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Species composition and dispersal of nuisance flies breeding on egg farms in southern Australia

P. J. James[A,F], *C. Krawec*[B], *N. A. Schellhorn*[C], *P. C. Glatz*[D] *and P. M. Pepper*[E]

[A]Queensland Alliance for Agriculture and Food Innovation (QAAFI), University of Queensland, Joe Baker Street, Dutton Park, Qld 4102, Australia.
[B]Ensystex Australasia, 3/4-6 Junction Street, Auburn, NSW 2144, Australia.
[C]CSIRO Agriculture Flagship, GPO Box 2583, Brisbane, Qld 4001, Australia.
[D]South Australian Research and Development Institute, Davies Building, Roseworthy Campus, Roseworthy, SA 5371, Australia.
[E]Formerly Department of Agriculture, Forestry and Fisheries, Boggo Road, Dutton Park, Qld 4102, Australia.
[F]Corresponding author. Email: p.james1@uq.edu.au

Abstract. The vectorial and dispersal capacities of flies make them a biosecurity and food safety risk on egg farms. The design of optimal control and biosecurity programs requires knowledge of species composition and patterns of abundance of the fly populations present. Although there have been many studies of flies breeding on egg farms in other countries there is little information available in Australia. We monitored numbers and species of flies breeding on cage egg farms in southern Australia and used mass marking with fluorescent resin dye to assess the dispersal of the major species from one of the farms. The main peak in fly numbers occurred in spring and early summer and was comprised predominantly of little house flies (*Fannia canicularis*). Significant numbers of false stable flies (*Muscina stabulans*) were trapped near accumulated manure, but relatively low numbers were present in bird housing areas. House flies (*Musca domestica*) were found in only low numbers or were absent at most times of the year. In the dispersal studies, 85% of marked *F. canicularis* and 67% of marked *M. stabulans* were trapped within 255 m of the layer sheds. The greatest distance from the farm at which marked *F. canicularis* flies were captured was 739 m for traps and 1.25 km for tapes whereas *M. stabulans* flies were trapped at all distances including in the most distant trap nearly 2 km from the farm. Modelling of trap catches by distance predicted maximum dispersal distances of 1.6 km for *F. canicularis* and 2.4 km for *M. stabulans.*

Additional keywords: chicken, *Fannia canicularis*, *Musca domestica*, *Muscina stabulans*, Newcastle disease, poultry.

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Introduction

Flies can breed in large numbers in intensive animal facilities and can carry pathogens responsible for a range of animal and human diseases (Greenberg 1971; Russell *et al*. 2013). These include exotic diseases of concern to the Australian poultry industries such as Newcastle disease (Rogoff *et al*. 1975; Chakrabarti *et al*. 2007) and avian influenza (Nielsen *et al*. 2011; Wanaratana *et al*. 2013). Accumulated manure associated with egg production systems presents a rich resource for fly breeding and a range of species have been shown to exploit this resource (Axtell 1999). The vectorial capacity of flies and their propensity to disperse to other properties make these flies a significant biosecurity and food safety risk for poultry farms (Rogoff *et al*. 1977; Olsen 1998; Chakrabarti *et al*. 2007; Hald *et al*. 2008) and flies breeding in high numbers are unpleasant for workers and can result in complaints from neighbours.

Despite the abundance of literature available from outside of Australia where in most instances the house fly, *Musca domestica* L. is the major species (Axtell 1999), there has been only one previous study of the species of flies which breed on Australian egg farms (Levot and Hughes 1995). Knowledge of which species are present and their pattern of abundance is important for the development of effective integrated control programs as well as for assessing disease transmission risk. In addition, knowledge of fly dispersal patterns can assist in the optimal siting of new facilities to minimise the risk of disease transmission between farms and neighbour annoyance. In this paper we report the species composition and seasonal dynamics of flies breeding on poultry farms in southern Australia. We also assessed dispersal of the two most numerous species, little house flies (*Fannia canicularis*) and false stable flies (*Muscina stabulans*) from one of the farms.

Materials and methods

Study sites

Fly populations were monitored on three commercial egg farms located in the Barossa Valley (34.5°S, 139.0°E) and

southern Mt Lofty Ranges (35.1°S, 138.8°E) in South Australia. These areas have a classic Mediterranean climate with cool wet winters and hot dry summers. The annual rainfalls for Farms 1, 2 and 3 during the year of study were 475 mm, 546 mm and 805 mm, respectively. The mean maximum (minimum) January (mid-summer) temperatures for the closest weather stations were 30.0 (14.5) °C for Farms 1 and 2 and 27.2 (11.8) °C for Farm 3 whereas the corresponding July (mid-winter) temperatures were 13.4 (4.4) °C and 12.9 (4.5) °C, respectively.

Farm 1 consisted of five high-rise sheds each 80 m by 20 m in dimensions, with open sides in the lower part of the manure accumulation area. Birds were housed in three-tiered rows of cages and manure accumulated below the shed floors. Farm 2 had single-storey sheds, with birds housed in three rows of cages stacked two high. Manure accumulated directly below the cages on a cement floor and sides of the sheds could be raised to facilitate ventilation and manure drying. The layer shed on Farm 3 was a completely enclosed 100 m by 14 m high rise facility with birds housed in three-tier rows of cages and manure accumulated in a manure pit below the shed floor. Ventilation and cooling on Farm 3 was by forced air circulation using 14 high throughput thermostatically controlled fans, four in the manure pit and 10 in bird housing areas. Evaporative cooling pads were positioned on the north side of the house opposite the fans on the upper level.

Fly numbers and species composition

On Farm 1 monitoring was carried out in three sheds (1, 3 and 5) where Sheds 1 and 5 were at each end of the shed row and Shed 3 was in the centre. At 2-week intervals 10 sticky tapes 700 mm long and 40 mm wide (Aeroxon, Fr. Kaiser Gmbh., Wiblingen, Germany) were hung from wire hooks attached to support beams at 2 m height in the bird housing area along each side and at each end of each shed. Tapes were placed in position at 1000 hours each day and removed 24 h later. In Sheds 1 and 5 monitoring was conducted for 12 months beginning in December. In Shed 3 monitoring commenced in late January, following complete manure cleanout and introduction of point of lay pullets, and finished in mid-December. On removal the tapes were carefully wrapped in a single layer of transparent commercial clingwrap (Glad®Wrap, Glad Products, Sydney, NSW, Australia) so that the flies were clearly visible. Tapes were returned to the laboratory and the number of flies on each tape counted. Flies were identified as *F. canicularis*, *M. stabulans*, *M. domestica* or classified as 'other' and the number of each group recorded. 'Other' included flies from several families, and as they represented less than 0.2% of tape catches and less than 3% of black light trap catches, they were generally not identified to species and are not reported here.

On Farms 2 and 3, monitoring was conducted by similar methods as for Farm 1 except that, following studies showing high correlations in densities of flies estimated within sheds using six or 10 tapes ($r > 0.99$ in all instances, data not shown), six tapes were used per shed, with one tape at each end and two along each side of each shed. Two sheds were monitored on Farm 2 and monitoring commenced at the beginning of March and finished in mid-December on both farms.

On Farm 1, flies were also collected from Nelson black light electrocuter traps with two 20-W fluorescent tubes for attraction (Nelson Superior Products, Beaverton, OR, USA) positioned at the southern end of the manure accumulation area, ~1.3 m above the floor in each shed. Collection trays were cleared at the start of each collection period and samples were collected over the same 24-h intervals as for the tapes. At the end of the collection period the samples were removed from the traps, stored in Ziploc bags and returned to the laboratory where they were weighed and the number of each species counted. For samples larger than 2 g, a sub-sample of 1.5 g was examined and the total number of flies of each species estimated from the total sample weight.

Dispersal

Dispersal of flies from the sheds was assessed on Farm 1 using the fluorescent dye marking method of Schellhorn *et al*. (2004). Two operators with hand-held back pack sprayers walked through the lower storey of each shed and sprayed SARDI Fluorescent Pigment (South Australian Research and Development Institute, Adelaide, SA, Australia) over the manure and onto fly resting sites. Spraying was carried out in all five layer sheds on the farm between 1000 hours and 1145 hours on two consecutive days.

Flies were recovered using sticky tapes (Aeroxon) and commercial baited traps (Swagman, Farmer Johns, Nuriootpa, SA, Australia). The Swagman traps were 22 cm in height with a 12-cm orange plastic dome at the top and clear plastic sides. Flies attracted to the odour entered through a funnel at the top. The traps were baited with the commercial attractant mix according to label directions, except that port wine was used instead of water to moisten the bait. Port wine was used as Hwang *et al*. (1978) showed that addition of alcohol to baits increased attraction of *F. canicularis* and local anecdotes suggested that addition of the wine increased the attractiveness of fly baits. Preliminary tests confirmed this bait to be attractive to the three main species found breeding on the monitored farms. The bait in each trap was placed beneath a wire mesh insert so that flies did not directly contact the bait and could be readily removed after collection. Traps and tapes were attached to wire supports 45 cm long and secured to garden stakes at 1-m height and extending 15 cm horizontally from the stake on one side and 30 cm from the stake on the other side. The traps were attached on the 15-cm side and the tapes secured from the 30-cm side, attached back to the stake in a triangular configuration to prevent movement in the wind. A trapping grid was established around the farm at 24 sites in north, south, east and west directions up to 2 km from the farm. The inner 16 sites were at ~15 m, 115 m, 215 m and 400 m from the outside of the sheds whereas the remaining trapping stations were at distances determined by topographical features, land use and constructions. Two trapping stations were also placed in the manure accumulation area of each shed after the completion of spraying.

Trapping was carried out in four separate periods 1, 3, 7 and 11 days after the second spraying. At the end of each period traps were placed into Ziploc bags, returned to the laboratory

and held at −25°C until all flies were dead. The traps were then removed, flies emptied from the traps into the bags and stored at −25°C until assessed. Tapes were wrapped in clingwrap as previously described and also stored frozen until needed. Fresh baits and tapes were used for each collection.

Flies collected on tapes or in traps were identified as *F. canicularis*, *M. stabulans*, *M. domestica* or 'others' and examined for fluorescent marks under black light illumination with a binocular microscope at ×40 magnification. Flies with specks of dye were categorised as 'marked' where a definite pattern of spray marks was apparent, or 'contaminated' where flecks of resin, which could have resulted from contact with other marked flies in the trap, were seen (Schellhorn *et al*. 2004).

Analyses

Differences in mean fly populations between sheds (Table 1) were analysed for those sampling periods when data were available for all sheds on all farms. Analysis was conducted using a generalised linear model with sampling station as the experimental unit and assuming a gamma distribution with a log link function. Numbers of the main fly species caught by the two sampling methods, electrocutor traps and tapes, on Farm 1 were compared using repeated-measures ANOVA with shed initially included in the model. Shed and its interactions with species and trapping method were not significant ($P > 0.05$) so the interactions were removed from the final analysis.

Table 1. Mean number of flies (±s.e.) per sticky tape day and species composition of flies caught by tapes in different sheds and over the period of the study

Means within columns followed by different letters are significantly different ($P < 0.05$)

	Total flies	*F. canicularis*	*M. stabulans*	*M. domestica*
		Farm 1		
Shed 1	22.0 (5.0)a	19.7 (4.7)a	0.6 (0.1)a	1.7 (0.6)a
Shed 5	37.6 (8.6)ac	34.1 (8.1)ac	0.8 (0.2)ac	2.7 (0.9)a
Shed 3	24.7 (7.3)ac	19.6 (6.0)ac	0.9 (0.2)ac	4.2 (1.9)a
		Farm 2[B]		
Shed 1	236.1 (69.1)b	230.5 (70.6)b	1.5 (0.4)bc	4.1 (1.9)a
Shed 2	268.3 (78.4)b	256.6 (78.6)b	2.7 (0.7)b	9.1 (4.1)a
		Farm 3		
Shed 1	56.1 (16.6)c	51.3 (15.7)c	2.4 (0.6)b	2.3 (1.0)a

[B]Single-storey sheds.

Numbers of flies caught inside the sheds and at the nearest trapping stations outside of the sheds on Farm 1 during the first sampling period of the dispersal study (Table 2) were compared using *t*-tests with separate estimates of variances when the variances were significantly different ($P < 0.05$). The effects of direction and distance on total (marked and unmarked) numbers of *F. canicularis* and *M. stabulans* were examined by two-way ANOVA with sampling station as the experimental unit and direction and distance as main effects. Initially the interaction term was included, but it was not significant ($P > 0.05$) and was omitted from the final models. As there was no effect of direction ($P > 0.05$) for either *F. canicularis* or *M. stabulans*, the data for different directions were combined and six models previously suggested to describe the decline in density of insects from a centre of dispersal (Taylor 1978; Southwood 1978) were tested for goodness of fit.

The models tested were:

(1) $n = \exp(a + b\ \text{distance}^d)$;
(2) $n = \exp(a + c/\text{distance})$;
(3) $n = \exp(a + b \log(\text{distance}))$;
(4) $n = \exp(a + b \sqrt{(\text{distance})})$;
(5) $n = \exp(a + b\ (\text{distance}))$; and
(6) $n = \exp(a + b\ (\text{distance})^2)$

where n = number of flies trapped and a, b, c, and d are fitted constants.

All analyses were conducted using GENSTAT version 11 (Payne *et al*. 2007).

Results

Seasonal patterns of fly numbers and species abundance

The seasonal patterns of abundance and species mix of flies on the three farms through the year are shown in Figs 1, 2 and 3. As patterns of abundance and species mix were similar in Sheds 1 and 5 on Farm 1 and in Sheds 1 and 2 on Farm 2, combined results are presented for each pair of sheds. Results for Shed 3 on Farm 1 (Fig. 1) are presented separately as this shed was subject to a different management regime than Sheds 1 and 5 with manure cleaned out and the sheds restocked in January. The most notable feature in all sheds monitored on all three farms was the overwhelming predominance of *F. canicularis*. Mean fly numbers were significantly higher ($P < 0.05$) in sheds on Farm 2 than on the other two farms and higher on Farm 3 than Shed 1 on Farm 1 (Table 1).

Table 2. Mean numbers (±s.e.) and percent marked of *F. canicularis* and *M. stabulans* flies trapped in baited traps and on sticky tapes inside the sheds and on the closest traps outside of the sheds

Location	*F. canicularis*				*M. stabulans*			
	Traps		Tapes		Traps		Tapes	
	No. per trap	% marked[A]	No. per tape	% marked	No. per trap	% marked	No. per tape	% marked
Inside sheds[B]	76.1 (36.5)	19.9	309.4 (45.0)	8.3	5.4 (2.3)	14.7	11.5 (3.4)	12.2
Outside sheds[C]	289.0 (116.2)	22.9	313.3 (71.0)	7.9	241.5 (70.9)	16.5	40.0 (9.0)	7.3

[A]Calculated from total trap catches inside or outside of the sheds.
[B]Numbers are means for 10 traps, two inside each of five sheds.
[C]Numbers are means for four traps located north, south, east and west of the farm, 15 m from the nearest shed.

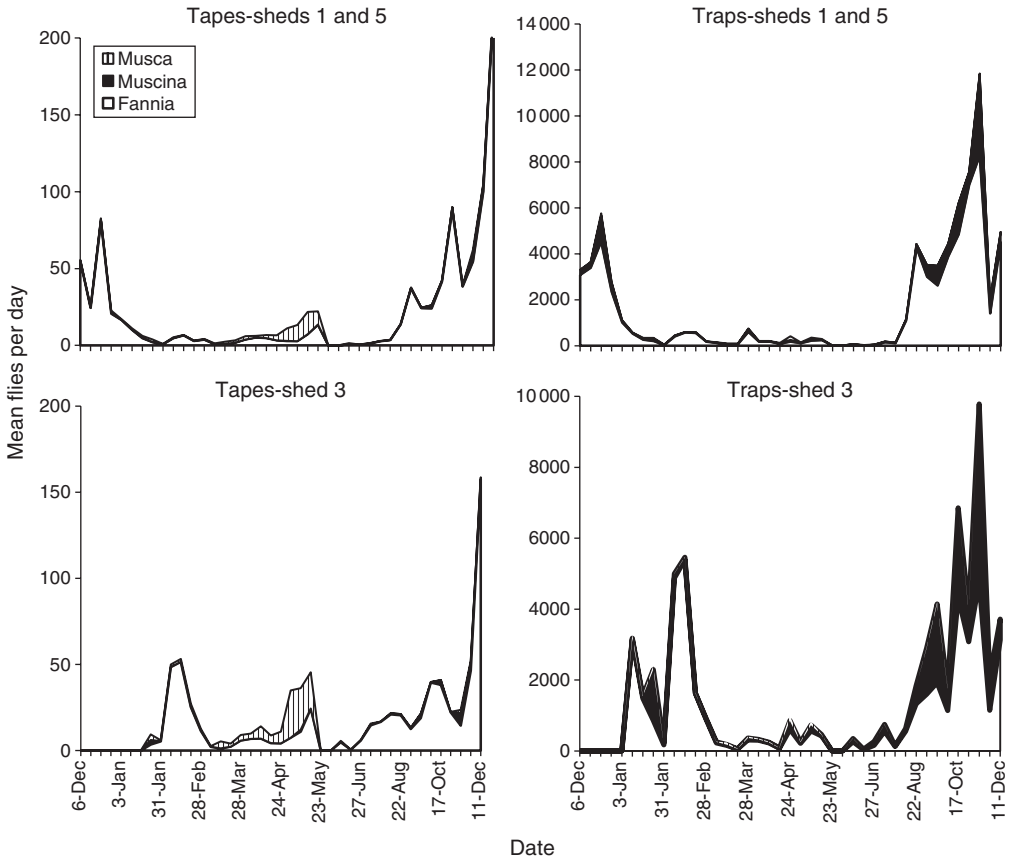

Fig. 1. Mean numbers of *F. canicularis*, *M. stabulans* and *M. domestica* flies trapped per sticky tape day (left side graphs) and in electrocutor traps (right side graphs) in Sheds 1 and 5 (top), and Shed 3 (bottom) on different dates on Farm 1. Note that Shed 3 was depopulated, had the manure cleaned out and was restocked with new hens during January. (Scales on the *y*-axis on some graphs have been truncated to give clearer illustration of species mix.)

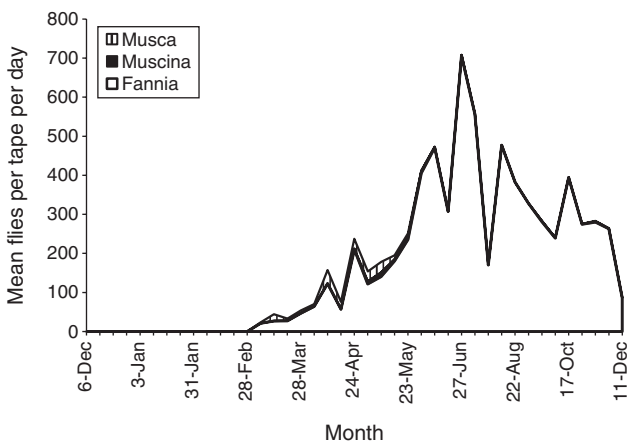

Fig. 2. Mean numbers of *F. canicularis*, *M. stabulans* and *M. domestica* flies per sticky tape day on different dates in two sheds on Farm 2.

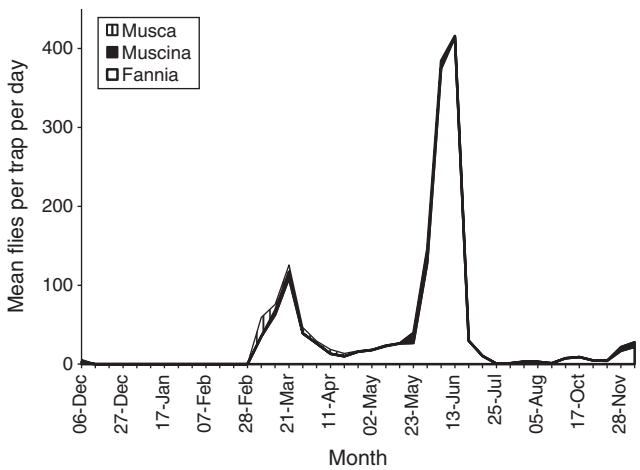

Fig. 3. Mean numbers of *F. canicularis*, *M. stabulans* and *M. domestica* flies per sticky tape day on Farm 3.

On Farm 1 the main period of high fly abundance was during spring and early summer although a smaller peak was apparent in tape catches during autumn. In Shed 3 the pattern was slightly different to Sheds 1 and 5 and a small peak in fly numbers was also observed in February following bird depopulation, cleanout and restocking of the shed. *Fannia canicularis* was present throughout the year whereas *M. stabulans* was apparent mainly during spring and summer.

The main period of house fly abundance on Farm 1 was in autumn when average catches of house flies rose to 14.0 (±2.0), 14.9 (±7.9), and 27.5 (±15.1), per tape in Sheds 1, 5 and 3, respectively.

Mean numbers (±s.e.) of *F. canicularis*, *M. stabulans* and *M. domestica* caught per day on tapes on Farm 1 over the period of the study were 21.8 (3.6), 0.7 (0.1) and 2.5 (0.7) respectively whereas the corresponding numbers caught in blacklight traps were 1464.3 (198.5), 353.5 (83.6) and 21.3 (3.6). Numbers of *F. canicularis* trapped by both methods were significantly higher than for the other two species ($P < 0.05$). However, whereas the numbers of *M. domestica* and *M. stabulans* caught on tapes were not significantly different ($P > 0.05$), numbers of *M. stabulans* caught with electrocutor traps in different sheds were 9–32 times higher than *M. domestica* ($P < 0.05$). These results and general observation suggested that *M. stabulans* comprised a greater proportion of the total fly population breeding in manure than indicated by the tape catches.

On Farm 2 the pattern in fly abundance was slightly different to Farm 1 with fly numbers increasing in autumn, then continuing at relatively high levels through winter and spring. The major species present was *F. canicularis* with *M. stabulans* also trapped in low numbers at most times of the year. Monitoring on this property did not begin until early March and house flies were present from this time throughout autumn, reaching peak mean counts (±s.e.) of 46.2 (±2.2) and 22.8 (±6.4) per tape in the two monitored sheds in early April. Few house flies were seen at other times of the year.

On Farm 3 overall mean counts (Table 1) were strongly influenced by two periods, the first in early autumn and the second in May and June. During the May–June peak daily catches rose above 400 flies per tape, almost eight times higher than the average over the period of the study. *F. canicularis* was overwhelmingly the principal species caught at all times of the year. House flies reached highest numbers (8.5 ± 3.6 flies per tape) during autumn, but none were caught between 13 June and 14 November. Low numbers had again begun to appear at the two final samplings in late November and early December. *M. stabulans* were trapped in low numbers throughout the year.

Fly dispersal

Fannia canicularis and *M. stabulans* were also the major fly species caught on tapes and in traps in the dispersal study. *M. domestica* flies were seldom seen and over the period of the experiment more blowflies (predominantly *Calliphora* spp.) than house flies were caught. Whereas for *F. canicularis* more flies were caught on tapes than in traps (14 783 for tapes compared with 12 019 for traps) for *M. stabulans* the numbers of flies caught on tapes was only 10.4% of that caught in traps (1558 for tapes compared with 14 997 for traps), suggesting that the tapes were also not a particularly efficient way of sampling *M. stabulans* in this experiment. For this reason in modelling dispersal we have focussed mainly on the results from traps.

Mean numbers of *F. canicularis* and *M. stabulans* caught on tapes and in baited traps inside the sheds and at the closest trapping stations outside of the sheds, together with the percentages marked, are given in Table 2. Numbers of flies caught inside the sheds were significantly lower than outside in all ($P < 0.05$) instances except for tape catches of *F. canicularis*. Only two *M. domestica* were trapped or caught on sticky tapes in these positions. The relatively high proportion of flies determined as marked in the trap catches of *F. canicularis* compared with the tape catches may indicate some transfer of dye within the traps. The difference was less apparent for *M. stabulans* and this may relate to a lower level of activity of *M. stabulans* within the traps.

Figure 4 shows total numbers of flies caught in traps and on tapes (marked and unmarked) over the period of the study at different distances from the farm. In all of the analyses of both marked and unmarked flies, significant effects of distance were indicated ($P < 0.05$) but there was no significant effect of direction ($P > 0.05$). There was a clear pattern of decreasing density of flies as distance increased. Only eight *F. canicularis* were caught in traps farther than 0.8 km from the farm whereas significant numbers of *M. stabulans* were caught in most traps, including the most distant trap almost 2 km away. The numbers of flies captured on tapes reinforced this pattern with few *F. canicularis* caught at distances of more than 0.8 km. It is notable, however, that over the period of the study 11 *F. canicularis* flies were caught on tapes at the most distant site, nearly 2 km from the layer sheds. None of these flies were marked.

Proportion of marked flies

Eighty-five per cent of *F. canicularis* flies and 67% of *M. stabulans* caught in traps 255 m or closer to the sheds

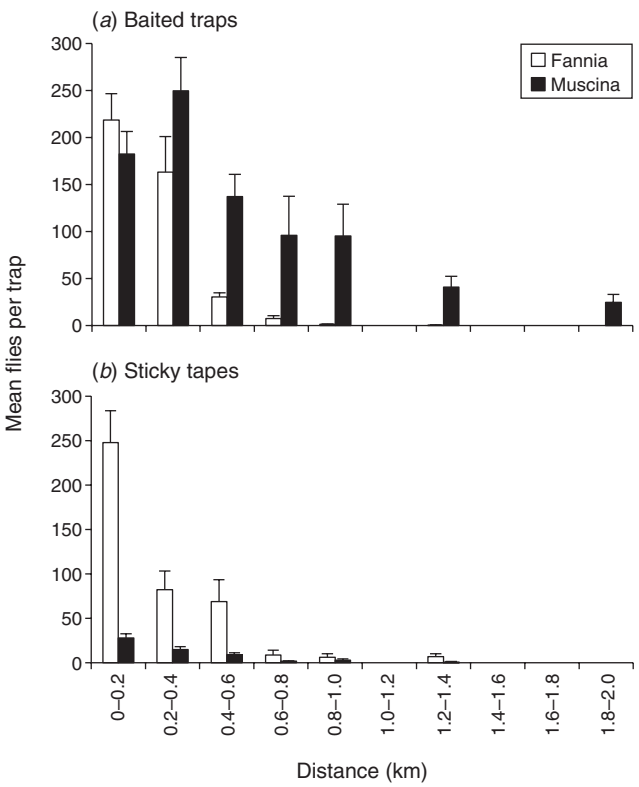

Fig. 4. Total numbers per site (±s.e.) of *F. canicularis* and *M. stabulans* flies caught in (*a*) baited traps and (*b*) sticky tapes at different distances from layer sheds (mean ± s.e.).

were marked. The greatest distance at which marked *F. canicularis* flies were trapped was 739 m (7 flies) whereas for tapes the greatest distance at which a marked *F. canicularis* fly was captured was 1.25 km (1 fly). Marked *M. stabulans* were caught in traps at all distances including in the farthest trap nearly 2 km from the farm.

When the data for percent marked are plotted within date (Fig. 5) a pattern is discernable with a higher proportion of marked flies trapped at sites close to the shed at early collections, but little effect of distance on the proportion marked at later dates. This pattern is consistent with the majority of unmarked flies having originated from the layer farm. The relatively high number of marked flies trapped in the last trapping period suggests that the dye marks persisted well for the period of the experiment.

Modelling fly dispersal

Of the models tested, Eqn 5 fitted the data for *F. canicularis* trap catches best, explaining 53.5% of variation (Fig. 6). Equation 1, the general equation developed by Taylor (1978) and found to provide best overall fit to the eight insect dispersal datasets that he examined described 51.3% of the variation for *F. canicularis* (Fig. 6*a*). For *M. stabulans*, the models did not fit as well with Eqn 6 the best fitting equation explaining 30.3% of variation and Taylor's (1978) general equation explaining 27.1% of variation (Fig. 6*b*).

Maximum dispersal distances were estimated from Eqn 5 as 1.6 km for *F. canicularis* and from Eqn 6 as 2.4 km for *M. stabulans*.

Discussion

By far the major problem species breeding on all three farms was *F. canicularis*. *Musca stabulans* flies were present for most of the winter, spring and autumn periods on all three farms, but in lower numbers than *F. canicularis*. *Musca domestica* was present in significant numbers for only a short period, mainly in autumn. House flies prefer higher manure moisture content for breeding than *F. canicularis* (Stafford and Bay 1987; Mullens *et al*. 2002) and this is likely to be a major reason for the predominance of *F. canicularis* in the fly populations associated with the poultry houses in our study. Larval development of *F. canicularis* is inhibited at temperatures above 30°C (Meyer and Mullens 1988) and at manure moisture content of less than 40% (Mullens *et al*. 2002).

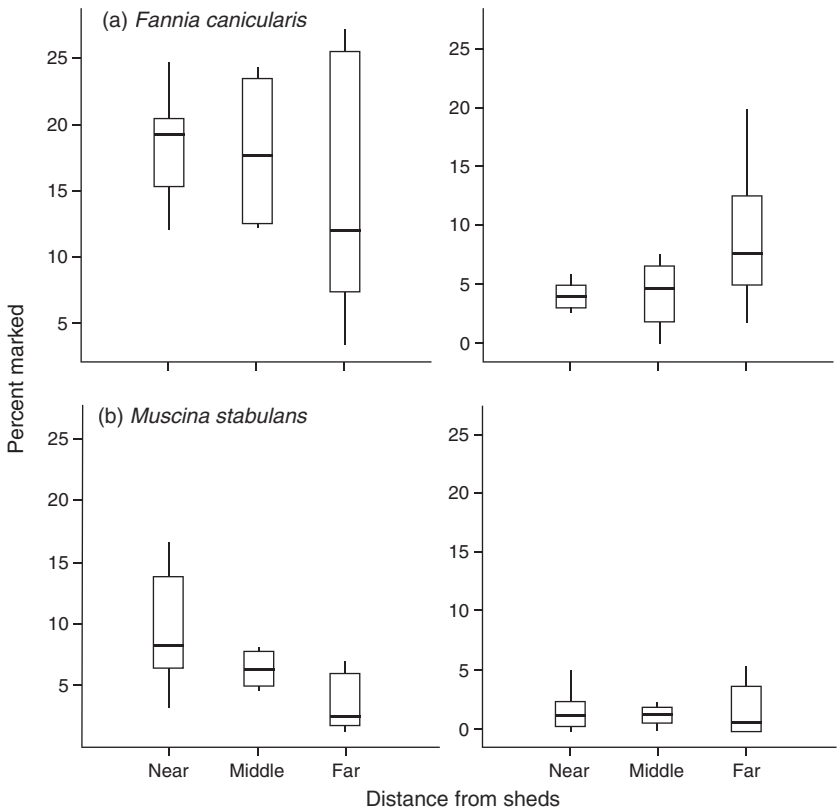

Fig. 5. Box and whisker plots[A] for (*a*) percent marked *F. canicularis* flies and (*b*) *M. stabulans* flies by distance in trap catches from Days 0 to 3 (left side graph) and 7 to 11 (right side graph) after first spraying (near = ≤115 m from the sheds, middle = >115 m to <400 m and far = ≥400 m). [A]Box and whisker plots demonstrate central tendency and spread of values. Middle line is the median, distal frames of box enclose the central 50% of values, 'whiskers' extend to the last value within 1.5x the median and × are probable outliers falling outside the boundaries of the box by more than 1.5x and less than 3x the size of the box.

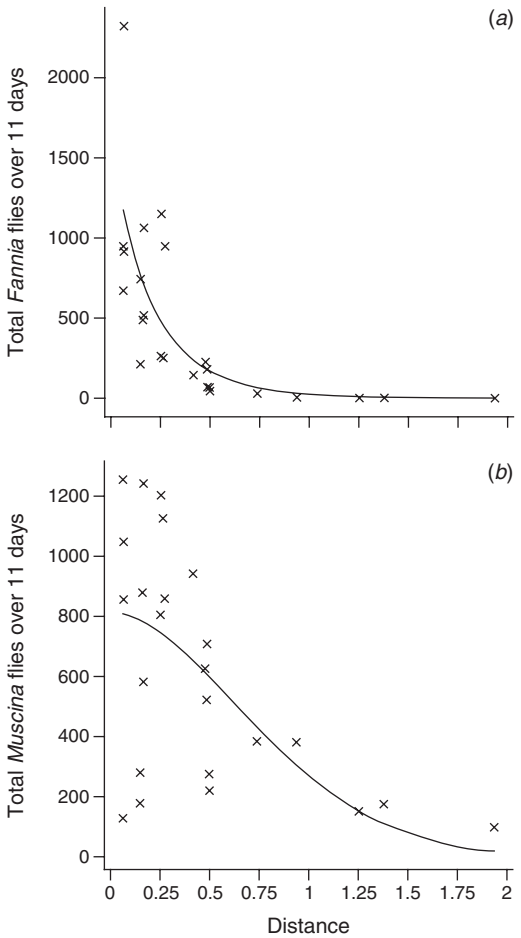

Fig. 6. Models fit for density by distance from farm (km) from which maximum distance of dispersal were calculated (*a*) *F. canicularis*, n = exp(7.3 ± 0.22 – 4.6 ± 1.5(distance)); (*b*) *M. stabulans*, n = exp(6.7 ± 0.12 – 1.2 ± 0.75(distance)^2.

Summers are generally hot and dry through most of southern Australia and high temperatures with rapid manure drying are the likely reasons for the decline in *F. canicularis* numbers observed during this period.

The fly sampling method used clearly affected estimates of the relative numbers of different fly species. Regardless of which trapping method was used, *F. canicularis* was by far the most numerous species. However, numbers of *M. domestica* measured using tapes were in most cases similar to or higher than those for *M. stabulans* whereas electrocutor traps placed in the manure accumulation areas on Farm 1 caught ~18 times more *M. stabulans* than *M. domestica*. This and observations during the dispersal study suggested that the sticky tapes were not very efficient in trapping *M. stabulans*. Differences in efficiency of the two trapping methods may also be related to the differences in the behaviour of the different fly species. Most *M. stabulans* remained close to the manure and tended to disperse laterally from the sheds, rather than moving up into bird housing areas. In comparison, *F. canicularis* and *M. domestica* were commonly found in significant numbers in bird housing areas and rested there at night. *Muscina stabulans* flies do not exhibit the lekking behaviour and territorial flight seen with *F. canicularis* (Zeil 1986) and are much larger than *F. canicularis*, which may also render them less likely to be caught on sticky tapes.

In the only other study of flies breeding in poultry sheds in Australia, conducted in caged layer houses near Sydney, New South Wales, *M. stabulans* and *F. canicularis* were also found to be the two most numerous species (Levot and Hughes 1995). However, in our study *F. canicularis* was the overwhelmingly dominant species, whereas in New South Wales the two species were trapped in approximately equal numbers. The greater relative abundance of *M. stabulans* indicated in the New South Wales study may be due to the wetter and more humid environment of the study location, but could also derive from the method of assessment used. In the New South Wales study bait tray catches were used to assess species composition. Lysyk and Axtell (1986) found that the numbers of *F. canicularis* caught in baited traps were less than 1% those of house flies in one instance and less than 10% in two others whereas for sticky tapes the corresponding proportions were 21%, 75% and 58%. Our observations also suggest that *F. canicularis* are not strongly attracted to standard fly baits and this method may have underestimated the relative importance of *F. canicularis*. In both studies *M. domestica* was not a major species for most of the year and only occurred in significant numbers during late summer and autumn.

Both *M. stabulans* and *F. canicularis* were also reported breeding in poultry litter removed from meat chicken sheds in Western Australia (Cook *et al*. 1999), but house flies and stable flies (*Stomoxys calcitrans*) were more abundant. The litter removed from meat chicken production facilities contained wood shavings, providing a more fibrous substrate than present in layer houses and was regularly watered when used in horticultural production, which favoured house fly and stable fly breeding.

Differences in the numbers of flies and patterns of abundance between the farms in this study were clearly influenced by differences in shed design and management practices. On Farm 1 the manure accumulated on the floor of the lower storey and was cleaned out annually or biennially, usually corresponding with bird depopulation and introduction of a new group of hens, whereas on Farm 2 manure accumulated on the cement floor immediately beneath the cages and was cleaned out multiple times through the year. There was a much more intensive spray regime on Farm 2 than on Farm 1 with at least 18 sprays, including surface and manure sprays, applied between March and December. Frequent manure clean out and regular spraying would almost certainly have reduced fly predator and parasitoid populations on Farm 2 (Wills *et al*. 1990). Reduction of the regulatory effect of natural enemies (Axtell 1999), coupled with possible resistance to treatment products because of frequent spraying (Levot and Hughes 1989; Keiding 1999) probably contributed to the relatively high winter fly populations observed on Farm 2. The increase in fly numbers following clean out and restocking in Shed 3 on Farm 1 in this study, which was not seen in the other sheds, was likely due to more rapid colonisation of new manure by flies than by predators and parasitoids (Peck and Anderson 1970). Higher moisture content in the manure from newly introduced

birds may also have been a contributing factor (Mullens *et al*. 2002).

On Farm 3 the layer house was completely enclosed, with a recessed manure pit and less subject to the effects of external temperatures than on the other two farms. Temperatures in the shed remained favourable for fly breeding throughout the winter and the two main fly peaks observed, in February and in May–June, were both associated with high rainfall events and resultant leakage of water into the manure pit.

Fly dispersal

Although there have been numerous studies of dispersal patterns of house flies (Broce 1993; Jones *et al*. 1999), there is little data available of the likely pattern of dispersal of the two main fly species found associated with egg production facilities in this study. We could not directly compare dispersal of *F. canicularis* or *M. stabulans* with that of *M. domestica* in this study because of the low numbers of house flies present (only one marked *M. domestica* was trapped in the monitoring grid outside of the sheds) but our results and those from one other study in England (Williams 1973) suggest that the dispersal distance of *F. canicularis* is generally less than for *M. domestica*. Eighty-five per cent of marked *F. canicularis* were caught in traps 255 m or closer to the sheds and the maximum distances from the sheds at which marked *F. canicularis* were recaptured were 739 m for traps and 1.25 km for tapes. In the study of Williams (1973) only 3% of ^{32}P-labelled *F. canicularis* released in a poultry house and recaptured over a 12-day period had dispersed to new sites and 9 of 332 recaptured flies (2.7%) were found at the most distant site 150 m from the release point, also suggesting a limited propensity of this species to disperse widely. Although only one marked *F. canicularis* fly was caught on tapes at sites more than 500 m from the farm in our study, 11 unmarked flies were caught on tapes at the most distant trapping site 2 km away. Whether these flies originated from the layer sheds or bred at other locations was not determined. Broce (1993) indicates that sometimes animal enterprises are blamed for producing flies that in fact breed at other sites and although we could not identify any other breeding sites, there were many domestic residences and other agricultural, horticultural and small-scale animal production facilities in close proximity where these flies could potentially have bred. In comparison, overseas studies indicate that although most house flies remain within 1.6 km of their point of origin, they can disperse much farther with distances of more than 20 km recorded over extended time frames (Broce 1993; Jones *et al*. 1999; Winpisinger *et al*. 2005). It is clear that house fly dispersal is strongly influenced by the availability of food and oviposition sites and the same is likely to be so of *F. canicularis* and *M. stabulans*.

Fannia canicularis has been shown to carry a range of pathogens of disease and food safety concern. In particular *F. canicularis* can carry the virus responsible for Newcastle disease and can transmit the disease between birds (Rogoff *et al*. 1977; Chakrabarti *et al*. 2007). Newcastle disease is an exotic disease of considerable concern to the Australian poultry industries and estimates of the likely dispersal patterns of *F. canicularis* will assist the development of biosecurity and eradication plans for Newcastle disease. In addition, *F. canicularis* was a common cause of complaints from householders close to farms in this study. This was largely because of the numerical dominance of *F. canicularis* but also because of its attraction to food and alcohol (Hwang *et al*. 1978) and because of the tendency for males to hover at human head height in shaded areas (Zeil 1986). These behaviours lead to *F. canicularis* aggregating in areas such as on verandas or beneath pergolas and causing considerable disruption to outdoor dining and social activities.

Musca stabulans dispersed farther than *F. canicularis*, with many marked and unmarked flies, caught in the most distant traps nearly 2 km from the sheds. Although *M. stabulans* has been recorded as carrying several pathogens of food safety concern (Olsen 1998) it seldom enters bird or human housing areas in high numbers and is much less frequently the cause of neighbour complaints than other fly species.

Previous studies of fly dispersal from livestock facilities have mostly used mark–release recapture methods (Broce 1993; Jones *et al*. 1999), most commonly using laboratory reared flies, although genetic markers and methods tracking microsatellites have been used more recently (Schurrer *et al*. 2004; Chakrabarti *et al*. 2010). Methods that use laboratory bred flies present the risk that behaviour of the flies is not the same as those that breed naturally *in situ* (Hagler and Jackson 2001) and when dispersal is being measured from as rich a breeding resource as the manure accumulated beneath poultry sheds, there is a risk that numbers of released flies are swamped by sheer size of the resident population. The method used here allowed marking of a relatively high proportion of naturally bred insects (Table 2). Dye marks were still clearly visible on flies trapped 11 days after the second spraying and previous studies with other insects showed no effect of dye marking on dispersal behaviour (Schellhorn *et al*. 2004). We consider that this method provides a robust and relatively simple and cheap method of tracking dispersal of flies from accumulations of manure.

Most recommendations for the control of nuisance flies breeding on poultry farms in Australia are adapted from overseas studies where *M. domestica* is the major problem species. Overseas recommendations may not be directly applicable to Australian circumstances in many instances. For example, many commercial insecticidal fly baits sold for use in Australia are designed primarily for use against *M. domestica* and use z-9-tricosene, a house fly pheromone (Carlson *et al*. 1971) as an attractant. *Fannia canicularis* has different mating pheromones (Uebel *et al*. 1975) and is not strongly attracted to common commercial fly baits (Lysyk and Axtell 1986). Baits designed for use against house flies may be of limited usefulness in Australian layer sheds where other species of flies are the major problem. In addition, monitoring methods and location of monitoring sites will need to be carefully considered in light of the major fly species present and the facility design. Knowledge of dispersal patterns of flies emanating from poultry facilities is important to a consideration of biosecurity planning and the risk of pathogen spread and the results presented here may assist in determining the location of new livestock facilities or urban developments in situations where the little house fly, *F. canicularis*, is the main problem fly species.

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