

# RESISTANCE TO DIAZINON IN NEW ZEALAND POPULATIONS OF THE EUROPEAN GREEN BLOWFLY, *LUCILIA SERICATA* (MIEGEN) (DIPTERA: CALLIPHORIDAE).

J.A. Wilson<sup>1</sup>, N.A. Haack<sup>1</sup>, A.C.G. Heath<sup>1</sup>, A.G. Clark<sup>2</sup>

<sup>1</sup>Entomology Group, AgResearch, Wallaceville, P. O. Box 40 063, Upper Hutt, New Zealand.

<sup>2</sup>School of Biological Sciences, Victoria University of Wellington, P. O. Box 600, Wellington, New Zealand.  
Email: allen.heath@agresearch.co.nz

## Summary

A treated-surface test was used in a bioassay to detect insecticide resistance to the organophosphorus compound (OP) diazinon, in larvae of field strains of *Lucilia sericata* in New Zealand from 1991 to 1997. Response measured by the lethal concentration killing 50% of the field population (LC<sub>50</sub>) ranged from 0.18 mg/L to 2.06 mg/L (Resistance Factors 3.0 - 34.3) and was influenced by regional and seasonal factors. Resistance to diazinon in *L. sericata* is discussed in relation to a putative competitor species, *L. cuprina*.

**Keywords:** *Lucilia sericata*, *Lucilia cuprina*, flystrike, diazinon, insecticide resistance, Diptera, Calliphoridae.

## INTRODUCTION

The European green blowfly, *Lucilia sericata* Miegen, has been present in New Zealand for over 100 years and has been a pest of sheep for a significant part of this time (Hutton 1901, Miller 1939, Heath 1986). *Lucilia sericata* is a dominant species in the heterogeneous flystrike fauna in New Zealand that also includes *Calliphora stygia* and *Chrysomya rufifacies* and more recently the Australian sheep blowfly, *Lucilia cuprina* (Heath *et al.* 1991). Control of flystrike species in the past and indeed at present, is achieved largely by preventative insecticidal treatment of sheep. During the 1960s, *L. sericata* from the Marlborough region in New Zealand developed resistance to sheep dips containing the cyclodienes, aldrin and dieldrin (Hart 1961). Withdrawal of these compounds from the market was rapid and presumably reduced the risk of higher and more widespread resistance developing.

Farmer awareness of resistance to organophosphorus insecticides (OPs) by blowflies increased with the introduction of the Australian sheep blowfly *Lucilia cuprina* during the late 1970s (Heath *et al.* 1991). *Lucilia cuprina* exhibits resistance to most classes of insecticides registered for the prevention of strike in Australia (Shanahan 1959, 1966, Roxburgh and Shanahan 1973, Hughes and McKenzie 1987, Hughes and Raftos 1983, Levot 1990, Kotze *et al.* 1997). More recently the resistance of *L. cuprina* to the OPs diazinon and propetamphos was determined in New Zealand (Gleeson *et al.* 1994, Wilson and Heath 1994). The presence of two sibling species under similar selection pressures, but with different responses to pressure offers an opportunity to evaluate the extent to which differential fitness is occurring in both species. Hall and Wall (1995) speculated that *L. cuprina* might eventually

displace *L. sericata* as the predominant primary flystrike species in New Zealand without suggesting how this might occur. However, there is evidence to suggest that *L. sericata* is largely unaffected by the advent of *L. cuprina*. The prevalence of *L. cuprina* in flystrike samples has been around 40 - 75% in the last 9 - 10 years compared with around 35 - 60% for *L. sericata* (Bishop pers. comm.). Prevalence figures include data for single species strikes as well as combination strikes with other species. This current study sought to establish the resistance status of *L. sericata* to the organophosphorus insecticide diazinon and also to see if this could provide evidence for adverse effects resulting from competition with *L. cuprina*.

## MATERIALS AND METHODS

### Insects

**Susceptibles** A laboratory strain of *Lucilia sericata*, susceptible to OPs and with no history of organophosphorus insecticide exposure, was obtained from ICI (New Zealand) Ltd (now Coopers Division, Schering-Plough Animal Health Ltd) in mid-1985 and maintained in culture at the Wallaceville Animal Research Centre, Upper Hutt, New Zealand for over 100 generations.

### Field Strains

*Lucilia sericata* field strains were obtained from flystrike lesions on sheep. Larvae from struck sheep were mailed to Wallaceville Animal Research Centre in 250 ml sample pottles containing a small amount of vermiculite. Larvae were reared through to adults and maintained as single species strains. Toxicological testing was carried out on F2 larvae. Flies were fed sugar and water *ad libitum* with larvae being reared on a diet comprising a mixture of

processed pet food and minced ox liver.

### Toxicology

Toxicological testing used a method described by Levot (1990). Briefly, 12 cm x 3 cm pieces of Whatman chromatography paper (3MM) were impregnated with 1 mL of insecticide in acetone. Insecticide concentrations were chosen after a preliminary test to give 0-100% larval mortality. Technical grade diazinon (91.5% a.i.) was obtained from Novartis (New Zealand) Ltd. Papers treated with acetone only were used as a control. Papers were rolled and placed into 50 mm x 10 mm glass vials. Between 50 and 150 first instar larvae, less than two hours old and hatched from eggs laid on ox liver, were placed into the vials. One mL of fortified sheep serum was added and the vials plugged with non-absorbent cotton wool. The serum had been fortified with 2% yeast extract and buffered with 0.5% monobasic potassium orthophosphate. Larvae were incubated for 24 hours at 25°C and under strip lighting. To record mortality, treated papers were unrolled into warm water and a distinction made using larval movement detected against a dark background.

### Statistical Analysis

Dose response data were analyzed by using a probit regression (Finney 1971) computer program obtained from NSW Agriculture, Sydney. Results are presented as  $LC_{50}$  and  $LC_{99}$  with 95% fiducial limits, slope and standard error of the log-dose probit mortality line. Slopes indicate change in mortality per unit change in insecticide concentration (Robertson and Priesler 1992). Percent control mortalities were corrected using the Abbott (1925) transformation. Resistance factors (RFs) were calculated by dividing the  $LC_{50}$  of the field strain by that of the susceptible strain.

Probit data were further analyzed by analysis of variance (ANOVA) methods in S-Plus (Everitt 1994). The  $LC_{50}$  for response to diazinon was used as the dependent variable and region, season and year were used as predictors of the magnitude of resistance. Regional designations are shown in Table 1 and were based on natural geographical barriers and area codes described by Crosby *et al.* (1998). Seasons were designated as summer (December, January, February), autumn (March, April, May), winter (June, July, August) and spring (September, October, November).

Table 1. Toxicological response of *Lucilia sericata* larvae to diazinon. Samples are categorised by New Zealand region and area.

Farm	Location	Sample date	$LC_{50}^1$ (95% FL <sup>2</sup> ) mg/L	$LC_{99}^3$ (95% FL) mg/L	Slope (SE <sup>4</sup> )	RF <sup>5</sup>
01	Laboratory	00.00.00	0.06 (0.06 - 0.07)	0.11 (0.09 - 0.11)	10.1 (0.56)	1.0
REGION 1						
Waikato						
02	Waingaro	31.01.94	0.30 (0.17 - 0.53)	1.76 (0.48 - 6.40)	3.04 (1.26)	5.0
03	Kihikihi	13.02.95	0.57 (0.48 - 0.66)	0.92 (0.59 - 1.41)	11.1 (0.41)	9.5
REGION 2						
Gisborne						
04	Gisborne	17.11.91	0.51 (0.46 - 0.57)	1.18 (0.93 - 1.48)	6.45 (1.18)	8.5
04	Gisborne	21.01.93	0.36 (0.30 - 0.43)	0.96 (0.72 - 1.28)	5.47 (1.02)	6.0
05	Gisborne	24.11.93	0.28 (0.22 - 0.36)	1.03 (0.60 - 1.78)	4.14 (0.94)	4.7
06	Gisborne	23.02.94	0.33 (0.28 - 0.39)	0.88 (0.62 - 1.26)	5.47 (0.92)	5.5
07	Wairoa	23.11.94	0.83 (0.72 - 0.96)	2.53 (1.77 - 3.62)	4.81 (1.00)	13.8
08	Gisborne	31.11.94	0.43 (0.35 - 0.52)	2.22 (1.28 - 3.86)	3.25 (0.77)	7.2
04	Gisborne	20.11.95	0.49 (0.42 - 0.56)	1.31 (0.88 - 1.95)	5.39 (0.63)	8.1
09	Wairoa	25.10.95	0.71 (0.58 - 0.87)	2.39 (1.38 - 4.13)	4.42 (0.98)	11.8
10	Wairoa	10.01.96	0.76 (0.62 - 0.94)	1.96 (1.19 - 3.22)	5.68 (1.36)	12.7
07	Wairoa	12.03.96	0.53 (0.44 - 0.64)	2.54 (1.51 - 4.25)	3.42 (0.56)	8.8
07	Wairoa	08.01.97	0.73 (0.66 - 0.80)	1.67 (1.33 - 2.08)	6.46 (0.97)	12.2

Hawkes Bay						
11	Waipukurau	03.01.92	0.73 (0.69 - 0.76)	1.44 (1.27 - 1.62)	7.88 (0.77)	12.2
12	Waipawa	06.01.92	0.66 (0.61 - 0.70)	1.66 (1.43 - 1.92)	5.78 (0.62)	11.0
13	Hastings	07.04.94	0.34 (0.28 - 0.41)	0.99 (0.62 - 1.58)	5.05 (0.76)	5.7
14	Hastings	08.04.94	0.45 (0.36 - 0.56)	3.83 (1.06 - 3.54)	3.66 (0.71)	7.5
14	Hastings	15.02.95	1.11 (1.02 - 1.20)	1.91 (1.59 - 2.29)	9.84 (0.70)	18.5
14	Hastings	04.11.95	0.64 (0.57 - 0.72)	1.50 (1.16 - 1.93)	6.34 (0.98)	10.7
12	Waipawa	28.12.95	0.59 (0.55 - 0.64)	1.41 (1.16 - 1.72)	6.16 (0.44)	9.8
14	Hastings	18.04.97	1.04 (0.96 - 1.13)	2.92 (2.35 - 3.61)	5.21 (0.68)	17.3
Wairarapa						
19	Masterton	30.12.91	0.43 (0.30 - 0.60)	1.50 (0.69 - 3.25)	4.27 (1.37)	7.2
20	Carterton	19.11.95	0.84 (0.77 - 0.92)	1.49 (1.22 - 1.82)	9.42 (1.01)	14.0
21	Masterton	10.01.96	0.61 (0.56 - 0.66)	1.62 (1.32 - 1.99)	5.45 (0.44)	10.2
22	Martinborough	17.01.96	1.09 (1.01 - 1.18)	2.17 (1.84 - 2.56)	7.79 (1.09)	18.2
20	Carterton	19.01.96	0.73 (0.67 - 0.80)	1.90 (1.54 - 2.34)	5.62 (0.57)	12.2
21	Masterton	24.02.96	0.78 (0.71 - 0.85)	2.62 (2.11 - 3.26)	4.41 (0.26)	13.0
19	Masterton	14.03.96	0.98 (0.87 - 1.10)	2.43 (1.84 - 3.21)	5.89 (0.84)	16.3
20	Carterton	07.05.96	0.84 (0.76 - 0.93)	1.85 (1.46 - 2.36)	6.78 (1.02)	14.0
23	Masterton	15.01.97	0.56 (0.51 - 0.62)	1.52 (1.28 - 1.80)	5.40 (0.61)	9.3
20	Carterton	15.01.97	0.68 (0.61 - 0.77)	2.03 (1.59 - 2.59)	4.92 (0.33)	11.3
21	Masterton	17.03.97	0.97 (0.89 - 1.05)	2.10 (1.77 - 2.49)	6.94 (0.63)	16.2
REGION 3						
Wanganui						
15	Wanganui	14.12.91	0.55 (0.51 - 0.59)	1.58 (1.31 - 1.89)	5.78 (0.62)	9.2
16	Wanganui	03.01.94	0.49 (0.43 - 0.56)	1.32 (0.97 - 1.78)	5.42 (1.12)	8.2
16	Wanganui	25.03.94	0.36 (0.28 - 0.47)	1.02 (0.59 - 1.75)	5.22 (1.51)	6.0
17	Kimbolton	20.02.95	0.73 (0.64 - 0.83)	1.94 (1.42 - 2.65)	5.49 (1.03)	12.2
17	Kimbolton	18.01.96	0.67 (0.63 - 0.71)	1.22 (1.11 - 1.35)	6.26 (0.36)	11.2
15	Wanganui	22.01.96	1.25 (1.12 - 1.39)	2.84 (2.32 - 3.62)	6.51 (0.41)	20.8
18	Feilding	05.03.96	0.53 (0.48 - 0.58)	1.78 (1.42 - 2.25)	4.39 (0.53)	8.8
16	Wanganui	25.03.96	0.67 (0.60 - 0.75)	1.88 (1.39 - 2.53)	5.19 (0.66)	11.2
16	Wanganui	14.11.96	0.72 (0.66 - 0.79)	1.60 (1.30 - 1.95)	6.79 (1.07)	12.0
Wellington						
24	Levin	09.02.94	0.38 (0.34 - 0.42)	1.31 (1.03 - 1.67)	4.31 (0.33)	6.3
25	Marton	09.04.96	0.75 (0.70 - 0.80)	2.41 (2.05 - 2.83)	4.61 (0.22)	6.3
26	Marton	09.04.96	1.18 (1.03 - 1.34)	3.03 (2.17 - 4.22)	5.68 (0.93)	19.7
REGION 4						
Marlborough						
27	Blenheim	28.02.91	0.32 (0.24 - 0.43)	0.95 (0.55 - 1.65)	4.88 (2.01)	5.3
27	Blenheim	13.12.91	0.58 (0.52 - 0.64)	1.59 (1.22 - 2.08)	5.28 (0.76)	9.7
27	Blenheim	20.01.92	0.75 (0.68 - 0.84)	1.55 (1.21 - 2.08)	7.43 (0.93)	12.3
28	Blenheim	07.12.92	1.29 (1.15 - 1.45)	3.28 (2.42 - 4.44)	5.76 (0.81)	21.3
28	Blenheim	07.12.92	1.29 (1.15 - 1.45)	3.28 (2.42 - 4.44)	5.76 (0.81)	21.3
28	Blenheim	25.04.94	0.75 (0.65 - 0.87)	1.70 (1.16 - 2.48)	6.58 (1.52)	12.5
27	Blenheim	27.01.96	0.82 (0.73 - 0.92)	2.02 (1.51 - 2.72)	5.96 (0.65)	13.7

29	Blenheim	03.03.96	1.26 (1.20 - 1.32)	2.38 (2.09 - 2.71)	8.42 (0.79)	13.7
28	Blenheim	05.03.96	2.06 (1.91 - 2.22)	4.69 (3.87 - 5.69)	6.49 (0.42)	34.3
28	Blenheim	10.12.96	0.95 (0.88 - 1.03)	2.26 (1.85 - 2.74)	6.23 (0.44)	15.8
30	Blenheim	12.01.97	1.31 (1.18 - 1.44)	3.54 (2.77 - 4.54)	5.36 (0.61)	21.7
27	Blenheim	20.01.97	0.85 (0.74 - 0.97)	3.23 (2.24 - 4.67)	4.00 (0.50)	14.2
28	Blenheim	14.04.97	1.15 (1.03 - 1.28)	4.25 (3.25 - 5.56)	4.09 (0.37)	19.2
Nelson						
31	Nelson	15.01.96	1.22 (1.14 - 1.31)	3.34 (2.77 - 4.03)	5.32 (0.40)	20.3
31	Nelson	17.04.96	1.10 (1.03 - 1.18)	2.74 (2.30 - 3.26)	5.89 (0.20)	18.3
32	Wakefield	26.02.97	0.76 (0.70 - 0.82)	1.94 (1.63 - 2.31)	5.70 (0.62)	12.7
REGION 5						
North Canterbury						
33	Amberley	28.12.91	0.63 (0.60 - 0.67)	1.39 (1.21 - 1.59)	6.85 (0.29)	10.5
34	Waiau	18.01.92	1.06 (0.95 - 1.19)	2.26 (1.67 - 3.06)	7.09 (1.30)	17.7
35	Cheviot	11.12.92	0.94 (0.86 - 1.04)	2.52 (1.90 - 3.32)	5.47 (0.73)	15.7
36	Cheviot	14.12.92	0.87 (0.83 - 0.90)	1.31 (1.19 - 1.44)	13.1 (1.35)	14.5
37	Scargill	01.03.94	0.47 (0.39 - 0.57)	1.26 (0.82 - 1.94)	5.44 (0.68)	7.8
38	Waiau	14.12.96	0.87 (0.79 - 0.97)	2.12 (1.66 - 2.71)	6.04 (0.78)	14.5
39	Amberley	14.12.96	0.83 (0.73 - 0.94)	2.86 (2.12 - 3.84)	4.32 (0.48)	13.8
35	Cheviot	13.01.97	0.80 (0.69 - 0.91)	2.35 (1.63 - 3.40)	4.95 (0.77)	13.3
35	Cheviot	13.04.97	0.64 (0.58 - 0.71)	1.91 (1.49 - 2.45)	4.88 (0.43)	10.7
Mid Canterbury						
40	Darfield	21.11.91	0.57 (0.62 - 0.53)	1.71 (1.40 - 2.08)	4.90 (0.40)	9.5
41	Ashburton	21.12.92	0.76 (0.62 - 0.93)	2.06 (1.17 - 3.64)	5.37 (1.28)	12.7
42	Lincoln	22.03.93	0.69 (0.62 - 0.77)	2.45 (1.86 - 3.24)	4.23 (0.49)	11.5
43	Ashburton	06.01.94	0.37 (0.31 - 0.44)	1.34 (0.89 - 2.03)	4.20 (0.68)	6.2
44	Rakaia	10.01.94	0.40 (0.35 - 0.47)	1.25 (0.86 - 1.82)	4.72 (0.51)	6.7
44	Rakaia	14.02.94	0.38 (0.35 - 0.42)	0.76 (0.61 - 0.94)	7.84 (0.84)	6.3
45	Ashburton	16.02.94	0.60 (0.50 - 0.72)	1.85 (1.12 - 3.04)	4.75 (0.91)	10.0
46	Leeston	18.04.94	0.37 (0.32 - 0.42)	0.96 (0.69 - 1.33)	5.57 (0.61)	6.2
47	Dorie	20.04.94	0.37 (0.33 - 0.43)	0.74 (0.54 - 1.03)	7.81 (1.20)	6.2
43	Ashburton	16.01.95	0.51 (0.46 - 0.57)	1.12 (0.90 - 1.40)	6.87 (0.62)	8.5
48	Ashburton	07.11.95	0.57 (0.51 - 0.64)	1.22 (0.95 - 1.57)	7.01 (0.98)	9.5
43	Ashburton	07.12.95	0.33 (0.29 - 0.38)	0.82 (0.63 - 1.07)	5.95 (0.93)	5.5
49	Ashburton	09.01.96	0.18 (0.13 - 0.24)	1.32 (0.80 - 2.17)	2.67 (0.25)	2.9
50	Ashburton	09.01.96	0.40 (0.35 - 0.45)	1.60 (1.18 - 2.16)	3.84 (0.25)	6.6
43	Ashburton	22.03.96	0.54 (0.50 - 0.59)	1.73 (1.40 - 2.14)	4.63 (0.44)	9.0
51	Ashburton	06.04.96	0.73 (0.65 - 0.83)	1.65 (1.28 - 2.12)	6.60 (0.91)	12.2
43	Ashburton	21.05.96	0.47 (0.43 - 0.51)	1.18 (0.99 - 1.41)	5.79 (0.48)	7.8
51	Ashburton	16.01.97	0.57 (0.53 - 0.62)	1.51 (1.27 - 1.81)	5.52 (0.69)	9.5
48	Ashburton	04.04.97	0.56 (0.50 - 0.64)	1.69 (1.27 - 2.25)	4.89 (0.74)	9.3
43	Ashburton	29.04.97	0.30 (0.24 - 0.37)	1.85 (1.27 - 2.71)	2.94 (0.26)	5.0
South Canterbury						
52	Hakataramea	09.01.96	0.42 (0.35 - 0.50)	0.69 (0.49 - 0.99)	10.7 (0.88)	7.0
53	Temuka	01.05.96	0.52 (0.47 - 0.58)	1.97 (1.59 - 2.44)	4.04 (0.30)	8.7

South Canterbury cont.						
54	Timaru	27.02.97	0.65 (0.61 - 0.70)	1.75 (1.48 - 2.06)	5.43 (0.38)	10.8
Otago Lakes						
55	Wanaka	13.11.92	0.47 (0.43 - 0.51)	1.18 (0.96 - 1.45)	5.82 (0.64)	7.8
Central Otago						
56	Kurow	10.01.96	0.60 (0.55 - 0.66)	1.41 (1.15 - 1.74)	6.23 (0.62)	10.0
57	Omarama	12.01.96	0.31 (0.27 - 0.35)	1.10 (0.82 - 1.48)	4.21 (0.50)	5.2
58	Cromwell	15.01.96	0.56 (0.52 - 0.61)	2.01 (1.65 - 2.44)	4.19 (0.40)	9.3
59	Cromwell	16.01.96	0.27 (0.24 - 0.30)	1.18 (0.95 - 1.47)	3.62 (0.34)	4.5
60	Alexandra	17.01.96	0.55 (0.50 - 0.60)	1.12 (0.93 - 1.36)	7.45 (0.80)	9.1
61	Omarama	14.02.96	0.38 (0.34 - 0.43)	1.89 (1.47 - 2.44)	3.35 (0.29)	6.3

<sup>1</sup> LC<sub>50</sub> Lethal concentration killing 50% of the test population

<sup>2</sup> Fiducial limits

<sup>3</sup> LC<sub>99</sub> Lethal concentration killing 99% of the test population

<sup>4</sup> Standard Error

<sup>5</sup> Resistance Factor

## RESULTS

A total of 99 samples from 61 localities were tested between November 1991 and April 1997. LC<sub>50</sub>s ranged from 0.18 mg/L to 2.06 mg/L (RFs 3.0 - 34.3, median = 10.5). The highest resistance to diazinon was recorded from farm 28, Blenheim (March 1996); the lowest was from farm 49, Ashburton (January 1996). LC<sub>50</sub>s of *L. sericata* larvae were strongly affected by regional ( $p < 0.005$ ) and year ( $p = 0.03$ ) parameters but unaffected by season. Data were F-tested (for two-sample variance) with either region 1 or year 1991, to determine the extent of influence each factor had in isolation. The means for these are presented in Tables 2 and 3. Table 3 shows a decline in diazinon resistance during 1993/94 followed by a steady increase in resistance between 1995 and 1997.

## DISCUSSION

New Zealand farmers have increasingly experienced a reduction in the protection period that organophosphorus (OP) insecticides provide their sheep against blowfly strike, in comparison with two decades earlier (Wilson and Clark 1996). This reduced protection has been strongly suggestive of some or all blowfly species developing resistance to the OP insecticides. The present study provides evidence to substantiate this view, showing widespread diazinon resistance in field populations of *L. sericata*, in addition to that known for *L. cuprina* (Wilson and Heath 1994). In Australia *L. cuprina* has long been resistant to OPs (Shanahan 1959, 1966, Roxburgh and Shanahan 1973, Hughes and Raftos 1983, Levot 1990), and it is suspected that New

Table 2. Diazinon LC<sub>50</sub>s for *Lucilia sericata* larvae presented by region.

Region	Number of samples	Mean LC <sub>50</sub> (mg/L) (min - max.)	
1	2	0.44 (0.30 - 0.57)	
2	30	0.67 (0.28 - 1.11)	NS
3	12	0.69 (0.36 - 1.25)	NS
4	16	0.99 (0.32 - 2.06)	**
5	39	0.55 (0.18 - 1.06)	NS

Table 3. Diazinon LC<sub>50</sub>s for *Lucilia sericata* larvae presented by year.

Year	Number of samples	Mean LC <sub>50</sub> (mg/L) (min - max.)	
1991	7	0.51 (0.32 - 0.63)	
1992	9	0.84 (0.47 - 1.29)	*
1993	3	0.44 (0.28 - 0.69)	NS
1994	17	0.45 (0.30 - 0.83)	NS
1995	11	0.64 (0.33 - 1.11)	NS
1996	36	0.75 (0.18 - 2.06)	**
1997	16	0.77 (0.30 - 1.31)	*

\* significant at the 95% probability level

\*\* significant at the 99% probability level

NS not significant at the 95% probability level

Zealand's founding population of *L. cuprina* came from Australia (Gleeson 1995). Levels of resistance to diazinon in *L. sericata* larvae have not yet reached those seen in *L. cuprina* in New Zealand (RF = 3 - 34, mean = 11 c.f. RF = 8 - 55, mean = 25 in *L. cuprina*, Wilson 1999) despite *L. sericata* populations having had similar opportunities to come

under OP selection pressure. These differences in phenotypic expression of resistance between the two species may relate to the different biochemical detoxification mechanisms each exploits.

*Lucilia cuprina* uses at least two metabolic detoxification systems for OPs; the specific mutant esterase, E<sub>3</sub> (Hughes and Raftos 1985, 1983) and glutathione S-transferases (Wilson and Clark 1996, Kotze 1993, Kotze and Rose 1987, 1989). There is also a possible contribution from the monooxygenases (Wilson *et al.* 1999, Kotze and Sales 1994, 1995, Kotze *et al.* 1997). On the other hand, there is little evidence to suggest a consistent association with resistance in *L. sericata* of the mechanisms identified in *L. cuprina*, although initial data are suggestive of a role for the E<sub>3</sub> esterase (Wilson 1999). Multi-factorial resistance mechanisms shown in *L. cuprina* may therefore account for a greater phenotypic level of expression of resistance than *L. sericata* can achieve.

The wide range of resistance factor values in both species shows there is potential for further increase, and such variations in samples of field populations are likely to be indicative of the genetic variability inherent in populations (Hughes 1981). The high end of this variation may exemplify the potential for selection for increased resistance in the presence of continuing insecticide pressure (Hughes 1981). It is possible too that the factors of region and year considered in this study (Tables 2 and 3) may reflect differences in insecticide pressure applied to larval populations. Regional and yearly variations may for instance, parallel changes in climatic conditions favourable or unfavourable for flystrike, with concomitant heavier insecticide use when flystrike prevalence justifies this action. However this can only remain speculative, as there are no good comparative data on insecticide usage at the farm level.

The widespread occurrence of OP-resistance in *L. sericata* combined with its high frequency of occurrence in strike samples (Bishop pers. comm.) suggests that *L. sericata* can withstand competition from *L. cuprina* in New Zealand. In Australia, *L. sericata* has been recorded as participating in flystrike but the history and magnitude of its contribution have been obscured by some earlier misidentifications that did not recognize the presence of *L. cuprina* (Tillyard 1933). The first reported

occurrence of *L. cuprina* in Australia was in the 1880s, but it was not until 1915 that flystrike was considered to be a major problem to the sheep industry in the country (Graham 1979). *Lucilia cuprina* and *L. sericata* would therefore appear to have had ample opportunity for inter-specific competition in flystrike lesions on living sheep prior to the widespread use of insecticides in Australia. An explanation for this apparent lack of competitiveness in Australian *L. sericata* populations may be as Norris (1959) suggested, a failure to develop the olfactory response to wool necessary for the initiation of strike on living sheep. However, this olfactory response does not appear to be lacking in European and, presumably, New Zealand *L. sericata* populations, so Norris' (1959) explanation does not seem particularly plausible. In addition, lack of similarity between Australian, New Zealand and United Kingdom sheep breeds with regard to fleece types and density of sheep numbers suggests other factors may be involved. If Norris' (1959) hypothesis is valid, then the enhanced preference by *L. cuprina* for a live host, compared with the lesser preference shown by *L. sericata*, might have increased the likelihood of the former species' exposure to OPs and provided strong selection pressure for the development of OP-resistance in *L. cuprina* in Australia. However, the New Zealand situation does not fit this model, as there is ample evidence of *L. sericata* in flystrike lesions. In fact, the ability of *Lucilia sericata* to compete with *L. cuprina* may be related to a numerical advantage. *Lucilia sericata* breeds more frequently in carrion than does *L. cuprina* (Heath and Appleton 2000) the assumption being that more sources of carrion are more likely to be exploited by *L. sericata* than live sheep are exploited by *L. cuprina*. Certainly, baited trap catches of *L. sericata* exceed those of *L. cuprina* by orders of magnitude (Heath and Appleton 2000). In addition, the carrion resource is likely to be more suitable (numerically greater and less desiccated) in the moist, temperate sheep rearing areas of New Zealand, compared with the more arid Australian sheep rearing areas. The common use of carrion by *L. sericata* would not only maintain its numbers at a higher level in New Zealand, relative to *L. cuprina*, but also provide a refuge from selection pressure by OPs. Interbreeding of the relatively small proportion of OP resistant *L. sericata* and susceptible 'carrion breeders' would help keep resistance at low frequencies.

Despite *L. sericata* exhibiting lower OP-resistance than *L. cuprina* in the field (Wilson and Heath 1994)

it is still a successful member of the flystrike fauna in New Zealand. A shift in such representation of either species is only likely to occur in New Zealand if either is able to gain an advantage by for example, developing resistance to increasingly popular alternative classes of insecticide such as the triazines and benzoyl ureas. In such a situation it is likely that any species which already shows multi-factorial resistance, will have the advantage.

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