.41- 6.264 x % moisture % moisture = 16%	
1972	2nd instar	103		113	89	103	84		149
	Assessment of combat mortality		$\log \underline{y} = 0.0282 \log \underline{x} + 1.595$					$\log \underline{y} = \log \underline{x} - (1.149(\log \underline{x} - 1.550)$	
1972	3rd instar (August)	34		34	35	35	35		29
	Assessment of density independent mortality based on rainfall		% mortality = 23.42+ 1.82 x rainfall cm rainfall = 15.93 cm					% mortality = 23.42+ 1.82 x rainfall cm rainfall = 15.93 cm	
1972	Beetles	14		17	17	17	17		14
			Sex prop. 0.44♀ Mean fecundity / ♀ B 15.8 eggs					Sex prop. 0.44♀ Mean fecundity / ♀ B 15.8 eggs	
1972	Eggs	151		118	161	117	159		97
	Dry summer assessment of density independent mortality based on soil moisture		% mortality = 142.41- 6.264 x % moisture % moisture = 9%					% mortality = 142.41- 6.264 x % moisture % moisture = 9%	
1973	2nd instar	11		16	22	16	22		14

Appendix 8-1 Regressions of the square root of the mean number (m^2) of second instar larvae in February on percentage occurrence recorded in groups of subplots within the Takapau life table plots.

Year	No	*r	Slope ± 95%			Intercept ± 95%		
1969			Not sampled					
1970	9	0.8691	0.202	0.103	A a	4.320	1.677	ABC abc
1971	9	0.9276	0.183	0.066	A a	7.398	1.128	AB a
1972	9	0.9573	0.251	0.068	A a	2.402	0.754	BC b
1973	9	0.9767	0.248	0.053	A a	1.368	0.471	C c
Overall	36	0.9662	0.250	0.020		2.230	0.495	

Appendix 8-2 Regressions of the square root of the mean number (m^2) of second instar larvae in March on percentage occurrence recorded in paddocks within the Takapau farming systems trial

Year	No	*r	Slope ± 95%			Intercept ± 95%		
1968			Not sampled					
1969	26	0.9308	0.273	0.045	A a	4.717	0.794	A a
1970	42	0.9697	0.262	0.022	A a	1.541	0.524	B b
1971	19	0.9607	0.215	0.032	AB b	2.619	0.883	BC bc
1972	16	0.9663	0.176	0.027	B b	3.269	0.615	BC c
1973	14	0.9303	0.156	0.039	B b	3.552	0.569	BC c
Overall	117	0.9090	0.234	0.020		2.956	0.479	

*r = correlation coefficient

Appendix 8-3 Regressions of the square root of the mean number (m^2) of third instar larvae in May on percentage occurrence recorded in groups of subplots within the Takapau life table plots

Year	No	r*	Slope ± 95%				Intercept ± 95%			
1969	9	0.9815	0.207	0.036	A	a	2.757	0.389	A	a
1970	9	0.9693	0.168	0.038	A	a	3.110	0.416	AB	b
1971	9	0.9682	0.163	0.038	A	a	3.315	0.600	B	b
1972	9	0.9497	0.174	0.051	A	a	2.423	0.690	B	b
Overall	36	0.9694	0.171	0.013			3.073	0.258		

Appendix 8-4 Regressions of the square root of the mean number (m^2) of third instar larvae in May on percentage occurrence recorded in paddocks within the Takapau farming systems trial

Year	No	r*	Slope ± 95%				Intercept ± 95%			
1968	27	0.9316	0.207	0.033	AB	ab	3.184	0.487	A	a
1969	32	0.9743	0.236	0.020	A	a	2.192	0.391	A	a
1970	35	0.9750	0.189	0.015	B	b	1.835	0.311	B	b
1971	36	0.9762	0.178	0.014	BC	b	2.360	0.377	B	b
1972	15	0.9161	0.143	0.037	C	c	3.138	0.615	B	b
Overall	145	0.9313	0.182	0.012			2.929	0.258		
* Life table and Farming system	181	0.9363	0.180	0.010			2.961	0.216		

* pooled data from the life table plots and farming systems trial

r* = correlation coefficient

Appendix 8-5 Regressions of percentage visible damage in May on the percentage occurrence in March recorded in paddocks within the Takapau farming system trial

Year	No	++r	Slope ± 95%			Intercept ± 95%		
1968			Not sampled					
1969	18	0.9154	0.904	0.211	A a	-1.044	3.546	A a
1970	8	0.6536	0.554	0.640	B b	-3.353	7.330	A a
1971	7	0.9377	0.437	0.186	B b	1.298	6.636	A a
Overall*	40	0.7512	0.545	0.157		6.918		

Appendix 8-6 Regressions of percentage visible damage in May on the percentage occurrence in May recorded in paddocks within the Takapau farming system trial

Year	No	++r	Quadratic component	S.E.	Linear component	S.E.	Intercept	S.E.
1968	19	0.9132	0.00523	±0.00482	0.3949	±0.0797	2.5513	±1.3160
1969	17	0.9268	0.01649	±0.01498	-0.5051	±0.1221	20.5243	±1.5884
1970	11	0.9106	0.00533	±0.00516	0.1471	±0.0780	1.0262	±2.1067
1971	10	0.9362	0.00175	±0.00350	0.3944	±0.0745	0.7138	±1.9879
1968 & 69	36	0.9323	0.00100	±0.00302	0.1443	±0.0542 A a	5.1241	±1.0038 A a
1970 & 71+	25	0.9271	0.00291	±0.00219	0.3048	±0.0437 B b	1.1733	±1.1314 B b
Overall+	61	0.8544	0.00106	±0.00269	0.6111	±0.0553	-0.6210	±1.2071

* Included are four observations from 1972 and three from 1973

\+ Included are four observations from 1972

++ correlation coefficient

Appendix 8-7 Regressions of the percentage visible damage in May on the square root of the mean number of second instar larvae (m^2) in March recorded in paddocks within the Takapau farming systems trial

Year	No	**r	Slope ± 95%			Intercept ± 95%		
1969	18	0.9431	3.129	0.585	A a	-13.822	2.929	A a
1970	8	0.6012	2.130	2.828	A a	- 8.389	7.739	B b
1971	7	0.9249	2.057	0.973	B b	- 5.391	7.261	AB b
All years*	40	0.8589	2.267	0.439		- 2.565	2.903	

Appendix 8-8 Regressions of the percentage visible damage in May on the mean number of third instar larvae (m^2) in May recorded in paddocks within the Takapau farming systems trial

Year	No	**r	Slope ± 95%			Intercept ± 95%		
1968	23	0.9413	0.195	0.032	A a	- 0.586	2.121	A a
1969	17	0.8776	0.183	0.055	A a	0.448	4.370	A a
1970	11	0.9403	0.171	0.047	A a	0.000	3.939	A a
1971	10	0.9496	0.175	0.047	A a	0.133	3.894	A a
All years+	65	0.9462	0.184	0.016		- 0.277	1.473	

* Included are four observations for 1972 and three for 1973

\+ Included are four observations for 1972

**r = correlation coefficient

Appendix 8-9 Regressions of log second instar larvae in March in generation P(n + 1) on generation P(n)

Year	No	++ r	Slope ± 95%			Intercept ± 95%		
1969-1970	18	0.6772	0.470	0.270	A a	1.432	0.053	A a
1970-1971	12	0.8920	0.387	0.138	A a	1.673	0.069	A a
Overall*	35	0.8700	0.629	0.126		1.068	0.060	

Appendix 8-10 Regressions of log third instar larvae in March in generation P(n + 1) on generation P(n)

Year	No	++ r	Slope ± 95%			Intercept ± 95%		
1968-1969	17	0.8022	0.533	0.218	AB ab	1.272	0.057	B b
1969-1970	15	0.8379	0.465	0.182	A a	1.271	0.047	A a
1970-1971	20	0.8301	0.493	0.164	B b	1.284	0.069	B b
Overall+	55	0.8348	0.547	0.099		1.174	0.035	

* Included are two observations from 1971-72 and 3 observations from 1972-73

\+ Included are three observations from 1971-72

++ r = correlation coefficient

Appendix 8-11 Frequency distributions of individual areas of visible pasture damage and their rate of appearance

*Class Interval	1970	1971	Increase 1970-71	1972	Increase 1971-72
0	10	2	2	1	1
1	10	3	6	1	2
2	3	4	12	0	0
3	5	7	3	0	4
4	1	2	2	0	2
5	0	4	0	0	4
6	0	1	2	2	3
7	1	2	2	1	6
8		3	0	3	1
9		0	0	5	1
10		1	1	4	2
11		1		3	2
12				1	1
13				1	0
14				3	0
15				1	0
16				1	0
17				0	1
18				2	
19				0	
20				0	
21				1	

* No. of areas of visible damage/subplot

Appendix 8-12 Tests of adequacy of the negative binomial model for describing the frequency distributions of individual areas of visible pasture damage and their rate of appearance.

	1970	1971	Increase 1970-71	1972	Increase 1971-72
No. classes	8	12	11	22	18
Mean	1.40	4.16	2.77	10.57	6.33
'k'	2.01	4.11	4.19	8.80	5.57
x^2	1.71	3.93	10.99	4.67	1.07
df	4	6	6	6	5
T	-0.37	-9.68	2.43	-61.73	-10.58
Set	3.02	15.56	6.20	34.59	29.50

'k' = parameter of dispersion for a negative binomial

df = degrees of freedom

x^2 = chi-squared rest

T = test of negative binomial

Set = - SE of T

Appendix 8-13 Calculations involved in simulating the growth of pasture damage caused by *C. zealandica* larvae in successive years.

Given

1) Number of individual areas of damage :

six, of the following areas; 0.79, 4.91, 7.07, 1.77, 0.20 and 3.14 m^2

2) Relationship for predicting the number of eruptions per ha in year (yr.+1) from x the % area damaged in yr.

$$y = 135.6x - 2.072x^2 / (x + 0.8)$$

3) Expansion of an individual area of damage in metres is given by

$$y = (3.942 / x) + 1.6$$

where x is the % area damaged in yr.

% damage (D) in year yr $D(yr)$	No. of Eruptions /ha	Components of D (yr+1) /ha	No. of Eruptions /ha	Components of $D(yr+2)$	No. of Eruptions /ha	Components of $D(yr+3)$
0.1788		0.5226		1.0726		1.9527
	25	0.3650		1.5695		3.4967
			70	1.0220		4.3946
					105	1.5330
Σ0.1788		Σ0.8876		Σ3.6641		Σ11.3770

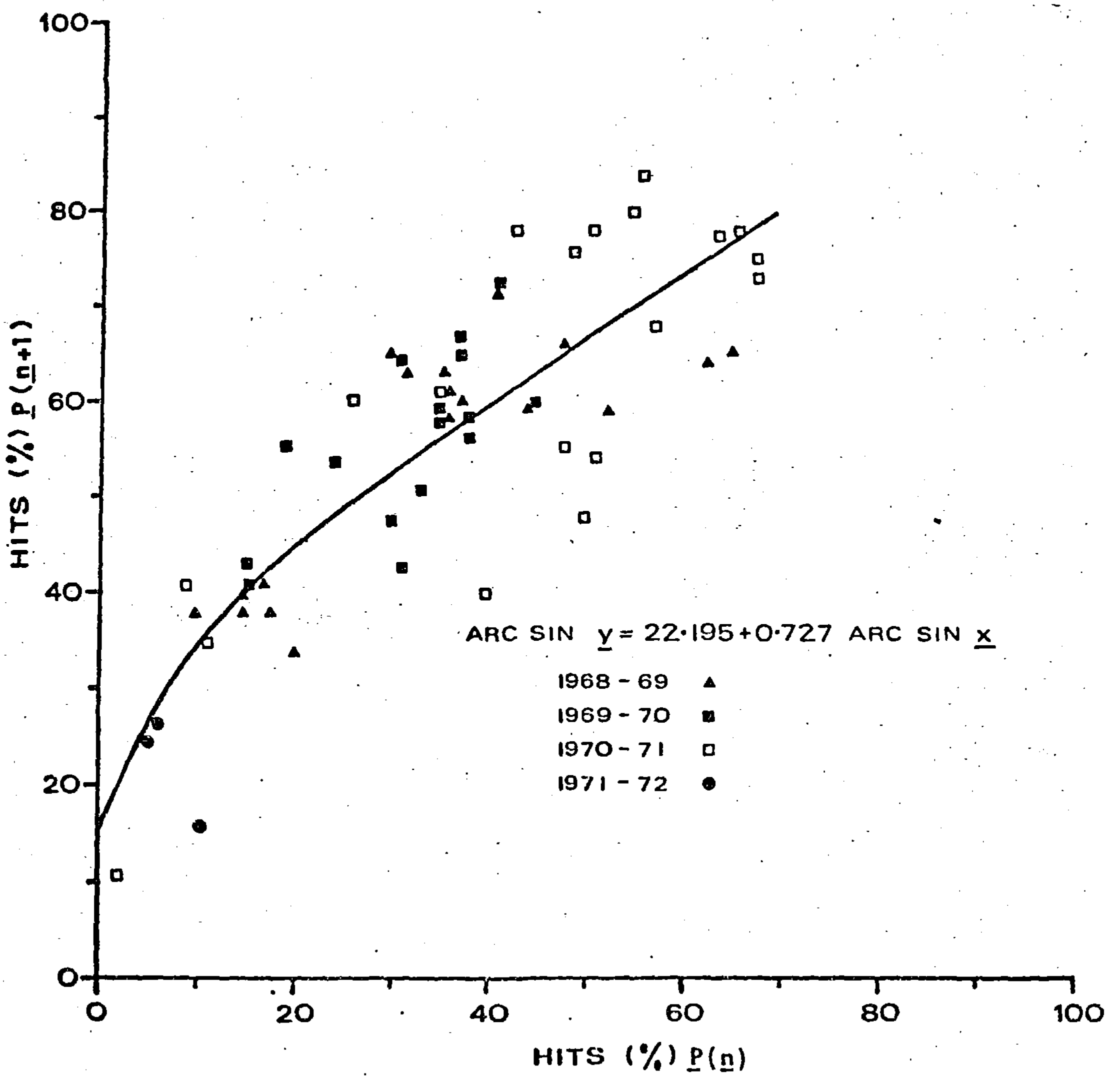
Appendix 8-14 Results of simulation studies using the models given in the next text for predicting the area of pasture damage from one year (Yr) to the next (Yr + 1)

% damage in year	% damage in year (Yr + 1)			
	Quadratic curve	Using relationships involving rate of appearance and growth of visible damage +	Using relationships involving population density *	Using relationships involving % occurrence **
2%	6.0	7.2	9.6	7.2
5%	13.6	13.6	16.4	13.2
10%	25.2	24.0	24.6	22.0
15%	35.6	31.6	30.4	29.6
20%	44.4	42.4	35.6	35.6
25%	52.0	50.0	40.0	40.0
30%	57.2	56.0	44.0	44.4
40%	64.0	65.2	52.0	52.4

+ Model A

* Model B

** Model C



Appendix 8-15 Relationship between percentage occurrence (% hits) for successive generations (n) of C. zealandica larval population (P) in May.

Appendix 8-16   Herbage production (DM kg/ha) of different strata based on pasture damage caused by *C. zealandica* larvae.

Strata+	1970 Undam	1970 Previous	1970 Newly	1970 LSD (5%)	1971 Undam	1971 Previous	1971 Newly	1971 LSD (5%)	1972 Undam	1972 Previous	1972 Newly	1972 LSD (5%)
Month												
Jan		Not sampled			1107	1025	878	236	1375	954	1287	473
Feb					1100	755	477	261	305	13	-153	292
March					759	239	240	149	406	344	111	152
April					851	395	191	117	833	710	222	152
May					504	333	133	170	417	281	227	85
June					445	483	95	250	304	345	208	115
July					894	472	229	268	353	261	257	75
August					1042	722	382	178	813	642	305	163
Sept.					1425	1287	1208	209	1207	1231	965	178
Oct.					1695	1781	1564	253	1364	1257	928	183
Nov.	1975	1424	1843	260	1519	1383	1206	244	1112	1409	1085	208
Dec.	1812	1155	1663	328	1461	1291	1448	234	348	516	376	102

\+ Undam = areas which are not damaged

Previous = areas which have been damaged by previous generations

Newly = areas in which damage has been caused by the current generation

LSD = least significant difference

Appendix 8-17 Analyses of variance of monthly herbage production harvested from pasture stratified on the damage of *C. zealandica* larvae.

	1971			1972		
Source of variation	df+	MSOS*	F test	df	MSOS	F test
Between months	11	8,798,573	* *	11	6,076,280	* *
Between strata	2	6,137,755	* *	2	2,614,311	* *
Strata x months	22	4,518,046	* *	22	3,754,965	* *
Between samples	432	67,203		432	59087	

Appendix 8-18 Analyses of variance of seasonal herbage production harvested from pasture stratified on the damage of *C. zealandica* larvae

Source of variation	df	MSOS	F test	df	MSOS	F test
Between seasons	3	851,28663	* *	3	52,556,037	* *
Between strata	2	19,904,946	* *	2	7,717,476	* *
Strata x seasons	6	33,006,453	* *	6	20,029,283	* *
Between samples	144	778,080		144	384,779	

+ df = degrees of freedom

* MSOS = mean sum of squares

Appendix 8-19 Plant species found in the study plots at Takapau.

Common Names	Botanical Names
Grasses	
Perennial ryegrass	*Lolium perenne*
Cocksfoot	*Dactylis glomerata*
Crested dogstail	*Cynosurus cristatus*
Goose grass	*Bromus mollis*
Poa trivialis	*Poa trivialis*
Chewings fescue	*Festuca rubra*
Poa annua	*Poa annua*
Sweet vernal	*Anthoxanthum odoratum*
Timothy	*Phleum pratense*
Barley grass	*Hordeum murinum*
Yorkshire fog	*Holcus lanatus*
Browntop	*Agrostis tenuis*
Clovers	
White clover	*Trifolium repens*
Subterranean clover	*Trifolium subterraneum*
Red clover	*Trifolium pratense*
Suckling clover	*Trifolium dubium*
Broadleaved weeds	
Annual mouse-eared chickweed	*Cerastium glomeratum*
Chickweed	*Stellaria media*
Dandelion	*Taraxacum officinale*
Catsear	*Hypochaeris radicata*
Juncus spp.	*Juncus spp.*
Yarrow	*Achillea millefolium*
Scotch thistle	*Cirsium vulgare*
Hawkesbeard	*Crepis capillaris*

Appendix 8-20 Analysis of variance of the botanical composition of herbage harvested from pasture stratified on the damage of *C. zealandica* larvae.

1971-1972		Ryegrass		Other grasses		Clovers		Broadleaved weeds and litter	
Source of variation	**df	+MSOS	F test	MSOS	F test	MSOS	F test	MSOS	F test
Between seasons	3	2547.09	* *	6259.46	* *	2124.88	* *	7366.74	* *
Between strata	2	4143.14	* *	2095.82	* *	4195.00	* *	7120.38	* *
Strata x seasons	6	426.98	NS	805.93	*	536.16	* *	560.71	NS
Between samples	333	271.80		288.28		170.64		325.14	
1972-1973									
Between seasons	+* 1	346.93	NS	969.25	* *	2463.59	* *	9858.46	* *
Between strata	2	1139.86	* *	77.98	NS	262.32	NS	2028.86	* *
Strata x seasons	2	2341.06	* *	34.11	NS	15.30	NS	3001.58	* *
Between samples	66	204.19		91.44		139.77		97.17	

+ MSOS = mean sum of squares

+* summer and autumn only

** df = degrees of freedom