Management Of Nuisance Fly Populations On Cattle Feedlots

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Final Report prepared for MLA by:

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FEEDLOTS

ABSTRACT

Nuisance flies are recognised as a problem on Australian feedlots despite improved manure management over the past decade. The species, abundance and extent of breeding of nuisance flies and their natural enemies were determined on three feedlots. House flies were identified as the major fly problem and their chemical resistance status determined. Several biological agents, in particular parasitic wasps, played an important role in fly control. An integrated pest management (IPM) strategy for nuisance fly control is provided and further work is proposed, including the use of biological control agents such as wasps and entomopathogenic fungi. Implementation of the IPM strategy and further R&D should provide the industry with effective, sustainable and economic fly control.

EXECUTIVE SUMMARY

The feedlot industry has applied a significant amount of effort to improved manure management practices over the past decade as a means of reducing odour emissions and fly problems. There is, however, evidence that fly populations remain a serious problem. Insecticide resistance and a desire to minimise the use of chemicals also drive the need to move to a more integrated approach to fly control.

A questionnaire survey of Australian feedlots on fly control showed that 83% of feedlot operators considered flies a problem and that working conditions, human health, animal welfare, chemical residues and production losses were rated as the most important adverse impact of flies. The survey indicated that flies are controlled by a range of physical, cultural and chemical means. Almost 60% of the feedlots used some form of chemical fly control. Forty-three percent of respondents used baits, about a quarter used insecticide sprays, and 15% used traps to control flies. The effectiveness of these treatments was considered to be moderate by the majority of the respondents. The data collected in this survey was used to finetune the feedlot fly and parasite monitoring programs, select commonly used chemicals for resistance testing and formulate integrated pest management guidelines for the control of fly populations.

Good control from insecticides relies on knowing what resistance is present in the fly populations and using the remaining effective chemicals in carefully planned programs. Flies from southern Queensland (SQ) showed a moderate level of resistance to diazinon (19 x), a lower level to trichlorfon (3.2 x) and were susceptible to azamethiphos and cyfluthrin. The central New South Wales (CNSW) and central Queensland (CQ) isolates showed moderate levels of resistance to diazinon (7 to 11 x), and appeared susceptible to azamethiphos and cyfluthrin. All feedlot isolates showed a reduced mortality response to Snip Fly Bait and the SQ and CNSW flies also showed a reduced mortality to Dy-Fly bait but not to the same extent as with Snip. The observed reduction in bait efficacy was due to a change in the flies' behaviour. The impact on field efficacy of these baits is uncertain, although some loss of control might be expected.

Populations of adult and immature nuisance flies and their parasites were monitored on three Australian feedlots with one SQ feedlot being continuously monitored over two years. The most commonly trapped adult flies on the SQ feedlot were house flies (*Musca domestica*, 38% of total fly catch) and hairy maggot blowflies (*Chrysomya rufifacies*, 27%). Other common species trapped were the bush fly (*M. vetustissima*, 15%) and the stable fly (*Stomoxys calcitrans*, 1.3%). All fly populations were low during the coldest winter months, house flies had one broad annual population peak extending over nine months, whereas stable flies showed two peaks in late autumn and late spring. House fly and stable fly populations were higher inside than outside the feedlot, whereas bush fly and blowfly catches were generally higher outside the feedlot. There was a strong correlation between the number of adult flies and behavioural responses of cattle irritated by flies. The frequency of tail swishes, ear flicks and head tosses can be used to gauge house fly and bush fly populations, and leg stomps correlated well with the stable fly populations. Systematic counts of the frequency of these movements can provide an estimate of prevailing fly populations.

Of the major fly species trapped on the feedlot, only house flies (86% of feedlot larvae) and stable flies (10%) breed on the feedlot, whereas all others predominantly breed outside the feedlot. The highest numbers of larvae were found where a mixture of manure, vegetation and moisture was present. The hospital/induction area, under the pen fence lines, drains and silage pits all provide such ideal substrates for fly development. Fly breeding is concentrated in relatively small pockets in the feedlot. A strategy for reducing fly breeding in the cattle feedlot would involve a more targeted and more frequent cleaning of these major fly breeding areas.

Manure scraping and removal from cattle pens and fence lines was generally performed on a routine basis at two to three month intervals. The subsequent reduction in adult or immature fly populations was short-lived. The build up of non-compacted manure under the fences occurred rapidly after cleaning, and fly breeding quickly returned to its previous level. Insecticidal treatments were infrequent and generally applied when there was a perceived need rather than on a routine basis. Fly baits, which attract and kill adult house flies only, were also used when deemed necessary. The insecticidal treatments had little if any impact on fly breeding or fly populations on the feedlot.

Biological control agents, including parasitic wasps, predatory mites and entomopathogenic fungi play an important role in lowering feedlot fly populations. Eight species of parasitic wasps, mainly *Spalangia* spp., were found on the SQ feedlot where they killed at least 27% of the developing flies. The parasitic wasps detected on the feedlot are also found in America and Europe, where they are commercially cultured for the control of flies in intensive livestock industries. The presence of these wasps provides Australian feedlot managers with the opportunity to use parasitic wasps for biological control of nuisance flies.

In the SQ feedlot the average level of mite infestation was 3.8% and 3.2% for house and stable flies respectively. The contribution of the various mites in the biocontrol of fly populations associated with livestock has not been generally established. Fungi from a few selected entomopathogenic genera were isolated from feedlot flies and were highly effective in killing house flies, making them potential candidates for the development of a fungal biopesticide for flies.

Integrated pest management (IPM) systems embrace the integration of cultural (mechanical/physical), biological and chemical control methods to reduce pest populations. IPM strategies need to be tailored for particular situations, incorporating all available approaches and reducing insecticide use. The ***RULES*** for an integrated pest management approach for nuisance flies on cattle feedlots, are presented below:

R*educing fly breeding sites*

- Manure management (under fence lines, sedimentation ponds, drains, hospital area, stock piles)
- Spilled feed (feed bunks, hospital area, stables, feed processing area)
- Silage (spills, cover pits completely)
- Carcases (compost, cover completely)
- Feedlot maintenance (troughs, drains, sedimentation ponds, vegetation)

U*sing insecticides selectively*

- Rotate chemical groups
- Targeted insecticide use (hot spots)
- Adulticides (residual rather than knockdown insecticide; spray resting sites not manure)
- Larvicides (use an insect growth regulator (IGR) which do not affect beneficial insects)
- Baits (use for house flies only and rotate between chemical groups)

L*ot feeding design principles*

- Appropriate pen foundation and optimal slope
- Feed and water trough design
- Fence design to allow for easy cleaning
- Construction of drains, sedimentation systems and effluent holding ponds
- Manure stockpile and composting area

E*nhancing populations of biological control agents*

- Biological control agents play an important role in fly control
- Preserve parasite and predator populations through appropriate management
- Augment parasite populations through strategic releases

S*ystematic monitoring of fly populations*

- Scouting (adults and larvae; to determine population thresholds)
- Traps for adults; larval density ratings for immatures
- Animal observations

It is recommended that:

1. Feedlot operators design and implement an integrated pest management (IPM) program for nuisance flies on their feedlot, incorporating the ***RULES*** given above.
2. MLA, DPI&F and ALFA jointly produce guidelines based on these ***RULES*** to assist feedlot operators in the design and implementation of IPM programs for nuisance flies on cattle feedlots.:
3. Further R&D on nuisance flies in cattle feedlots be carried out, to develop and use parasitic wasps and entomopathogenic fungi for biological fly control and to determine how to optimally combine these tools with feedlot design and management to provide effective fly control with minimal use of insecticides.

BACKGROUND

Within the cattle feedlot environment, accumulated manure under fence lines and in drains, spilt feed around feed troughs, manure piles, silage pits and the edges of sedimentation basins and holding ponds provide ideal locations for fly breeding. If manure management is inadequate there is considerable potential for fly breeding. Uncontrolled fly populations may lead to reduced production from flies 'worrying' the cattle as well as complaints from neighbours.

Industry has applied a significant amount of effort to improved manure management practices over the past decade as a means of reducing odour emissions and fly problems. There is, however, recognition that fly populations remain a serious problem at many feedlot sites despite the improved manure management practices. Insecticide resistance and a desire to minimise the use of chemicals also drive the need to move to a more integrated approach to fly control.

Meat and Livestock Australia (MLA) funded a research project investigating fly species and populations and their control measures in Australian beef cattle feedlots. The research was conducted by a team of scientists from the Department of Primary Industries and Fisheries (DPI&F) Queensland in collaboration with a research entomologist from the US Department of Agriculture.

This report contains summaries of all project activities, guidelines for an integrated fly management system and recommendations. A full report on fly and parasite population monitoring on cattle feedlots is provided as an Appendix.

PROJECT OBJECTIVES

The major objective of this research was to develop a set of best practice guidelines for the control of fly populations in cattle feedlots by:

- Identifying and monitoring the species and numbers of nuisance flies at a feedlot for the duration of the project;
- Identifying and monitoring resident parasitic and predatory insects and mites at the feedlot;
- Establishing if there are regional differences in populations of nuisance flies and resident parasitic and predatory insects and mites;
- Identifying the major fly breeding sites within the feedlot;
- Identifying feedlot management practices that either favour or discourage fly breeding;
- Developing alternate methods/approaches to overcome any problems identified with current management practices;
- Assessing the impact of current insecticide use on nuisance fly numbers and parasites and predators;
- Evaluating the resistance status of fly populations to currently used chemicals; and
- Utilising the information gathered to develop recommendations for integrated fly management programs, incorporating management practices, life cycle considerations, the strategic use of chemicals and other novel control practices to prevent fly population build-up.

METHODOLOGY

Survey – Fly control on cattle feedlots

In March 2002, the Fly Control Practices Survey was mailed to 162 feedlot managers throughout Australia. The survey requested managers to answer several questions regarding fly control practices carried out in their feedlots.

In some questions, the respondent was asked to rank various parameters in order of importance. This included fly species, adverse impacts, importance and degree of implementation of various management practices and chemical control methods including cattle treatments and the use of sprays, baits and traps.

The survey participants were requested to mail their completed questionnaires back to the DPI&F Intensive Livestock Systems Unit Office in Toowoomba where the responses were collated and analysed on computer spreadsheets.

The main distribution list for this survey was obtained from the Australian Lot Feeders Association (ALFA) through a representative of MLA. This list included the 115 feedlots with the greatest recorded cattle capacities (from 1000 to 50000 head) from throughout Australia. The survey was sent to an additional 47 Queensland feedlots having recorded capacities down to 500 head. The contact details for the additional Queensland feedlots were obtained from DPI&F records.

Resistance to insecticides in flies from cattle feedlots

Flies: House flies (*Musca domestica*) were collected from three feedlots in major feedlot production areas: southern Queensland (SQ), central Queensland (CQ) and central New South Wales (CNSW). Reference strains were obtained from Novartis Pty Ltd, Sydney (REFN) and the Centre for Entomological Research and Insecticide Technology (CERIT) at the University of NSW (REFC).

Topical insecticide application: 1 µl of serial dilutions of active constituents (technical grade) in butanone were applied to the thorax of female flies (20 per batch, duplicate batches). The number of dead flies after 24h at 27^{O}C/60-70% RH was determined for each batch and the LD50 calculated using a PROBIT program. The values are reported as µg active constituent per mg fly.

Cage (bait) assays: 50 female flies were exposed to either sugar and bait (choice) or bait alone (no choice) in a fly cage (450x300x300mm) for 48 hours (water was present in all cages, duplicate cages used unless otherwise indicated). The bait (0.5g) was presented either on a wet filter paper in an open Petri dish or painted onto cardboard (hang-up). The number of dead flies was determined at 1, 2, 4, 6, 24 and 48h. Percent mortality at 48 h was used as the indicator for resistance.

Fly and parasite population monitoring on cattle feedlots

The monitoring program was designed to detect variations in fly and parasite populations over time (seasonal and shorter term) and locations (different feedlot sites, sites outside the feedlot) and to determine the effects of feedlot management practices on these populations. To assist with this task, weather information (temperature, rainfall) and the timing of management practices (cattle pen and sediment pond cleaning, insecticide application) were recorded.

The fly and parasite population monitoring was carried out continuously from October 2001 to October 2003 in one feedlot in southern Queensland. Collections and observations were made at fortnightly intervals (weekly fly population monitoring until May 2002). One-off fly and parasite population monitoring was carried out on two additional feedlots located in different climatic regions, in central NSW and central Queensland.

The sampling systems for adult flies were traps with visual and/or odour attractants. As trapping systems are often species or family specific, a variety of trapping systems was used to obtain good samples of the target flies. These systems included Terminator traps (house flies, bush flies), Lucitrap (blowflies), Alsynite traps (stable flies) and sticky sheets (all flies). Traps were placed throughout the feedlot and at locations one to two kilometres outside the feedlot to obtain an estimate of background fly populations. The impact of adult flies on feedlot cattle was also assessed through quantitative observations of cattle behaviour, such as tail swishes, head tosses, ear flicks and leg stomps.

Flies in their immature stages were collected by core sampling manure, feed and soil from sites considered potentially suitable for fly breeding. At each site five samples were collected to assess differences within the sites, e.g. in cattle pens around feed bunks, the centre of the pen and under the fence. Larvae and pupae were subsequently extracted from the samples by the use of appropriate flotation techniques and identified in the laboratory.

Parasitic wasps were obtained from sentinel fly pupae exposed in the feedlot environment for one monitoring period, and from pupae collected in the feedlot. Mites were collected from adult flies caught on sticky traps and with a sweep net and placed in 70% alcohol. Fungi were isolated from live and dead feedlot flies within a few days of collection.

RESULTS AND DISCUSSION

Survey – Fly control on cattle feedlots

Survey findings

The major findings of the survey, which was sent to 162 operators of feedlots and 46 (28%) of these responded, are summarised below:

- There appeared to be no bias in the returned sample, either geographically or in terms of feedlot size.
- Only 17% of respondents recorded that flies were not considered a problem at their feedlot.
- Bush/house flies and stable flies were identified as the main species of concern.
- The warmer months from November to February were the worst months for flies.
- Working conditions, human health, animal welfare, chemical residues and production losses were rated as the most important adverse impact of flies, while impact on neighbours was rated as the least important of the listed impacts.
- Management practices considered most important for fly control and most commonly implemented included those which related to pen design, cleanliness and drainage.
- Management practices considered the least important and least commonly implemented included use of sprays and traps, removal of spilt feed and incorporation of manure into soil following spreading.
- 78% of respondents used some form of chemical treatment on cattle at induction to the feedlot.
- Chemical treatments used at induction included moxidectin, zeta-cypermethrin, ivermectin, deltamethrin (±ethion), triclabendazole, fenthion, doramectin, albendazole, fenbendazole, diflubenzuron, amitraz, cypermethrin, and oxfendazole.
- 58% of respondents used some form of chemical fly control in the feedlot.
- 43%, 24%, and 15% of respondents used baits, sprays and traps respectively to control feedlot flies.
- Active ingredients used in fly spray treatments included cyfluthrin, azamethiphos, bendiocarb, cyromazine, diazinon, fenthion, permethrin, pirimiphos-methyl, pyrethrins plus piperonyl butoxide and trichlorfon.
- Alfacon (azamethiphos) and Solfac (cyfluthrin) were the most commonly used spray products.
- The areas around the feedlot where sprays were most commonly applied included horse stables, feed storage and processing areas, manure stockpile areas, drains and feed bunks/bins.
- The most commonly used method of spray application was the ground based spray rig.
- Dy-Fly Plus (methomyl + Z-9-tricosene) and Snip (azamethiphos + Z-9-tricosene) were reported to be the most commonly used bait products.
- Baits were mainly used around feed storage and processing areas and feed bunks/bins.
- Fly traps were only used by 7 respondents (15%) with home made traps the most common type.

- Fly traps were most commonly used around feed storage and processing areas, stables and pens.

Survey conclusions

This fly control survey has addressed project objectives by drawing on the collective wisdom and experience of Australian feedlot operators to gather valuable insights into fly control issues and to quantify and document existing management practices and their perceived effectiveness. Useful data collected by the survey included qualitative information regarding:

- The seriousness of fly problems in feedlots.
- The prevalence of different fly species.
- The timing and nature of the adverse impacts of nuisance flies.
- Management practices used to control flies.
- The popularity of various cultural and physical/chemical fly control practices.
- The types of insecticides, baits and traps used in feedlots and their areas of application.

The data collected in this survey was used for:

- Finetuning the feedlot fly and parasite monitoring program.
- Selecting commonly used chemicals for resistance testing.
- Formulating and documenting integrated pest management guidelines for the control of fly populations in cattle feedlots.

This questionnaire survey resulted in important information being gathered on fly management practices used at forty-six typical Australian beef cattle feedlots. The study has indicated that flies at Australian feedlots are controlled by a range of physical, cultural and chemical means. Most of the currently recognised management practices listed in the survey were considered by the respondents to be important and have been widely implemented in their feedlots.

The study found that cultural (non-chemical) practices were regularly used for fly control, including regular pen cleaning, pothole maintenance, cleaning under fence lines and feed areas, removing spilt feed and slashing grassed areas. Practices related to pen cleaning and provision of good drainage characteristics rated highly, with greater than 70% of participants reporting that they were either important or very important.

According to several of the optional written comments offered by survey participants, timeliness and thoroughness of pen cleaning/drainage activities were particularly important factors. One respondent noted that trampling of fly larvae by cattle in feedlot pens minimises larval development. However, a small amount of manure left in an empty pen can cause a significant fly problem.

Almost 60% of the feedlots used some form of chemical fly control. Forty-three percent of respondents used baits, about a quarter used insecticide sprays and 15% used traps to control flies. The most common areas where sprays were applied were horse stables, feed storage/ processing areas, manure stock piles, drains and feed bunks/bins, and feed storage/ processing areas and feed bunks/bins for baits.

A wide variety of knockdown, residual and larvicidal chemicals from different classes such as organophosphates, synthetic pyrethroids and insect growth regulators were applied. The effectiveness of these treatments was considered to be moderate by the majority of the respondents. Knowledge of the flies' resistance status towards different classes of insecticides would be of great value in optimising the use of chemical control. This was provided by other work being undertaken in this project.

The information collected in this survey was pivotal in the development of appropriate Integrated Pest Management guidelines for Australian beef cattle feedlots.

Resistance to insecticides in flies from cattle feedlots

Control of the house fly (*M. domestica)* in intensive livestock industries has historically relied on the use of insecticides. Resistance to many insecticidal groups has substantially reduced their effectiveness. Overseas, resistance has been reported to almost all fly control chemicals. Good control from insecticides relies on knowing what level of resistance is present and using the remaining effective chemicals in carefully planned programs.

To establish the resistance status of house flies from feedlots, two bioassays were used: topical application (direct application of contact insecticides to flies) and a cage assay (insecticides formulated as baits).

Topical insecticide application

Because there was no susceptible reference strain of *M. domestica* available in Australia, published data for the World Health Organisation (WHO) susceptible reference strain and other susceptible strains was used as reference values to calculate resistance factors from topical assays.

Both the CERIT (REFC) and Novartis (REFN) reference strains showed moderate levels of resistance to diazinon (25 to 39 fold) and lower levels of resistance to trichlorfon (5.3 to 5.9 x) compared to the WHO susceptible strains. There was no apparent resistance in the Novartis reference strain to azamethiphos or cyfluthrin.

The SQ isolate of *M. domestica* showed a moderate level of resistance to diazinon (19 x), a lower level to trichlorfon (3.2 x) and it was susceptible to azamethiphos and cyfluthrin. The CNSW and CQ isolates showed moderate levels of resistance to diazinon (7 to 11 x), but they were somewhat lower than the SQ isolate. The CNSW and CQ isolates appeared susceptible to azamethiphos and cyfluthrin. No assays have been conducted with trichlorfon for these isolates.

Cage assay

Flies of the Novartis reference strain *M. domestica* are knocked down completely by Dy-Fly and to over 90% by Snip within 48 hours in choice and no-choice assays. All feedlot isolates showed a reduced knockdown response in choice and no-choice tests to Snip. Whereas SQ and CNSW also showed a reduced knockdown to Dy-Fly in the choice test, no reduction was apparent in the no-choice test. No reduction was apparent in either test to Dy-Fly for the CQ isolate.

The reduced effectiveness of the Snip fly bait is unlikely to be due to the diminished toxicity of azamethiphos. The resistance factors obtained in the topical application assay were similar for the reference and the feedlot strains. The observed reduction in bait activity must therefore be due to reduced feeding on the bait, a behavioural change of feedlot flies, possibly induced by recurrent exposure to baits.

The results indicate changed responses of feedlot flies to Snip and to a lesser degree Dy-Fly. The impact on field efficacy is uncertain, although some loss of control might be expected.

Fly and parasite population monitoring on cattle feedlots

A comprehensive program to monitor fly and parasite populations at a southern Queensland (SQ) feedlot was designed and implemented. The population monitoring program targeted adult flies and their immature stages (larvae and pupae) and biological organisms that adversely affect both adult and immature fly stages. The natural enemies included parasitic wasps (lay their eggs inside fly pupae and devour the immature fly), predatory mites (feed on fly eggs and larvae and attach to adult flies) and entomopathogenic fungi (spores germinate on the fly cuticle and the growing fungi penetrate the cuticle to access food resources). A snapshot of fly and parasite populations was also obtained on two additional feedlots located in different climatic regions, namely in central NSW (CNSW) and central Queensland

(CQ).

The sampling systems for adult flies were traps containing odour attractants and sticky traps. The major trapping systems were the Terminator trap (house flies, bush flies), Lucitrap (blowflies, house flies, bush flies) and the Alsynite trap (stable flies, house flies). The impact of adult flies on feedlot cattle was assessed through quantitative observations of cattle behaviour, such as tail swishes, ear flicks, head tosses and leg stomps.

Flies in their immature stages were collected by core sampling manure, feed and soil in strategic places. An abundance rating for larvae and pupae at these sites was recorded. Larvae and pupae were subsequently extracted from the samples by the use of appropriate flotation techniques.

Parasitic wasps were obtained from sentinel fly pupae exposed in the feedlot and from collected feedlot pupae after an appropriate development period. Mites and fungi were isolated from adult and immature flies collected on the feedlot.

The results presented in this report cover the fly and parasite population monitoring activities from November 2001 to October 2003.

Adult fly populations

Over 1.6 million flies were caught on the SQ feedlot over the two-year period and just less than half of these were blowflies. The most commonly trapped species were house flies (*Musca domestica*, 38% of total fly catch) and hairy maggot blowflies (*Chrysomya rufifacies*, 27%). Other common species trapped were the bush fly (*M. vetustissima*, 15%), stable fly (*Stomoxys calcitrans*, 1.3%), the small hairy maggot blowfly (*C. varipes*) and the bluebodied blowfly (*Calliphora augur*).

Seasonal effects on fly catches

There was clear evidence that feedlot fly populations are influenced by seasonal changes (Figure 1). Air temperature was the main driver of major fly population increases and reductions. Rainfall also affected the populations of some fly species, although to a lesser extent than temperature. There was no prolonged extreme dry or wet period during the monitoring phase, thus the effect of such an event on fly populations was not established. The most common fly species on the feedlot, the house fly, had one broad annual population peak extending over most of the year with the exception of the coolest winter months (Figure 1). Minor maxima and minima in house fly populations appeared to be caused by better than average rainfall and drier, hotter periods respectively. Bush fly population peaks occurred in spring (major peak) and late autumn and were short lived, lasting for only a few weeks. The stable fly has two annual population peaks in the feedlot, the major peak in late autumn and the minor peak in late spring/early summer. Stable fly populations decline during the middle of the summer and in late winter, but the population reduction in winter occurs later than for the house and bush flies. *Chrysomya* spp. provide the bulk of the feedlot blowflies and they show a similar population profile to stable flies. The bluebodied blowfly has population maxima in winter and is practically absent from the feedlot during the summer.

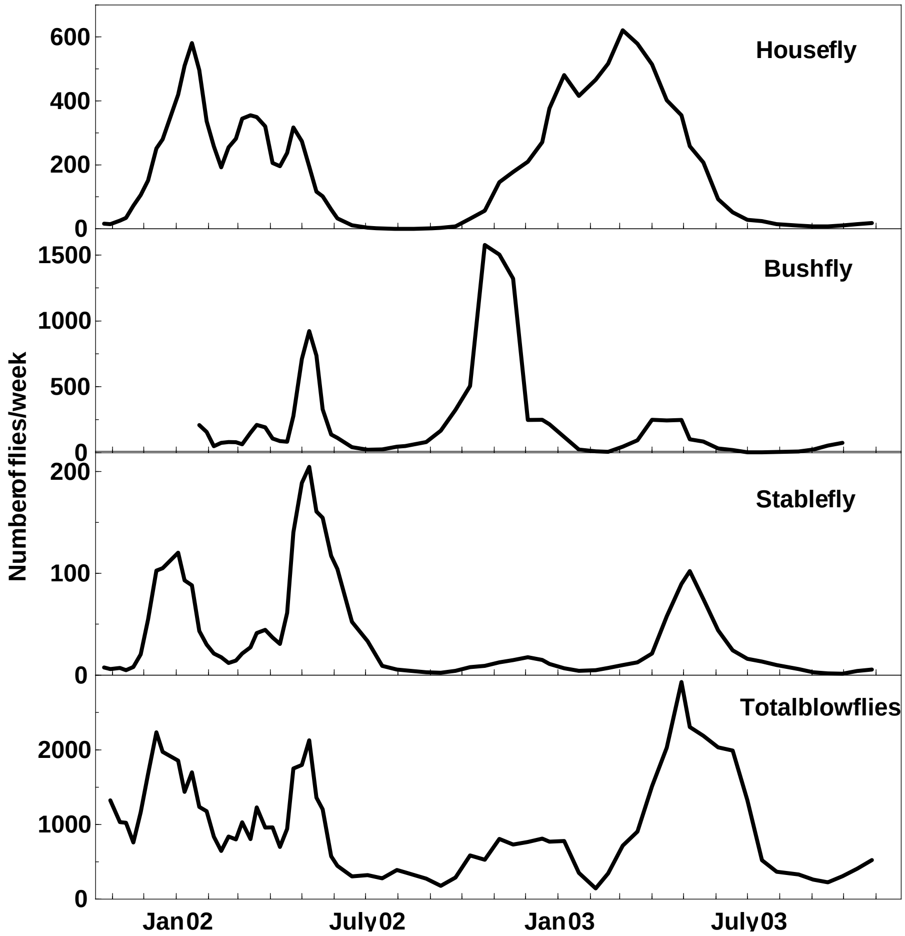

Figure 1 Average weekly trap catches for house flies, bush flies, stable flies and total blowflies from November 2001 to October 2003.

Comparison of feedlot sites

Fly traps were placed at or near the following sites within the feedlot:

- Feed mill
- Dam (freshwater storage)
- Silage pits
- Sedimentation pond
- Manure stockpiles
- Cattle pens
- Vegetation between pens
- Horse stables
- Hospital/induction area
- Outside the feedlot complex (to establish background levels)

The distribution of various fly species inside and outside the feedlot was distinctly different. House fly populations were higher inside than outside the feedlot and they were distributed across the entire feedlot, with populations higher in the vicinity of cattle. The highest bush fly catches were obtained outside the feedlot and at the manure stockpiles in the feedlot. Stable fly populations were concentrated at the manure stockpiles and the silage pits. Very few stable flies, which depend on animal hosts for blood meals, were caught outside the feedlot. Blowfly catches were the highest in the traps outside the feedlot, followed by the manure stockpile traps.

Feedlot management practices

The four major insecticide applications during the monitoring period did not have a major impact on adult fly populations. The prevalent seasonal trends in fly populations after the treatment appeared to be the same as pre-treatment. It is possible that the insecticides had short term effects on fly populations which were not reflected by the weekly or fortnightly monitoring program. Fly bait was used in the induction area, the hospital and the feed mill when perceived necessary, which could be as often as weekly during the summer months.

The results of the resistance tests of the feedlot house flies, moderately resistant to diazinon (organophosphate, OP) but no or low-level resistance to cyfluthrin (synthetic pyrethroid) and azamethiphos (OP) and behavioural resistance to fly baits, are congruent with infrequent insecticidal spraying and more regular use of fly baits at the feedlot.

Observations of feedlot cattle behaviour

Cattle irritated by flies will initiate actions in order to minimise their irritation. These actions aim to reduce the number of flies on the animal or prevent the flies from carrying out their annoying habits, e.g. collecting moisture from eyes or nose or biting to obtain a blood meal. Such fly-induced cattle behaviour includes bunching up into a tight group, tail swishes, ear flicks, head tosses and leg stomps. Observations of feedlot cattle behaviour were made at each feedlot visit in order to obtain an index of fly annoyance.

Tail swishes were the most commonly observed activity (average over monitoring period 6.9/minute, highest average 19/min.), followed by ear flicks (2.6 and 11/min.). Head tosses and leg stomps were recorded much less frequently with the highest averages at 3 and 1.7/min respectively.

The frequency of the animal movements correlated well with the number of house and bush flies caught in the traps over the monitoring period, e.g. frequent movements coincided with high fly populations. Likewise, the number of leg stomps correlated well with the stable fly populations, confirming the hypothesis that leg stomps are primarily a defensive reaction to biting stable flies.

The close correlation between animal movements and fly populations make formalised observations of cattle a valid tool for assessing feedlot fly populations. Counts of one or several of these movements on a number of animals (5 to 10) over a specified time (e.g. 1 minute) will give an indication of prevalent fly populations associated with this movement.

Immature fly populations

The vast majority of immatures found in the feedlot were house flies, with 86% of larvae found during the entire monitoring program belonging to this species. Stable fly (10%) and *Physiphora clausa* (Otitidae) (3%) larvae were also detected on the feedlot in significant numbers, while all other larvae together accounted for less than 1% of the total.

Tight correlations between the larval and pupal density ratings (field observations) and the number of fly larvae and pupae extracted in the laboratory were obtained.

Seasonal effects

The seasonal abundance of larvae and pupae closely matched the patterns observed for adult flies. House fly larvae were found in elevated numbers over about 9 months of the year (October to June). Stable fly larvae and pupae were recovered at much lower numbers and their major population peak was in autumn 2003 with two minor peaks in spring and autumn 2002. During the hot summer almost no immature stable flies were found in the feedlot. It appears that the major fluctuations in larval and pupal populations are a result of seasonal conditions.

A close correlation between larval/pupal abundance and trapped flies across the seasons was also observed. The peaks and troughs in the house fly trap catches generally follow those of larval and pupal abundance with a couple of weeks delay. As the immature stages progress to adult flies, a lag of about one to two weeks is to be expected in hot weather, somewhat longer in cooler conditions.

Feedlot sites

Larvae were found in all selected sites, with average extractions of all species ranging from 150 to 850 larvae per sample (Figure 2). The highest average numbers of house fly larvae were recovered from the hospital/induction area and the cattle pens. The sedimentation pond, manure stockpiles, silage pit and drains produced values close to the average, whereas the yield of larvae from horse stable samples was well below the others. Stable fly larvae were found in highest numbers in the drains and the hospital. The sedimentation pond also contained above average numbers of stable fly larvae whereas the other sites were below average.

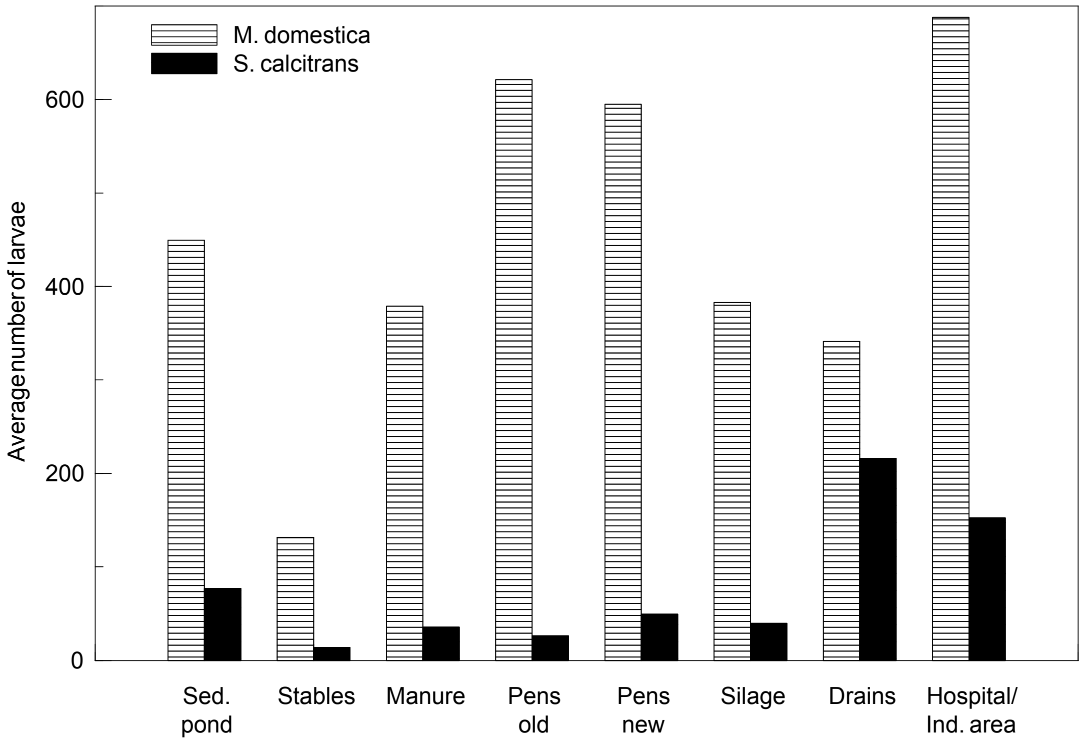

Figure 2 Average numbers of larvae extracted from various feedlot sites

The ranking of feedlots sites by larval production was reasonably consistent across seasons. The highest yielding sites, the hospital and cattle pens, were consistently high compared to the other sites. The sedimentation pond was high in summer and spring and low in autumn and winter. The manure stockpiles, although overall an average fly breeding site, produced most of the house fly larvae in winter.

The highest numbers of larvae were found where a mixture of vegetation, manure and moisture was present. These factors combined, provide ideal breeding grounds for a variety of fly species. The hospital/induction area, under the fence lines in cattle pens, drains and silage pits all provide such ideal substrates for fly development.

At each feedlot site, five manure/soil samples were collected in different locations, to pinpoint preferred egg laying and developmental spots within the feedlot sites. The larval abundance varied greatly between different locations. In the hospital/induction area, the hospital yards had particularly high larval counts probably due to high amounts of feed residue (hay and grain), low cattle numbers and infrequent cleaning. In cattle pens, the highest ratings were consistently obtained under the fence lines which produced between 76 and 89% of the larvae from this site. The larval abundance adjacent to the feed bunk was higher than in the middle of the pen, but still much lower than under the fence lines. In the sedimentation pond, larvae were generally located at the liquid-solid interface which moved up and down the pond edge depending on water influx. The sedimentation pond inlet, including the drain, gave the highest reading. In the drains, the highest numbers of larvae were observed in areas with poor drainage. The highest larval abundance in the manure piles was observed in fresh, wet deposits removed from sedimentation ponds or catchment drains, followed by the manure stock pile used for composting carcasses. The ratings of the other manure piles were considerably lower, particularly the larval ratings. The pit face gave the highest rating in the silage pits. In the horse area the most productive fly breeding location was in the day spelling paddock, where larvae and pupae were found in a mixture of soil and hay around the feeding bins.

These findings indicate that major fly breeding is concentrated to relatively small pockets in the feedlot. A potentially successful **strategy for reducing fly breeding in the cattle feedlot would involve a more targeted and more frequent cleaning of these major fly breeding areas**. For example, in the cattle pens the manure under the pen fences should be removed more frequently than only during the normal complete pen clean out which occurred every two to three months at the SQ feedlot; in the hospital the mixing of hay and manure should be minimised and/or the area should be cleaned more frequently; in the sedimentation pond the solid/liquid interface should be kept as small as practical; in the silage pits the presence of spilled silage should be minimised. Such strategies may result in better control of fly breeding than the current processes and they should be part of an IPM system for fly control in cattle feedlots**. It is recommended that the benefits of more frequent, targeted cleaning procedures for fly control be investigated**.

Effects of feedlot design and practices

Cattle pens in the newer section of the feedlot have a pen surface with a 3% slope, considered optimal by industry for drainage and odour control, whereas the older section has minimal pen surface gradient. The average numbers of larvae recovered from the new and old pens over the whole monitoring period were identical but their distribution within the pens was different. However, differences between the old and new pens other than design, such as cattle breeds, feed rations and residues, stocking rates and shade cloth, may have significantly impacted on fly breeding. Most of these factors appeared to assist fly breeding in the new pens. Therefore, it is possible that the anticipated beneficial effects of increased pen slope on fly breeding were negated by other differences or that pen slope did not have a significant effect on fly breeding. Manure accumulated under the fence lines regardless of pen gradient and fence lines were identified as the major fly breeding site associated with cattle pens. Furthermore, this assessment of fly breeding was obtained during a relatively dry period when pen gradient may not have been a critical issue.

There was some evidence that a concrete base under cattle pen fence lines may assist in reducing under-the-fence fly breeding. Thirty percent fewer larvae were recovered from concrete base than from earth base fence lines in pens of similar design and with the same cattle breed and feed rations.

Manure scraping and removal from cattle pens and fence lines was generally performed on a routine basis at two to three month intervals. After many, but not all, pen cleaning events, a reduction in numbers of larvae was observed. However this reduction was short-lived, commonly observed only in the first measurement following the cleaning. The reduction was often not substantial in terms of the existing immature fly populations and fly production quickly returned to its season-driven level. Our observations indicated that a build up of non-compacted manure under the fences occurred rapidly after the cleaning, thus re-establishing the flies' preferred breeding sites. Similar observations were made for the sedimentation pond. As mentioned above, a more targeted and more frequent cleaning of major fly breeding sites should assist in fly control.

Insecticidal treatments were infrequent and generally applied when there was a perceived need rather than on a routine basis. Fly baits, which attract and kill adult house flies only, were also used when deemed necessary. All of the insecticide treatments targeted the feed bunks and some also included the pen fence lines. The larval abundance in pens was not substantially reduced by any of the treatments. The chemical treatments may have resulted in minor, short-term reductions. It appears that insecticidal treatments had little if any impact on fly breeding or fly populations on the feedlot.

The results of the resistance tests of the feedlot house flies, moderately resistant to diazinon (organophosphate, OP) but not or weakly resistant to cyfluthrin (synthetic pyrethroid) and azamethiphos (OP) and behavioural resistance to fly baits, are congruent with infrequent insecticidal spraying and more regular use of fly baits at the feedlot.

Of the flies trapped on the feedlot, only house flies and stable flies breed on the feedlot, whereas all others predominantly breed outside the feedlot and presumably are attracted to the feedlot by its odours. Minimising feedlot odours may reduce its attractiveness to flies breeding outside the feedlot and thus lower their populations in the feedlot. Bush flies breed in undisturbed cattle dung and as our study has confirmed, the feedlot environment is unsuitable for their breeding. It is interesting to note that not a single buffalo fly was caught in any trap on the feedlot which was located in an area where they would commonly be found on grazing cattle. Buffalo flies also breed in undisturbed cattle dung and spend all of their adult life on animals. Blowflies breed in carcasses and this study has shown that this takes place primarily outside the feedlot. However, it is crucial that feedlot carcasses are completely covered when they are buried in composting piles to prevent blowfly breeding on the feedlot.

Parasite populations

Parasitic wasps

Parasitic wasps were collected in the feedlot using two independent methods. Firstly, through controlled exposure of house fly pupae to the feedlot wasp populations (= sentinel pupae) and secondly through appropriate processing and examination of the fly pupae collected for the immature fly population program.

Sentinel pupae

Parasitism of sentinel pupae was generally between 0% and 20%, but it reached 35% on two occasions. Fly emergence occurred in 81% of the sentinel pupae. A total of 530 pupae (4.2% of the 13,000 exposed pupae) were parasitised and 606 wasps emerged. Most pupae yielded only a single parasitic wasp, but multiple wasp emergence was observed a few times. The most common wasp parasites in sentinel pupae were *Muscidifurax raptor* and *Spalangia cameroni*.

Feedlot fly pupae

The percentage of parasitised pupae collected in the feedlot was 11%, while a fly emerged from 30% and nothing emerged from 59% of the pupae. The rates of parasitism and viability were consistent for house fly, stable fly and other feedlot pupae. Not counting the non-emerging pupae, parasitic wasps reduced the emergence of flies by 27%. However, the actual suppression of fly emergence by parasitic wasps is higher because wasps also sting pupae to feed on them (dudding) or eggs are laid but no wasps emerge. Such pupae will produce neither a fly nor a wasp and thus are classified as non-emerged pupae in our assessment. Parasitic wasps are clearly one of the important biological control agents for fly pupae in this feedlot.

Eight species of parasitic wasps emerged from fly pupae collected at the feedlot. About 90% of these wasps were *Spalangia* spp., with *S. endius* the most common species (50% of all wasps). Other wasp species included *M. raptor* and *Trichomalopsis* sp. and wasps from the family Diapriidae. Only a single parasitic wasp emerged from most pupae, but multiple wasps (maximum 15) emerged from some pupae. Multiple wasp emergence was observed with *Trichomalopsis* sp. and Diapriidae. Between 86% and 92% of the wasps emerged from *M. domestica* pupae for all wasp species except *Trichomalopsis*. This emergence pattern matches well with the ratio of extracted house fly to stable fly pupae (88:12), indicating that the wasps equally parasitise both fly species. About two thirds of all emerged wasps were female with a similar sex ratio across all species, except for *Trichomalopsis* sp. with 99% females. The species of wasps found in the feedlot pupae were basically the same as in the sentinel pupae, however, the proportion of the species was distinctly different.

Wasp populations followed basically the same seasonal pattern as fly populations: population peaks during summer and troughs during winter. *S. endius* was the most abundant species in most months, with broad population peaks from October to June. *S. nigroaenea* and *S. cameroni* populations increased about two to three months later than *S. endius* but disappeared about the same time (June). *S. cameroni* was the most common species in the small population of surviving wasps during winter 2003. The presence of *M. raptor* was inconsistent in 2001/02 (only January and June 2002 provided reasonable numbers) but it had a population pattern similar to *S. nigroaenea* in 2002/03. There was no clear difference in seasonal patterns of wasp populations which had emerged from house flies or stable flies respectively.

The percentage of pupae parasitised varied greatly between collections. The average percentage of parasitism for house fly and stable fly pupae was similar in many months, but there were a few differences. During the cold months of July and August the level of parasitism was low for house flies, but remained close to the average for stable flies (in 2003 this trend continued into spring). The level of parasitism was generally not correlated with the number of pupae extracted from the feedlot samples.

The four major species of wasps were found at all monitored feedlot sites, indicating wasp presence and activity throughout the feedlot. The highest numbers of wasps were recovered from the silage pits, the hospital area and the cattle pens. All feedlot sites showed parasitism rates of between 7% and 16%. The hospital and stables had the highest parasitism rates (16% and 13% respectively) and the sedimentation pond and manure piles the lowest rates (7% and 8%).

There was no evidence that scraping and/or cleaning cattle pens had a substantial impact on the levels of parasitism. Two insecticidal treatments within three weeks (January/February 2002) appeared to lower the level of parasitism over the subsequent month, but no such reduction was observed after the 2003 applications (January and April).

The level of parasitism was higher in the feedlot pupae (11%) than the sentinel pupae (4.2%). This difference could be due to presentation of pupae (containers versus manure/soil), the age of the pupae or a difference in the attractiveness between colony and field produced pupae.

The species of wasps found in the feedlot pupae were basically the same as in the sentinel pupae, however, the proportion of the species was distinctly different. The feedlot pupal data demonstrates that *Spalangia* spp. are the dominant parasitic wasps in this feedlot. *M. raptor* and *S. cameroni* were the most common wasps in the sentinel pupae. *S. endius* was the most common species in the feedlot pupae, but was hardly present in sentinel pupae. This difference is probably due to the variable ability of parasitic wasp species to locate buried pupae and to differences in pupal age. This comparison also indicates that feedlot pupae are the better method of establishing wasp parasitism rates in a cattle feedlot.

The parasitic wasps detected on the feedlot are the same species found in similar American and European studies. The presence of these wasps provides Australian feedlot managers with the opportunity to use parasitic wasps for biological control of nuisance flies. Several of the parasitic wasp species found on the Australian feedlots are commercially cultured in the USA for the control of flies in intensive livestock industries. The know-how of producing and applying the parasitoids on feedlots has already been established in USA facilities. With the knowledge that these species are endemic in Australia, such cultures could be set up in this country. **It is recommended that the production and application of parasitic wasps for nuisance fly control on feedlots be initiated and their effectiveness in Australia be investigated**.

Mites associated with feedlot flies

As well as the parasitic wasps a number of other arthropods occurring in dung can limit fly populations. Predaceous mites for example can feed on house and stable fly eggs and larvae. A number of these mites closely associated with coprophagous flies, such as *M. domestica*, have been found to have high biocontrol potential against Diptera. For the intensive livestock industries, these mites have largely been reported as species from the families Macrochelidae, Uropodidae and Parasitidae. A number of native and exotic species of mites, including *Macrocheles* sp. *Glyptholaspis* sp. and *Parasitus* sp. are known to attack *Musca* sp in Australia.

Samples of flies were examined for phoretic and parasitic mites on a number of occasions during our study, particularly at times of peak fly numbers. At least two species of mites, the macrochelid mite, *Macrocheles* sp., and an unidentified trombidiid species, have been found on *M. domestica* and *S. calcitrans*, generally in low numbers. Aggregations in manure of what appear to be Uropodids have also been seen, however no systematic examination of manure was carried out for mites.

The average mite infestation level was 3.8% and 3.2% for house and stable flies respectively. Peaks in infestation levels occurred in autumn/early winter in both years. Major peaks occurred after fly numbers started to decline. Mites on *M. domestica* tended to be predominately unidentified "red" trombidiid mites with small numbers (<2%) of *Macrocheles* sp. largely found between April to May each year. The silage pit showed consistently higher than average percentage of infested flies, reaching a maximum of 44% in May 2003. As for the wasps, such largely undisturbed substrates are likely to favour population increases. Mites on stable flies were predominately *Macrocheles* sp. (>75%) with smaller numbers of red trombidiid mites. As for the house flies there was considerable variation in the stable fly infestation levels between the sites with a maximum of 15% recorded at the manure piles.

The contribution of the various mites in the biocontrol of fly populations associated with livestock has not been generally established and to date, no mites have been produced commercially. In laboratory studies, predaceous mites such as the Macrochelids can kill up to 36 house flies per day per mite by feeding on eggs and early instar larvae. In an early field study, there were up to 45% fewer flies when mites were present. Apart from maintaining natural mite populations by judicious use of pesticides and a range of cultural practices, no additional studies are envisaged.

Entomopathogenic fungi

Bacteria, viruses and fungi can also limit fly populations and probably play a role in a feedlot situation. Fungi are unique among the microbial insect pathogens in that they primarily infect their hosts through the external cuticle. The potential for microbial control using fungi has been well recognised. Two of the most common fungi developed for commercial applications in insect control are *Beauveria bassiana* and *Metarhizium anisopliae*.

A large number of fungi were recorded during our studies from adult flies and pupae with many being common saprophytes. Only fungi from a few selected entomopathogenic genera were isolated and kept in pure culture. In laboratory bioassays, four *B. bassiana* and *M. anisopliae* isolates caused 100% fly mortality within 6 days with the most effective isolates killing 100% of flies within 4 days. These isolates were highly effective in killing house flies, making them potential candidates for the development of a fungal biopesticide for flies. Some of these isolates have also successfully killed adult and immature stages of sheep blowfly.

Our preliminary studies on fungi in feedlot flies indicate that there is a potential for controlling nuisance flies with endemic species of fungi. Researchers in the United States have also made progress in their investigation of fungal control of nuisance flies. DPI&F has an established fungal biopesticides group with current research projects on a number of livestock pests including buffalo flies, ticks and blowflies. **It is recommended that further studies be conducted to explore the development of local species of entomopathogenic fungi as an IPM tool for the management of nuisance flies in cattle feedlots.**

Fly and parasite population monitoring in other feedlots

In addition to the comprehensive fly and parasite population monitoring carried out in a SQ feedlot, a snapshot of these populations was also obtained on two additional feedlots located in different climatic regions, namely in central NSW (CNSW) and central Queensland (CQ).

The major nuisance flies, house flies, stable flies, bush flies and blowflies were the same in all three monitored feedlots located from central New South Wales to central Queensland. There were differences in their relative abundance between the feedlots: House fly was the most common fly in all feedlots while stable fly was more abundant in the CNSW feedlot than the Queensland feedlots during these one-off collections. The highest trap catches were obtained in the CQ feedlot which also scored the highest nuisance fly rating, by its manager.

The CQ feedlot had the highest larval rating and numbers of larvae extracted. House fly larvae were the most common larvae in all feedlots and they constituted >90% of the larvae in both Queensland feedlots. Stable fly larvae made up 13%, 6% and 1% of the extraction in the CNSW, SQ and CQ feedlots respectively. Most of the other fly larvae were *P. clausa* in the CNSW and CQ feedlots. The larval rating and abundance, including the species distribution, correlate well with the values for the adult flies in the same feedlot.

The level of parasitism was similar in all feedlots, ranging from 9% to 12% which was close to the two-year average of 11% in the SQ feedlot. The CNSW and SQ feedlots also had similar fly emergence rates, whereas fewer flies emerged from the CQ pupae. The parasitic wasps killed at least 21%, 23% and 35% of flies developing in the CNSW, SQ and CQ feedlots respectively (Figure 3).

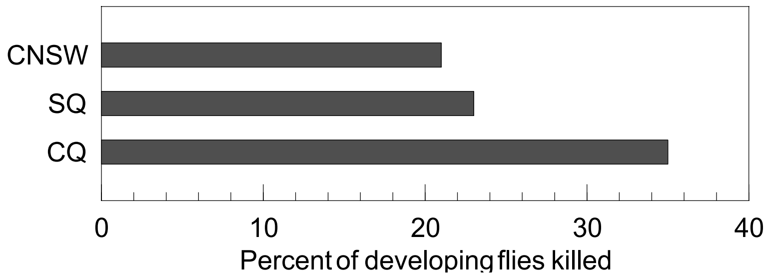

Figure 3 Percent of developing flies killed by parasitic wasps in three feedlots

The major parasitic wasp species were identical in all feedlots. *S. endius* was the most common wasp in the CNSW and SQ feedlots, *S. cameroni* the most abundant in the CQ feedlot. *Spalangia* spp. were the principal wasp parasites of flies in three Australian feedlots from central NSW to central Queensland.

In the CNSW feedlot, three species of mites were found on *M. domestica*. Two of these species, belonging to the families Trombidiidae (1.9%) and Macrochelidae (0.1%), detected on sticky traps, were similar to those found on SQ flies. Groups of small white nymphal mites (Pygmephoridae) were also detected on 6.5% of flies. In CQ, only a single species of mite (Trombidiidae, 2.4%) was found on *M. domestica* captured with sticky traps and nets.

This study has provided an extensive set of data on nuisance fly and parasite populations on three Australian feedlots. It has provided information on which fly species, and when and where they are present in the feedlot. The major fly breeding sites and the seasonal variations in fly breeding were established. The presence and activity of parasitic wasps, predatory mites and entomopathogenic fungi were also documented. These natural enemies of flies play an important role in limiting fly populations in cattle feedlots and this should be taken into consideration when devising fly control strategies. On the basis of this Australian data and information on nuisance fly ecology and control from other sources (mainly from the USA) an approach to integrated fly control in cattle feedlots and recommendations were developed. They are presented in the Conclusions and Recommendations section.

SUCCESS IN ACHIEVING OBJECTIVES

The project objectives, listed in detail in a previous section, can be grouped into four major themes: the species and numbers of nuisance flies and associated parasites present on cattle feedlots, major fly breeding sites and management practices impacting on fly breeding, the resistance of feedlot flies to currently used insecticides, and recommendations for integrated fly management programs. All objectives were addressed in this project in a manner and to an extent so as to provide essential information on Australian feedlot nuisance fly populations lacking at the start of the project. This information and prior knowledge were used to develop recommendations for an integrated fly management program, extension material and additional R&D work.

Populations of nuisance flies and their parasites were determined through a comprehensive monitoring program on a commercial feedlot in southern Queensland over two years. The species and numbers of immature and adult flies were regularly assessed at fortnightly intervals inside and outside the feedlot. Weather data and feedlot management events were also recorded. This information allowed us to assess the effect of weather and management events on fly populations. Fly parasites and predators, such as parasitic wasps, predatory mites and entomopathogenic fungi were collected and identified. We demonstrated that parasitic wasps play an important role as biological agents in the control of nuisance flies. The presence of the major flies and parasites was confirmed in two additional feedlots in other climatic regions. This is the first major study on fly and parasite populations in Australian feedlots and it demonstrated that the parasitic wasp species are the same as those reported globally, an important factor for their proposed use as biological control agents. The information obtained from the monitoring program increased the knowledge of fly and parasite populations on cattle feedlots and enabled us to develop an integrated fly management strategy.

Major fly breeding sites in the feedlot were located through regular manure and soil sampling. Two fly species accounted for almost all breeding in the feedlot. Fly breeding was restricted to relatively few and small areas which should be given special attention in feedlot sanitation programs. The impact of feedlot management practices, such as cleaning, insecticide applications and manure management, on fly populations was assessed. The newly acquired knowledge was also incorporated into the integrated fly management strategy.

Knowledge of the resistance status of feedlot flies against chemicals used for fly control is an essential part of an integrated approach to fly control. The resistance of flies from three Australian feedlots to commonly used insecticides and baits was determined in laboratory assays. Although no high levels of resistance were detected, some of the available products showed reduced effectiveness in killing feedlot flies. Little information on insecticidal resistance in nuisance flies in Australia was available prior to this project, but we now have evidence of their current resistance status.

The principal objective of the project was to develop guidelines for an integrated fly management strategy. The successful completion of the other objectives was a prerequisite for this task. Such guidelines were derived from the experimental results obtained in this project, specialist knowledge in the research team and publications from other experts in this field. The guidelines were presented as elements of an integrated pest management for nuisance flies on cattle feedlots, using an anagram forming the word RULES for easy memory retention and recall. The guidelines are presented in this report (in Conclusions and Recommendations) and, somewhat abridged, in extension material for industry use (MLA tips & tools). A second extension brochure, containing information on nuisance flies (life cycle, identification, natural enemies) which is relevant to the feedlot industry, was also produced.

All objectives in this project were completely met. Experimental work in commercial feedlots, laboratory investigations and subsequent processing, compiling and interpretation of project data provided the information to fill knowledge gaps and answer critical questions. The information on nuisance flies and their natural enemies in Australia was greatly increased. Guidelines for integrated fly control in cattle feedlots were developed on the basis of new data and prior information. The Australian feedlot industry has now a better understanding of the nuisance fly problem and will be able to increase the effectiveness of fly control through an adoption of the guidelines.

IMPACT ON MEAT AND LIVESTOCK INDUSTRY

The feedlot industry has applied a significant amount of effort to improved manure management practices over the past decade as a means of reducing odour emissions and fly problems. There is, however, evidence that fly populations remain a serious problem at many feedlot sites despite the improved manure management practices. Insecticide resistance and a desire to minimise the use of chemicals also drive the need to move to a more integrated approach to fly control.

This project has delivered results and analyses of a comprehensive monitoring program on nuisance flies and their natural enemies in cattle feedlots. We have established the resistance status of feedlot flies towards commonly used insecticides. In two separate ‘tips & tools’ extension publications, industry was given detailed guidelines for integrated fly control in cattle feedlots and relevant information on life cycle and identification of nuisance flies and the importance of natural enemies for their control.

Adoption of the integrated fly control strategy by the feedlot industry will lead to improved control of nuisance flies on feedlots. This strategy integrates cultural (mechanical/physical), biological and chemical methods to optimise fly control. The second publication on nuisance flies and their natural enemies increases the feedlot operators' knowledge and understanding of nuisance flies and their habitat. It enables them to make more informed decisions and thus to improve their fly control program. The project has thus delivered relevant information and targeted guidelines for immediate implementation of integrated and effective fly control on cattle feedlots.

Improved feedlot fly control will deliver a suite of benefits to industry. Lower fly populations in the feedlot will lead to increased production gains resulting from a reduction in biting and annoyance of cattle by flies. Working conditions for feedlot employees will improve and transmission of diseases decrease with lower fly numbers. The risk of complaints from neighbouring landholders is also reduced by effective fly control. This results in better community relations and generally enhances the image of the industry.

The integrated fly management strategy minimises the use of insecticides while taking full advantage of cultural and biological control methods. Lower insecticide usage minimises the risk of residues in beef products and the environment, thus enhancing the clean-and-green image of the Australian feedlot industry and the beef industry, as a whole. Furthermore, the detrimental impact of insecticides on beneficial insects is reduced, workplace health and safety standards in the feedlot are improved and the costs for purchase and application of insecticides are lowered.

The project work also demonstrated the potential of new, non-insecticidal tools for controlling nuisance flies on cattle feedlots. Parasitic wasps and entomopathogenic fungi, two biological control agents which are currently present in the feedlot ecosystem, either play an important role, or have the potential to do so, in reducing fly populations. Parasitic wasps are being commercially produced and sold for fly control in intensive animal industries in the USA. We determined that the major wasp species in Australian feedlots are the same as those used in the USA. Current R&D work in DPI&F indicates that the fungi isolated from feedlot flies also have a great potential to be effective biopesticides for flies. It is thus recommended, that research on the development and application of these two biological control agents be initiated. The availability of these agents would enable industry to further improve fly control and reduce the use of insecticides.

The reduction of fly breeding sites through improved feedlot sanitation was also recognised as one of the crucial components of an IPM strategy. It was recommended that feedlot sanitation should target breeding hot spots identified through project work. However, it was also recognised that quantitative information on the impact of changes in feedlot sanitation on fly populations was required to devise optimal sanitation procedures for fly control. Therefore, it was recommended that the effect of a program of structured variations in feedlot management practices on fly populations be determined in future R&D work.

The interactions between fly populations, parasites and predators, management practices and their effects on flies and parasites, and environmental parameters are complex. However, they all need to be considered in devising strategies for optimal fly control. A computer based decision support system (DSS) could be developed to integrate each of these factors influencing the feedlot fly situation to predict fly populations over time, for different control scenarios. A DSS would provide the most comprehensive and effective assistance to feedlot operators making day to day decisions on fly control. We have recommended the development and implementation of such a DSS.

The project has delivered to industry new information on feedlot flies and guidelines for integrated fly management, which can be implemented immediately, and made recommendations which will provide fully integrated fly control through new biological tools, targeted management and a PC based decision support system.

The implementation of the findings and recommendations of this project will enable the feedlot industry to make major advances in the management of nuisance flies, leading to a wide range of ensuing benefits for the industry and the wider community.

CONCLUSIONS AND RECOMMENDATIONS

Integrated pest management (IPM) for nuisance flies on cattle feedlots

Integrated pest management (IPM) systems embrace the integration of cultural (mechanical/ physical), biological and chemical control methods to reduce pest populations. IPM strategies need to be tailored for particular situations, incorporating all available approaches and lessening and increased precision of insecticide use (New 2000). The elements of an integrated pest management approach for nuisance flies on an intensive, outdoor animal facility, such as cattle feedlots, are presented in this section.

Elements of IPM for nuisance flies

***R**educing fly breeding sites*

- Manure management (under fence lines, sedimentation ponds, drains, hospital area, stock piles)
- Spilled feed (feed bunks, hospital area, stables, feed processing area)
- Silage (spills, cover completely)
- Carcases (compost, cover completely)
- Feedlot maintenance (troughs, drains, sedimentation pond, vegetation)

***U**sing insecticides selectively*

- Rotate chemical groups
- Targeted insecticide use (hot spots)
- Do not spray on feed
- Adulticides
    - Residual rather than knockdown insecticide
    - Spray resting sites not manure
- Larvicides
    - Use an insect growth regulator (IGR) such as cyromazine which does not affect beneficial insects
- Baits
    - Use for house flies only and rotate between baits with insecticides from different chemical groups

***L**ot feeding design principles*

- Appropriate pen foundation and optimal slope
- Feed and water trough design
- Fence design to allow for easy cleaning
- Construction of drains, sedimentation systems and effluent holding ponds
- Manure stockpile and composting area

***E**nhancing populations of biological control agents*

- Biological control agents play an important role in fly control
- Preserve parasite and predator populations through appropriate management
- Augment parasite populations through strategic releases

***S**ystematic monitoring of fly populations*

- Scouting (adults and larvae; so that application of control can be based on population thresholds not perception)
- Traps
- Animal observations
- Larval density ratings

Follow these ***RULES*** to implement integrated pest management of nuisance flies on cattle feedlots.

Reducing fly breeding sites

Reduction of breeding sites is a critical element of an IPM program. It is largely achieved through adequate feedlot sanitation using cultural methods. House flies and stable flies breed in moist manure, spills of feed and silage and mixtures of vegetation and feedlot run-off, e.g. drains. Compacted or dry manure is not suitable for fly breeding. Bush flies breed in undisturbed dung pads and blowflies breed in carcases. It appears that flies breed largely in a few and relatively small areas in the feedlot. Feedlot sanitation for fly control should be targeting these areas.

- Manure accumulated under fence lines in cattle pens is one of the major fly breeding areas in the feedlot. Frequent removal of this uncompacted manure will reduce the substrate available for fly breeding. To completely stop fly breeding, this would have to be done every 7 days during summer (less frequently in cooler seasons), but this may not be practical. A fortnightly removal should still provide clear benefits. The manure will have to be managed so that fly development does not continue after removal, e.g. it has to be composted or dried out.
- A similar strategy should be used for the drains and the sedimentation pond. The presence of wet manure deposits should be minimised. Thus, regular cleaning of these areas, particularly after major rainfall events, should occur.
- Manure in the stock piles must be managed to minimise its suitability for fly breeding. Composting of the manure in windrows prevents fly breeding because of high temperatures generated in this process. Align and shape manure stockpiles and composting wind rows to avoid ponding of rainfall – runoff.
- The hospital area was also one of the prime fly breeding sites, due to a low stocking density, the presence of hay and infrequent cleaning. More frequent cleanouts and a reduction of hay spillage on the manure should achieve a reduction in fly breeding in the hospital area.
- Feed spillages should be avoided where possible and cleaned up regularly. The major fly breeding in feed spills was found near feed bunks, in the hospital area, the horse stables and the feed processing area. Feed spills should be removed promptly and added to composting manure. Feed residues should not be left in bunks for extended periods.
- Moist silage provides a suitable substrate for fly breeding. Spills, particularly along the silage pits, should be avoided and the silage pits should be covered and the edges sealed to reduce fly breeding in this area.
- Cattle carcases should be composted rather than buried. The carcases have to be completely covered with manure to prevent blowflies accessing them to breed. With appropriate manure cover, the temperatures in the pile will kill fly larvae and other organisms.
- General feedlot maintenance will also contribute to fly control through a reduction in breeding sites and resting places for adult flies.
    - Check regularly for water leaks from troughs, as they increase the moisture content of manure pads and thus facilitate fly breeding.
    - Weeds should be controlled and grass and other vegetation kept short, particularly around pens, drains and sedimentation ponds. This makes it more difficult for flies to find resting places and reduces the vegetation–manure interface, a preferred breeding substrate for stable flies.
    - A thorough feedlot clean-up before the start of the fly season, e.g. early spring, will slow down the increase in fly populations

Using insecticides selectively

Insecticides can be used to assist in the control of nuisance fly populations on cattle feedlots but they should not be the principal strategy. They should only be used if adequately implemented cultural and biological methods fail to keep fly population under an acceptable threshold. If insecticides have to be used the following guidelines should be considered to avoid unnecessary, ineffective or detrimental applications.

- Insecticides should only be handled and used according to label instructions.
- Insecticides should only be applied if a fly monitoring program indicates that a predetermined population threshold has been exceeded. They should not be used on a scheduled calendar basis. This strategy prevents needless treatments and lowers costs.
- The chemical groups, e.g. organophosphates, synthetic pyrethroids, insect growth regulators, should be rotated to prevent build up of resistance in the flies. Repetitive exposure of flies to the same insecticide will result in the development of resistance, thus rendering the chemical ineffective.
- Applications of insecticides should be targeted to hot spots rather than broadcast across the entire feedlot. For control of adult flies, treatments should be restricted to resting places, e.g. exterior of feed bunks, pen fences, underside of shade cloth, trees and other vegetation. To control breeding, larvicides should only be applied to major breeding sites, e.g. under pen fence lines, drains, sedimentation pond, hospital area. Insecticides should never be applied to feed or areas which come in direct contact with feed.
- The use of larvicides will not deliver instant relief but will provide better control over time. The use of cyromazine is recommended over other currently available larvicides because it does not detrimentally affect beneficial insects.
- If an adulticide has to be used, residual insecticides are preferred over knockdown insecticides. Knockdown insecticides are short lived and fly populations are likely to recover quickly after an application. Residual insecticides should be sprayed or painted on major resting sites of adult flies. However, the repeated use of residual insecticides creates a high potential for selection for resistance against them, particularly if a single product is used.
- Fly baits are only effective against house flies as they contain a house fly attractant. They can be applied either in bait stations, scattered or painted on surfaces. Some behavioural resistance to currently available fly baits was detected in house flies, thus their effectiveness should be monitored.
- Combinations of larvicides with fly baits have been shown to be a successful strategy in delaying development of resistance.

Lot feeding design principles

Design of many feedlot sections can be optimised so as to facilitate fly control. The majority of the design features will make cleaning and removal of potential breeding sites easier or more effective.

- Employ appropriate pen foundation construction methods and materials to produce a uniform, durable pen surface capable of withstanding the loadings from cattle and cleaning machinery without breaking down to form pot holes and depressions.
- Pen slope should preferably be in the range from 2.5 to 4% to promote rapid drainage and hence drying of the manure pad after rainfall, while limiting manure transport from the pen area. Pen cross-slope should be less than the pen down-slope to avoid pen to pen drainage.
- Feed and water troughs should be designed for ease of cleaning, preferably with enclosed, vertical sides to eliminate any build-up of spilt feed or manure underneath. They should be equipped with durable aprons (generally concrete) sloping away from the trough to promote good drainage while avoiding pen surface degradation (pot hole formation).
- Water troughs should be designed for ease of waste water disposal and cleaning, generally low volume, shallow, narrow troughs to minimise waste water volume generated by cleaning. Waste water should be discharged away from the pen, preferably in a durable surface drain or via underground sewer pipe, to prevent the formation of wet patches.
- Fence panels should be relatively widely spaced (up to 3.2 m) to improve the efficiency of under-fence cleaning. The bottom fence cable or wire should be approximately 400 mm above the constructed pen surface to allow easier under-fence cleaning.

- Drains should be designed for flow velocities that avoid deposition of manure.
- Drains should be designed for ease of cleaning, generally with either V or trapezoidal cross-sections and flat batters. A durable base should be provided to enable cleaning machinery access as soon as possible after rain.
- Sedimentation basins should be designed for ease of cleaning with a durable base to enable cleaning machinery access as soon as possible after rain.
- Sedimentation systems and holding ponds should be designed to enable mowing and/or spraying of vegetation around the perimeter.
- Manure stockpile and composting areas and carcass composting areas should be established on durable, well-drained earth pads.

Enhancing populations of natural control agents

Biological control agents play an important role in lowering feedlot fly populations. Particularly, parasitic wasps achieved 21-35% control of nuisance flies in the three monitored Australian feedlots. Other natural control agents included predatory mites and entomopathogenic fungi. It is important that the presence and activity of these biological agents be encouraged or enhanced through appropriate management.

- Parasitic wasps kill fly pupae by stinging them. They lay their eggs inside fly pupae and the resulting wasp larvae devour the immature flies before they can develop into adults. The wasp larvae subsequently develop inside the fly pupal cases until they emerge as adult wasps after several weeks. One or several wasps can develop inside one fly pupa. Adult wasps also sting and kill fly pupae and feed on pupal contents, but no eggs are laid (dudding); or eggs are laid but wasps die before reaching the adult stage. Parasitic wasps are small (1 to 3 mm) and are normally not seen.
- Mites and fungi can also limit fly populations. Predaceous mites feed on house and stable fly eggs and larvae. Fungi are unique among the microbial insect pathogens in that they primarily infect their hosts through the external cuticle.
- The primary management strategy is to preserve existing feedlot populations of biological control agents. Insecticide applications should be avoided if possible or used judiciously when necessary. Most insecticidal treatments aimed at adult flies will also kill parasitic wasps. Fly populations will recover quicker from an insecticidal treatment than parasitic wasps due to their shorter life cycle, resulting in reduced biological control during this lag period. If insecticides have to be used, consider the use of larvicides combined with baits. The IGR cyromazine is an effective and selective larvicide for flies and has no detrimental effect on parasitic wasps. Fly baits selectively target and kill house flies.
- An additional strategy is to augment the natural populations of parasitic wasps to increase the control achieved by these biological agents. Augmented populations are obtained through releases of colony bred wasps. This biological control method is currently being used in the United States where several wasp species are commercially available. Although at present, none of the wasps which parasitise flies are available in Australia, they could become available through a proposed R&D project with an Australian biological control company.
- Drier conditions in fly breeding substrates favour parasitic wasps and mites and impede fly breeding, hence the aim should be to facilitate the drying of all substrates suitable for fly breeding.

Systematic monitoring of fly populations

Fly population monitoring is an important element of an IPM program. Such a program can provide information on the identity of the problem species and on fluctuations in fly populations. It can provide an early warning for anticipated fly waves before adult fly populations escalate. Fly control is more effective if it is implemented before fly numbers increase.

Fluctuations in fly populations are caused by the longevity and fecundity of adult flies, development time and survivability of immature flies, the predation and parasitism by natural enemies (biotic factors), climatic conditions, feedlot design and management practices (abiotic factors). Seasonal changes in the fly populations are, within certain limits, consistent and predictable. Temperature has a major impact on the duration of the life cycle and on the activity of adult flies. Rainfall also plays an important role, as a relatively high moisture content in manure (40-70%) is required for successful fly breeding. Optimising abiotic factors such as pen slopes to keep the manure as dry as possible, targeted and frequent removal of manure under the fence lines to minimise fly breeding sites and the selective use of insecticides can assist in reducing fly populations.

Flies can reduce productivity of feedlots by directly reducing production, increasing production costs or limiting marketing opportunities. Fly population thresholds at which action is to be initiated need to be established. Biting flies, e.g. stable flies, have a low economic population threshold above which substantial production losses can occur. House flies, bush flies and blowflies are less likely do cause such direct losses, but in high numbers elicit defensive actions in animals which can lead to lower productivity. House flies can become a nuisance to feedlot staff or neighbours, thus necessitating the setting of an acceptable population threshold on the feedlot. Some blowflies can cause myiasis on animals and all flies can transmit viral, bacterial or fungal diseases either from animal to animal or from animal to human. To minimise disease transmission, management and maintenance of fly populations at or below transmission thresholds is required.

To keep track of fly population fluctuations and to assess the effectiveness of actions, population monitoring needs to be carried out on a regular and systematic basis. The monitoring system and the site, timing and duration of the monitoring have to remain constant. The results should be assessed immediately after the monitoring period and recorded. Records on a graph will facilitate recognising trends in fly populations.

Preferably a single operator should carry out the population monitoring to provide consistent results. Some of the monitoring systems are more subjective than others and only a single operator can deliver useful results. In some horticultural industries, monitoring of pest population is achieved through the use of professional scouts. These scouts gather information on the identity and location of pest problems (scouting) and assist with the selection of suitable treatments and the assessment of their effectiveness. Scouting should be continued during the entire fly season as major breeding sites may change.

Several monitoring systems for fly populations are available. Monitoring of adult flies can be achieved by using sticky sheets or traps, or structured observations of fly resting sites or animal behaviour. The extent of fly breeding can be established through inspections of major fly breeding sites. Monitoring immature fly populations will give an earlier indication of increases in fly populations than adult monitoring.

- Sticky sheets will retain flies landing on the sheet. Preferably, they should be placed on vertical surfaces, e.g. walls or posts, near preferred fly resting sites. They should be kept away from excessive dust which renders the sticky surface ineffective. The species and number of flies caught on the sticky sheet over a fixed time can be determined. The exposure time of the sticky sheet must be chosen to avoid saturation with flies (1 to 7 days may be appropriate). Identification of the major feedlot flies can be achieved using a simple fact sheet and a magnifying glass. Sticky sheets are commercially available. Alternatively, smaller sticky surfaces, such as fly tapes or fly ribbons could be used for a less accurate fly monitor.
- The Alsynite trap selectively attracts stable flies, however it also works well as a sticky trap for house flies. The cylindrical Alsynite panel strongly reflects UV light (from the sun) which makes it attractive for stable flies. A transparent sticky sheet is wrapped around the cylinder to catch landing flies. The Alsynite trap is also commercially available (from the USA).
- Fly counts on preferred fly resting sites, such as fence railings, feed bunks, walls or other sites where flies usually congregate can also be used as a rough indicator for fly populations. This method is less accurate as counts may depend on time of day, weather conditions and other variables. It is also difficult or impossible to identify fly species.
- Our results have shown that there is strong correlation between animal movements and the number of adult flies in the feedlot. The frequency of tail swishes, ear flicks and head tosses can

be used to gauge house fly and bush fly populations. Likewise, the number of leg stomps correlated well with the stable fly populations. Counts of these movements over a specified time (e.g.1 min) on several animals (e.g. 5 to 10) can provide an estimate of prevailing fly populations.

- Larvae are the most appropriate indicator for immature fly populations. Inspection of manure at major fly breeding sites such as under the pen fence lines, the hospital area, drains, sedimentation pond, silage and wet manure stock piles can provide a measure of immature fly populations. At each site, manure needs to be turned over and examined at several locations and a larval rating (e.g. from 0 [no larvae] to 5 [completely packed with larvae]) assigned to each site. House fly and stable fly larvae can be distinguished using a fact sheet and a magnifying glass.

To achieve effective fly control with minimal cost and insecticide use, the IPM elements discussed above have to be integrated into an overall scheme. The interactions between fly and parasite/predator/ pathogen populations, feedlot management systems, costs and environmental parameters are complex. Although simply drawing together the IPM elements listed above will provide improved fly control, optimal control could be achieved through the use a PC-based decision support system (DSS). **A DSS would provide the most comprehensive and effective integration of available information and resources through investigating various scenarios before recommending or implementing control programs. Therefore, the development of such a DSS for fly control on cattle feedlots is recommended.**

Recommendations

It is recommended that:

1. Feedlot operators design and implement an integrated pest management (IPM) program for nuisance flies on their feedlot. The IPM program should contain the following elements:

   R*educing fly breeding sites*

   U*sing insecticides selectively*

   L*ot feeding design principles*

   E*nhancing populations of biological control agents*

   S*ystematic monitoring of fly populations*

2. MLA, ALFA and DPI&F jointly produce guidelines to assist feedlot operators in the design and implementation of IPM programs for nuisance flies on cattle feedlots. These guidelines should contain:

   - Input to feedlot design
   - Strategies for nuisance fly control and their respective advantages and disadvantages
   - Information on scouting and assistance on the identification of flies and the location of major breeding sites
   - Information on natural enemies and optimisation of their impact on nuisance flies
   - Recommendations on insecticide use

3. Further R&D on nuisance flies in cattle feedlots be carried out to determine the impact of improved feedlot design and management and of novel biological tools on nuisance fly control and to determine how to optimally combine these tools to provide effective feedlot fly control with minimal use of insecticides. This R&D to include:

- Feedlot design and management
- Development, production and release of parasitic wasps to augment their natural feedlot

population

- Development and application of entomopathogenic fungi
- Design and create a decision support system to integrate biological science, environmental and climate data, management strategies and economic considerations to achieve optimal fly control in cattle feedlots.

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APPENDIX - FLY AND PARASITE POPULATION MONITORING ON CATTLE FEEDLOTS

Appendix

Fly and parasite population monitoring on cattle feedlots

February 2004

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INTRODUCTION

Meat and Livestock Australia (MLA) is currently funding a research project investigating fly species and populations and their control measures in Australian beef cattle feedlots. The research is being conducted by a team of scientists from the Department of Primary Industries and Fisheries (DPI&F) Queensland in collaboration with a research entomologist from the US Department of Agriculture.

Project Background

While the feedlot industry has significantly improved manure management practices over the past decade, thereby reducing both odour and fly problems, there is recognition that flies remain a problem at many feedlots. The threat of insecticide resistance and a desire to minimise the use of chemicals also drive the need to develop a more integrated approach to fly control. Furthermore, the impact of flies on animal and human health and welfare are also important issues to be addressed.

Project Objectives

The major objective of this research was to develop a set of best practice guidelines for the control of fly populations in cattle feedlots by:

- Identifying and monitoring the species and numbers of nuisance flies at a working feedlot for the duration of the project;
- Identifying and monitoring resident parasitic and predatory insects and mites at the feedlot;
- Establishing if there are regional differences in populations of nuisance flies and resident parasitic and predatory insects and mites;
- Identifying the major fly breeding sites within the feedlot;
- Identifying feedlot management practices that either favour or discourage fly breeding;
- Developing alternate methods/approaches to overcome any problems identified with current management practices;
- Assessing the impact of current insecticide use on nuisance fly numbers and parasites and predators;
- Evaluating the resistance of fly populations to currently used chemicals; and
- Utilising the information gathered to develop recommendations for integrated fly management programs, incorporating management practices, life cycle considerations, the strategic use of chemicals and other novel control practices to prevent fly population build-up.

Expected Project Outcomes

- Better control of nuisance and biting flies;
- Fewer complaints from neighbours and feedlot staff about flies;
- Production gains from reduction in annoyance and biting of cattle by flies,
- Reduced insecticide usage;
- Lower risk of resistance to insecticides in major fly species;
- Lower risk of chemical residues in Australian feedlot beef;
- Less negative impact on beneficial predators and parasites;
- Reduced environmental impact;
- Minimal transmission of diseases;
- Enhanced clean-and-green image of feedlot industry and associated market benefits.

The outcomes of this research will ultimately benefit the whole industry as well as individual operators.

FLY AND PARASITE POPULATION MONITORING

Introduction

A comprehensive program of fly and parasite population monitoring was designed and implemented on a feedlot on the Darling Downs in southern Queensland. The selection process for the feedlot and the set-up of the monitoring program were described in FLOT.306 Milestone Report No 2. The population monitoring program targeted adult flies by using different trapping systems and immature fly stages (larvae and pupae) by examination of manure pad/soil samples. The presence and identity of parasites and predators (wasps, mites, fungi) on adult flies and immature stages was also determined from these samples. A progress report on fly and parasite population monitoring was provided in March 2003 (Milestone Report No 4)

One-off monitoring of fly and parasite populations, over three consecutive days, was also conducted in two feedlots located in areas with different climatic conditions. One feedlot was located in central New South Wales, the second in central Queensland.

Fly species expected to be present at the feedlot and for which trapping/collecting systems were put in place, include house flies (*Musca domestica*), bush flies (*M. vetustissima*), stable flies (*Stomoxys calcitrans*), flesh flies (Sarcophagidae), buffalo flies (*Haematobia irritans exigua*), blowflies (Calliphoridae) and black carrion flies (*Hydrotaea rostrata*). Natural enemies which could be present include parasitic wasps, flies, mites, beetles and fungi. Both, adult and immature fly stages were examined for parasites.

The fly and parasite population monitoring program was derived from knowledge of the biology and behaviour of the target species. A brief overview of some important aspect of fly biology is presented here to facilitate various aspects and interpretation of the program.

The rate of reproduction of flies depends on the species of fly and environmental conditions. For example, the house fly can complete a life cycle in as little as 7 days, or take up to 50 days, depending on environmental conditions. The life cycle of the house fly is shown in Figure 1.

Flies breed in mixtures of soil, moisture and partly decomposed organic matter such as manure, spilled feed and decaying silage. The availability of these breeding sites in the feedlot environment depends on the extent of maintenance and sanitation procedures. Fly numbers can increase rapidly unless they are controlled.

Damp pens produce odours that attract flies and provide sites for them to breed. The house fly lays its eggs in organic matter including animal manure that has attractive odours and is within the moisture range of 40-70% water (by weight). The larvae require that moisture range for survival and development while the pupae are found in drier areas. The moisture content of fresh manure is slightly above this range. If pen conditions can be kept outside of this range most of the time, fly breeding activity will be significantly reduced.

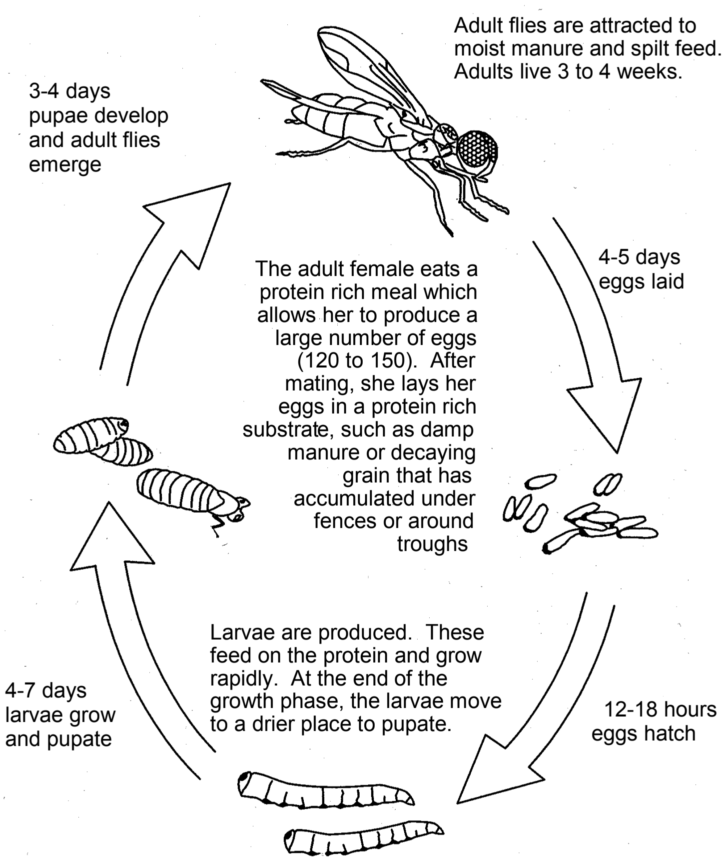

Figure 1 Life cycle of house fly (*Musca domestica*)

Common natural enemies of flies are parasitic wasps, predatory mites and pathogenic fungi. Parasitic wasps lay their eggs in fly pupae and the resulting wasp larvae devour the immature fly before it can develop into an adult. The wasp larvae subsequently develop inside the fly pupal case until they emerge as adult wasps after several weeks. One or several wasps can emerge from one fly pupa.

As well as the parasitic wasps a number of other arthropods occurring in dung can limit fly populations. Predatory mites for example can feed on house fly eggs and larvae. Generally the mites attach to adult flies and beetles to transport populations from one area to another. This sort of behaviour is called phoresy.

Entomopathogenic fungi also contribute to the natural control of insects, including flies. Fungal spores germinate on the fly cuticle and the growing fungi penetrate the cuticle to access food resources, eventually killing the fly. Recent work in DPI&F has demonstrated the potential of using fungi as an effective biological control agent for insects.

Objectives

The objectives of the fly and parasite population monitoring program at the feedlot were:

- Identifying and monitoring the species and numbers of adult nuisance flies throughout the year;
- Identifying and monitoring resident parasitic and predatory insects and mites at the feedlot;
- Identifying the major fly breeding sites within the feedlot;
- Identifying feedlot management practices that either favour or discourage fly breeding;
- Assessing the impact of current insecticide use on nuisance fly numbers, parasites and predators.

Methodology

It was anticipated that fly and parasite populations vary over time (seasonal and shorter term) and with location (different feedlot sites, outside feedlot) and that they are influenced by feedlot management practices. The monitoring program was designed to detect these variations and if possible associate them with a cause. To assist with this task, weather information (temperature, rainfall) and the timing of management practices (cattle pen and sediment pond cleaning, insecticide application) were recorded.

The sampling systems for adult flies were traps with visual or odour attractants. These trapping systems are often species or family specific. Thus, a variety of trapping systems were used to obtain good samples of the target fly species. These systems included Terminator traps (house flies, bush flies), Lucitrap (blowflies), Alsynite traps (stable flies) and sticky sheets (all flies). The impact of adult flies on feedlot cattle was also assessed through quantitative observations of cattle behaviour, such as tail swishes, head tosses, ear flicks and leg stomps.

Flies in their immature stages were collected by core sampling manure, feed and soil in strategic places. An abundance rating for larvae and pupae at these sites was recorded. Larvae and pupae were subsequently extracted from the samples by the use of appropriate flotation techniques.

Parasitic wasps were obtained from sentinel fly pupae exposed in the feedlot environment for one monitoring period, and from the pupae found naturally in the feedlot. Mites were collected from adult flies caught with a sweep net and placed in 70% alcohol. Fungi were isolated from live and dead feedlot flies within a few days of collection.

This report covers the fly and parasite population monitoring activities from October 2001 (start of program) to October 2003. Adult fly populations were measured at weekly intervals from October 2001 to the end of May 2002 and fortnightly afterwards. The number of flies caught in the traps used in time series graphs (fly numbers versus date) are three point moving averages to lessen variability. Immature fly and parasitic wasp population measurements and animal behaviour observations were carried out weekly from October 2001 to January 2002 and fortnightly for the remainder. Inspections for mites and fungi were done a couple of times over the monitoring period.

During the monitoring period, two additional rows of cattle pens were constructed parallel to the existing two rows in the new pen area (see Figure 2). Cattle were introduced to the new pen rows on 31 July and 25 September 2002 respectively.

The locations of fly traps and manure/feed/soil sample collection points are shown in Figure 2. Traps were placed throughout the feedlot and at three locations one to two kilometres outside the feedlot to obtain an estimate of background fly populations. Background locations B1 and B2 were used during the first year, locations B2 and B3 during the second year. Manure, feed and soil samples were obtained from sites considered potentially suitable for fly breeding. At each site five samples were collected to assess differences within the sites, eg in cattle pens around feed bunks, the centre of the pen and under the fence.

The results from the population monitoring program and the discussion are provided in sections, corresponding to the monitoring of adult fly populations, immature fly populations and parasite populations. In each section an assessment of the effects of weather conditions (seasons, short term) and feedlot management on the monitored population is presented.

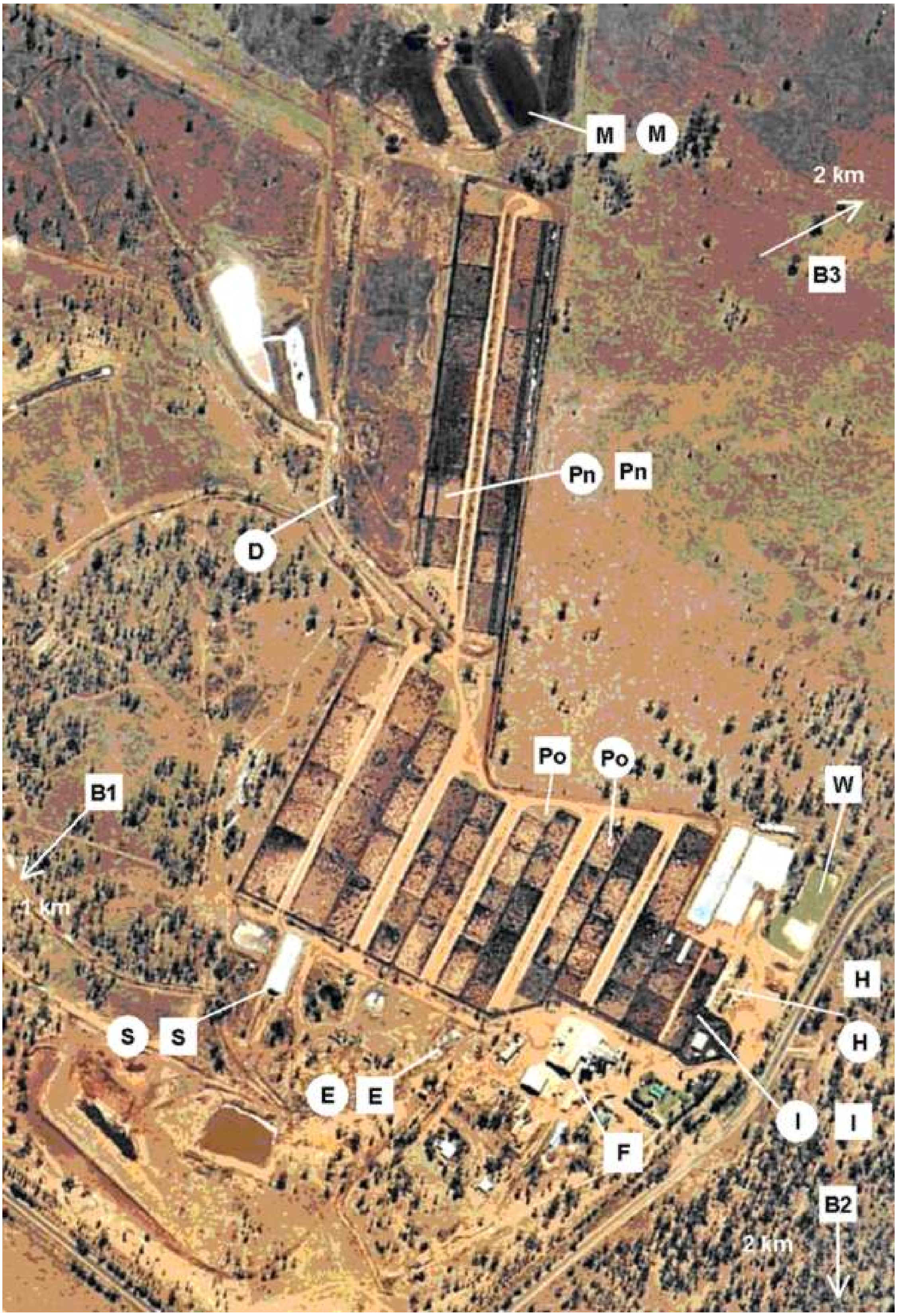

Figure 2 Trapping locations (square labels) and manure/feed/soil sampling sites (round labels) on the feedlot (M manure, P cattle pens {o old, n new}, W water (dam), H horse stables, F feed mill, E sedimentation pond, S silage, I hospital/induction area, D drains, B background traps).

Adult fly population monitoring program

The sampling devices for adult flies were a variety of commercial and experimental fly traps. Most of these traps contain odorous attractants and are designed to attract and trap a wide variety of fly species, while others are more selective for certain genera or species. The traps and attractants routinely used in the feedlot fly population monitoring, along with the target species, are listed in Table 1. These traps were selected from a wider range of traps and attractants initially installed on the feedlot (see Milestone Report No 2) for their consistent performance in attracting target flies.

Table 1 Fly traps and attractants widely used on the feedlot and their target species

Traps	Attractants	Target species
Sticky sheets (yellow)	None	House flies, stable flies
Wind-orienting trap	LDMS	Bush flies, blow flies, house flies
Lucitrap	LDMS	Blowflies, bush flies, house flies
Terminator/Magnum*	Fly attractant (Farnam) plus dead flies	House flies, bush flies
Alsynite (sticky)	None (UV reflecting)	Stable flies

* Same trapping systems in different sizes (referred to as Terminator trap in this report)

The most commonly used traps were the Terminator trap with a commercial liquid attractant (Farnam Pty Ltd) plus dead flies, the Lucitrap with a liver, dung, maggots and sodium sulfide (LDMS) attractant and the Alsynite trap. These traps attract different flies and will predominantly catch their target species from the general fly population. In the Terminator trap, the flies are caught in a large bottle containing a fly-attractive liquid. The flies fall into the liquid and through their decay contribute to the generation and maintenance of the attractant smell. We modified the Terminator trap by inserting a screen which prevented the trapped flies from falling into the liquid. To minimise fly escape from the trap, a pest strip releasing a volatile insecticide was also placed in the mesh insert. In order to maintain the trap's attractiveness, approximately two thousand dead flies (from laboratory fly colony) were added to the liquid at each trap service. The attractant in the Lucitrap was in a separate, screened container, and a volatile insecticide was placed in the trap so that the captured flies could be easily transferred to plastic container or bag. The flies on the sticky sleeves from the Alsynite traps were counted and identified on sticky sleeves.

The traps were serviced weekly (31 October 2001 to 4 June 2002) or fortnightly (18 June 2002 to 28 October 2003). The flies were brought back to the laboratory and stored either in 70% alcohol or dried until sorting, identification and counting was carried out. Smaller batches of flies (up to 1000) were entirely processed, whereas from larger batches a sub-sample of about 1000 flies was processed and the total content calculated from the weight ratio of the sub-sample to the whole batch. The trap catches are reported as average weekly catch unless stated otherwise.

Animal behaviour observations were made to obtain an estimate of the irritation caused by flies on the cattle. The observations were made on two groups of animals in separate pens at fortnightly intervals. The number of head tosses and tail flicks (indicating flies on the body), ear flicks (bush flies seeking moisture around eyes and mouth), and leg stomps (indicative of stable fly presence) were obtained from ten randomly selected cattle in each pen.

Results and Discussion

A list of the fly species caught on the feedlot, with their scientific and when available common names, is given in Table 2. The fly species, which were considered pertinent to the purpose of the nuisance fly project, are listed in the upper part of the table. There were only small numbers of other insects, e.g. dung beetles in the traps, but they have been omitted from this report.

Table 2 Common and scientific name of the fly species trapped at the feedlot

Common name	Scientific name
House fly	*Musca domestica*
Bush fly	*Musca vetustissima*
Stable fly	*Stomoxys calcitrans*
Oriental latrine fly*	*Chrysomya megacephala*
Steelblue blowfly*	*Chrysomya saffranea*
Hairy maggot blowfly*	*Chrysomya rufifacies*
Small hairy maggot blowfly*	*Chrysomya varipes*
Australian sheep blowfly*	*Lucilia cuprina*
Bluebodied blowfly*	*Calliphora augur*
Flesh fly	*Sarcophaga* spp.
None assigned	*Atherigona* sp
Eastern goldenhaired blowfly	*Calliphora stygia*
Lesser house fly	*Fannia canicularis*
False stable fly	*Muscina stabulans*
Black carrion fly	*Hydrotaea rostrata*
None assigned	*Hydrotaea spinigera*
None assigned (small green metallic fly)	*Physiphora clausa (Family Otitidae)*
None assigned	F.Anthomyiidae
None assigned	F. Milichiidae
None assigned	F. Sepsidae
Little dung fly	F. Sphaeroceridae
Soldier fly	F. Stratiomyidae
Hover (Drone) fly	F. Syrphidae
Horse flies	F. Tabanidae
None assigned	SubF. Ameniinae

* Blowfly species used to calculate total blowflies
Fly species above separation line used to calculate total fly numbers

To facilitate an overview of the feedlot fly populations, the blowflies (marked with an asterisk in Table 2) are combined to form one group referred to as total blowflies unless a relevant differentiation is required.

The total numbers of flies, grouped by species, caught in all traps during the monitoring period October 2001 to October 2003 are shown in Figure 3.

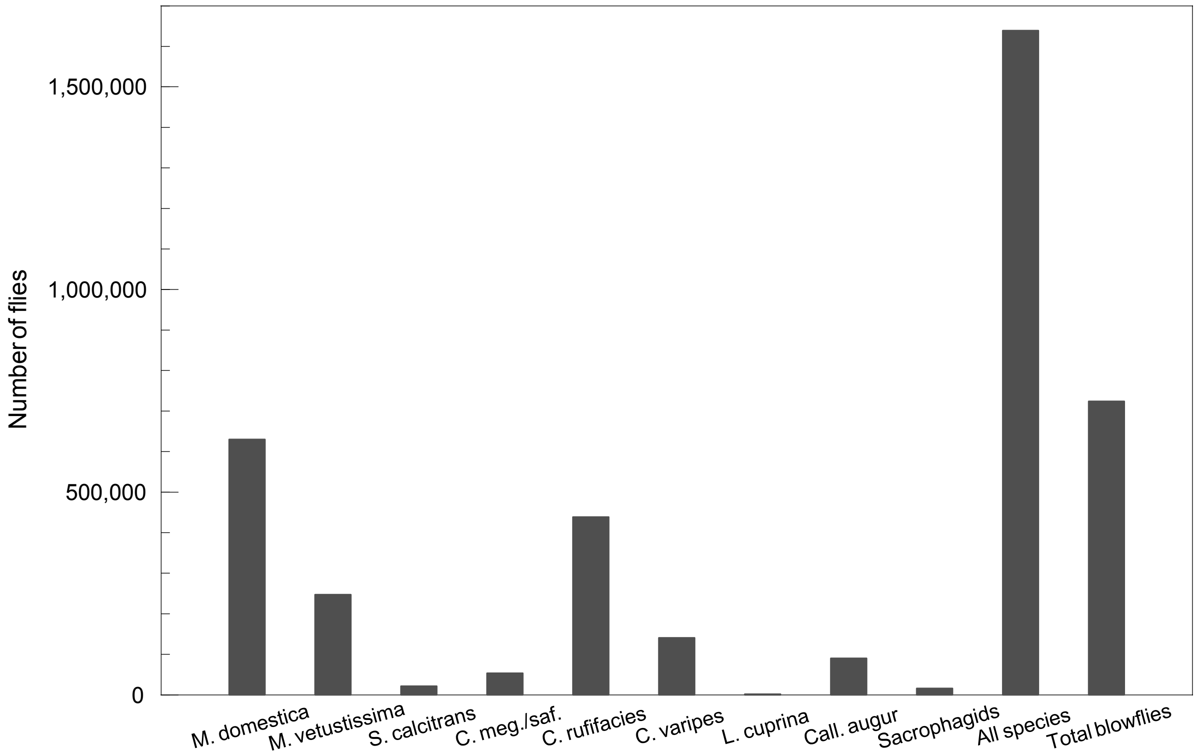

Figure 3 Total number of flies trapped on the feedlot from October 2001 to October 2003

Over 1.6 million flies were caught in the traps and just less than half of these were blowflies. The most commonly trapped species were house flies (630,000, 38%), hairy maggot blowflies (*Chrysomya rufifacies,* 440,000, 27%) and bush flies (247,000, 15%).

Average catches of the four major fly species from all traps over the monitoring period are provided in Figure 4. House flies and blowflies were the dominant species caught throughout the entire period. High numbers of bush flies were observed late October/early November 2002.

The differences between species observed in the average trap catches, do not necessarily correspond to similar differences in field populations. The behaviour of flies and particularly their responses to trap design and attractant results in different “trapability” for each species. This point is illustrated in Figure 5, which shows the average numbers for each fly species caught on the feedlot in three traps with different designs and attractants. The Lucitrap with LDMS attractant caught mainly blowflies, with the hairy maggot blowfly being the dominant species, and to a lesser extent house flies and bush flies. The Terminator trap caught mainly house flies and to a lesser extent bush flies and few other flies. Stable flies were only caught on the Alsynite trap. The Alsynite trap also caught house flies, but less than the Terminator trap, a few bush flies and no blowflies. These differences need to be considered when comparing and interpreting trap catches. The evaluation of feedlot fly populations is made for each fly species from the catches of one or two appropriate traps, eg the Lucitrap for blowflies, the Terminator trap for house and bush flies and the Alsynite trap for house and stable flies.

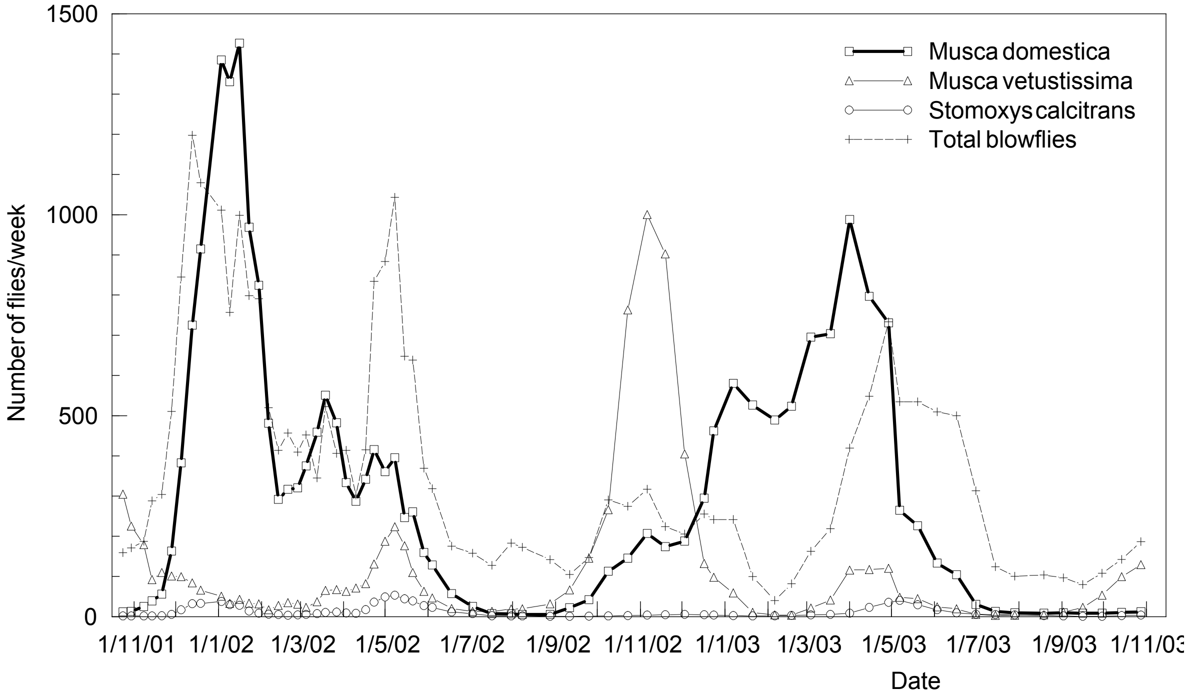

Figure 4 Average weekly catches of common feedlot fly species in all traps from October 2001 to October 2003.

Flies, like other insects, have fluctuating populations under natural conditions and changes in numbers are a reflection of abiotic (environmental) and biotic (parasites, predators, etc) factors. Fly populations are influenced by the availability and suitability of breeding sites and food resources, current and preceding environmental conditions such as air temperature and rainfall, the presence and activity of parasites and predators and feedlot practices such as insecticidal applications. One or a combination of these factors can modify fly populations and it is not always possible to unambiguously associate population changes with a dominant factor. The major seasonal effects on fly populations, the differences between feedlots sites and the effects of feedlot management practices are presented in the following sections.

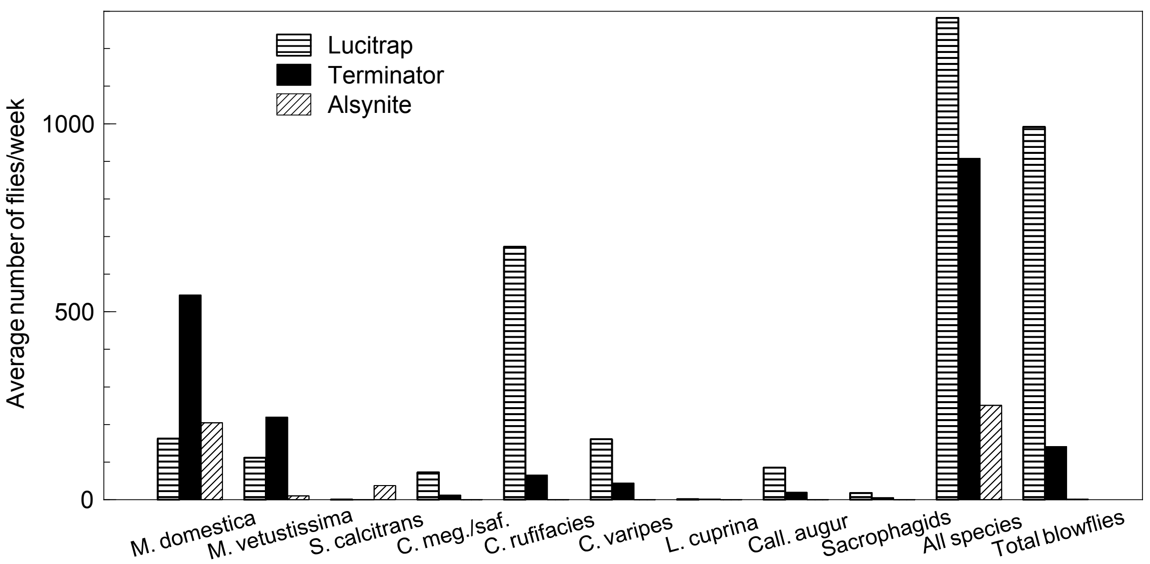

Figure 5 Average weekly fly catches in the Lucitrap, Terminator and Alsynite traps on the feedlot from October 2001 to October 2003.

Seasonal effects on fly catches

The temperature profiles were similar for both years during the monitoring program (Figure 6). The lowest and highest temperatures were –6^{O}C and 40^{O}C, recorded on 1 August 2003 and 12 January 2002 respectively. The lowest monthly average minimum temperature was −0.3 ^{O}C in July 2002 (compared to 3.7 ^{O}C in July 2003) and the highest monthly average maximum temperatures were 32.8 and 32.7 in January 2002 and 2003 respectively. Compared to the long-term (1957-2003) averages (Figure 6) July 2002 had colder nights than average, while summer 2002 and spring and early summer 2003 were hotter than average.

Rainfall was recorded on 180 days (24%), with 50 mm being the highest daily rainfall (23 February 2003). Rainfall totals for the first (November 2001 to October 2002) and second (November 2002 to October 2003) year were 558 and 577 mm, compared to a long term average of 611 mm. The majority of the rainfall (75%) was recorded in the months of October to March, which is consistent with the long term average. Rainfall during the hot January was well below the long term average for both years.

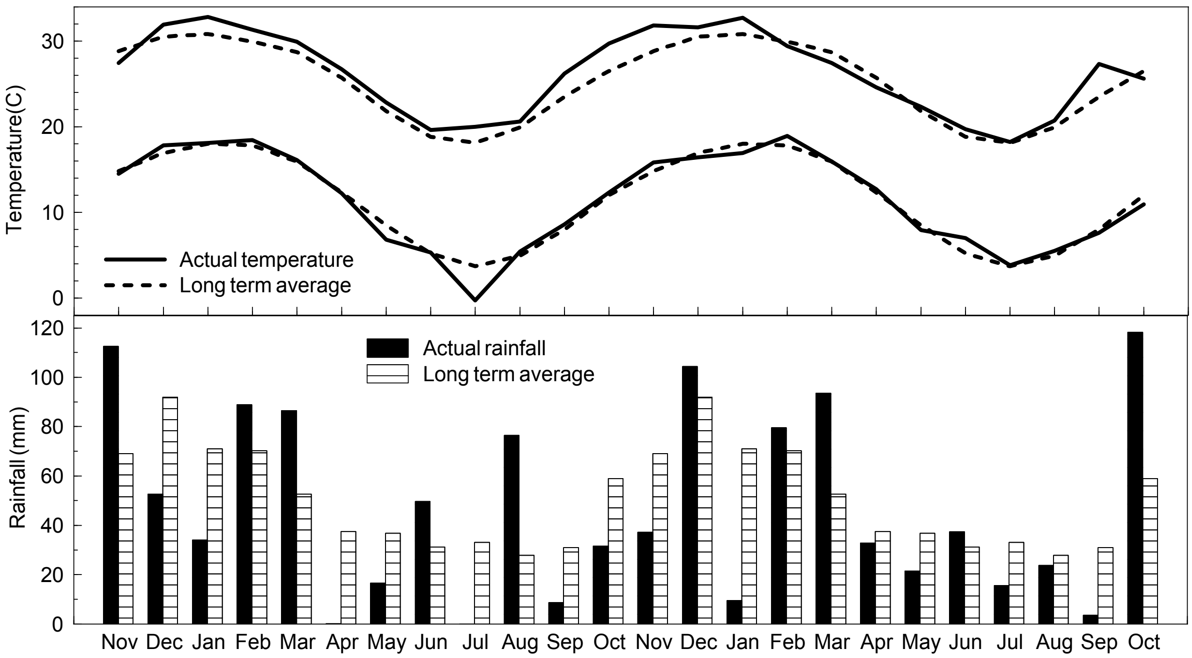

Figure 6 Monthly averages of daily minimum and maximum temperatures and rainfall at feedlot against long term averages

An overview of seasonal catches for house, bush, blow and stable flies in an appropriate trapping system and the corresponding weather data, daily rainfall and minimum and maximum daily temperatures, is provided in Figure 7. All fly species had low populations during the coldest winter months, July and August. Population peaks appeared at different times for different fly species. House flies had one annual, broad population peak starting in spring and extending over about eight or nine months. Bush flies, stable flies and blowflies showed bi-modal seasonal population densities with peaks in spring/early summer and autumn. However, the timing and duration of these fly population peaks varied with species.

More detailed examinations of seasonal fly populations are presented for the major fly species in two ways: Graphical representations of the results by fly species for appropriate trapping systems (Figure 8 to Figure 11) and average weekly trap catches across all feedlot sites for each calendar month (Table 3).

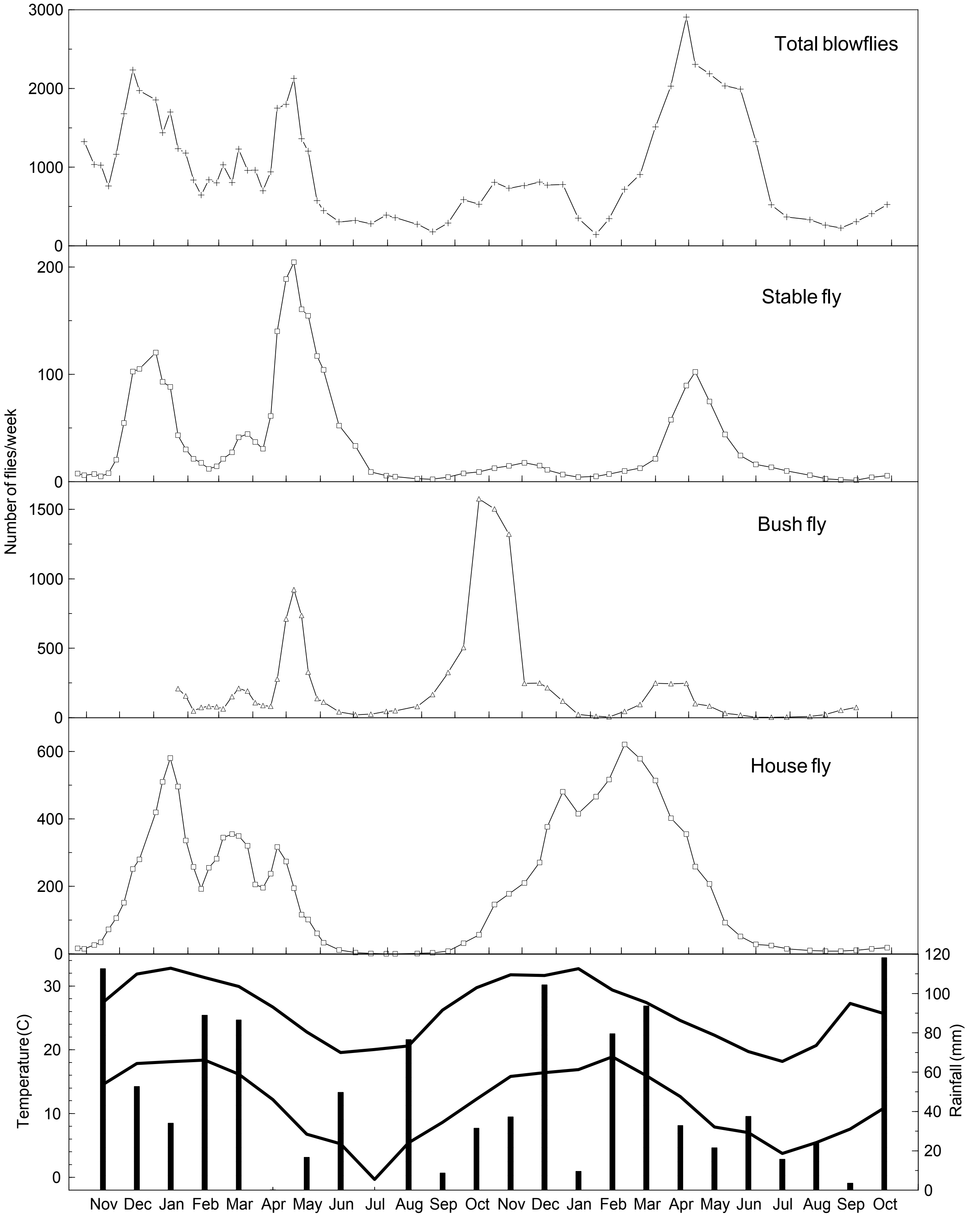

Figure 7 Average weekly trap catches for house and stable flies on Alsynite traps, bush flies in the Terminator trap and total blowflies in Lucitraps, monthly rainfall (bars) and monthly averages of daily minimum and maximum temperatures from November 2001 to October 2003.

Table 3 Average weekly fly catches across all feedlot sites grouped by month

Fly species	Trap	2001 Oct	Nov	Dec	2002 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
M. domestica	Te				7392	1331	1608	1038	723	197	16	12	75
	Al	16	56	251	464	245	333	242	141	15	0	0	5
M. vetustissima	Te				208	74	166	69	501	57	25	48	236
	LT	802	162	126	25	23	46	132	97	13	12	7	23
S. calcitrans	Al	7	7	103	67	18	36	55	177	71	9	3	2
Total blowflies	LT	1261	821	2234	1400	838	1052	777	1591	321	279	345	212
C. meg/saf	LT	6	9	154	147	91	105	32	60	10	1	0	0
C. rufifacies	LT	912	536	1669	1122	735	911	663	1112	139	30	14	33
C. varipes	LT	100	136	329	128	10	34	60	308	39	21	5	29
Lucilia cuprina	LT	17	6	6	1	1	1	1	1	0	0	0	0
Call. augur	LT	227	134	75	2	1	1	21	111	132	226	326	151
Sarcophagids	LT	33	28	29	33	30	28	13	9	3	1	1	4

Fly species	Trap	2002 Oct	Nov	Dec	2003 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
M. domestica	Te	218	228	417	944	683	1150	1448	290	249	6	14	13	
	Al	40	184	285	486	479	614	402	262	58	24	7	8	18
M. vetustissima	Te	595	1912	249	34	1	66	244	100	28	2	8	51	
	LT	285	1797	125	6	0	19	87	12	74	10	5	7	230
S. calcitrans	Al	10	13	14	4	6	12	58	92	30	13	4	2	5
Total blowflies	LT	724	583	808	464	96	1049	2027	2063	2609	520	283	225	522
C. meg/saf	LT	6	12	15	16	3	63	225	384	270	71	2	1	2
C. rufifacies	LT	279	459	667	400	91	890	1185	1157	1017	136	8	53	291
C. varipes	LT	245	96	110	39	1	93	594	490	1163	168	39	5	158
Lucilia cuprina	LT	2	1	1	0	0	0	0	1	1	0	0	0	5
Call. augur	LT	193	15	14	9	0	3	23	30	159	145	234	166	66
Sarcophagids	LT	21	17	27	7	3	23	16	3	11	4	3	17	35

Te Terminator trap; Al Alsynite trap; LT Lucitrap

House flies

Trap catches of house flies in the Alsynite and Terminator traps (Figure 8) showed similar seasonal patterns. The Terminator trap, which includes an odorous attractant is more enticing for house flies than the Alsynite trap. At the initial deployment of the Terminator traps in January 2002 (almost 3 months after the Alsynite traps), only one trap was installed at the manure stockpiles, resulting in high trap catches (up to 7000 flies/week) which are probably not representative of the overall feedlot house fly populations (values off-scale in Figure 8). House flies were found at the feedlot for most of the year except in the coolest winter months. Basically, one broad yearly population peak containing one or more smaller maxima was obtained. The shape and timing of the major house fly population peaks appear to be largely governed by air temperature (see Figure 7). House fly populations will increase when a certain threshold temperature is achieved in spring. A major population decline is only observed after a corresponding drop in temperature. The trap catches grouped by months (see Appendix XX) also show this major seasonal population pattern. The minor population maxima and troughs appear to be correlated with rainfall. Substantial rainfall increases the density of house flies whereas a prolonged dry period, particularly during the warmest months, results in a subsequent population decline. Such minor populations peaks were observed after good rainfall at the beginning of February 2002, the end of March 2002, December 2002 and February 2003. January 2002 and 2003 were hot and dry, resulting in associated reductions in the house fly populations.

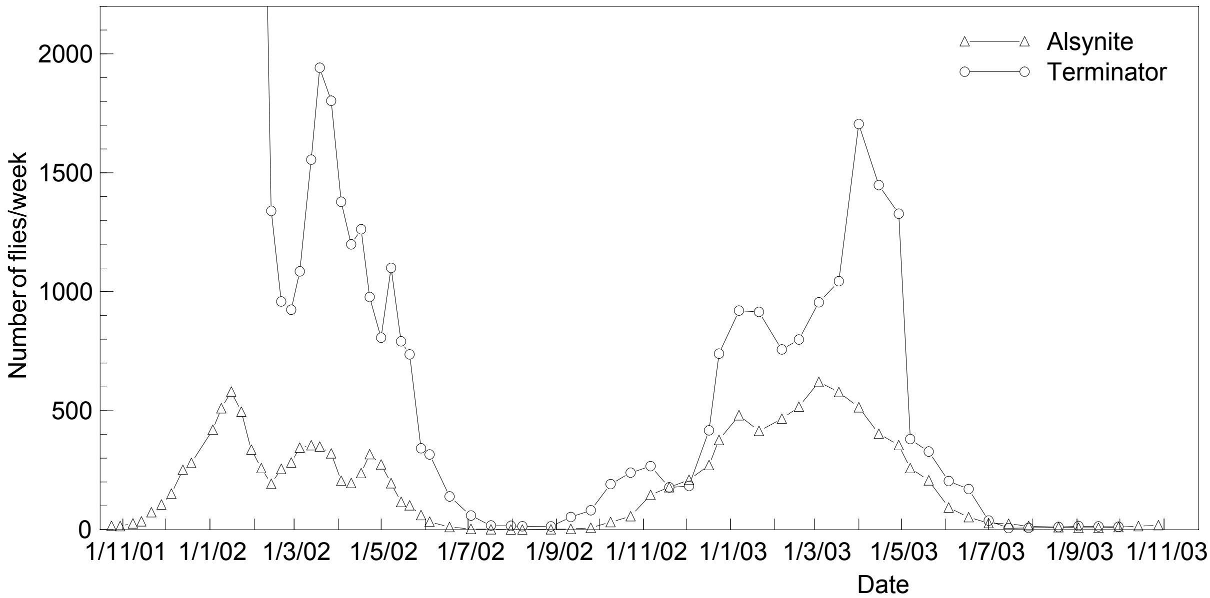

Figure 8 Average weekly *M. domestica* catches in the Alsynite and Terminator traps on the feedlot.

Bush flies

Populations of bush flies were monitored with the Lucitrap and the Terminator trap (Figure 9). The Terminator trap caught more bush flies than the Lucitrap, except during the major bush fly wave when the two traps were equally effective. Compared to house flies, the bush fly population peaks were short lived and occurred at different times of the year. The major peak appeared in spring and its timing coincides with what local farmers call a harvest fly wave. A secondary population peak was observed in April/May. The short duration of the spring 2002 bush fly population peak is striking, with only one fortnightly trap catch 5-10x higher than the preceding and subsequent catches in both trapping systems (the 3-point moving average used for data plotting conceals this fact). As demonstrated in subsequent sections, bush flies do not breed in the feedlot and the trapped bush flies migrate into the feedlot.

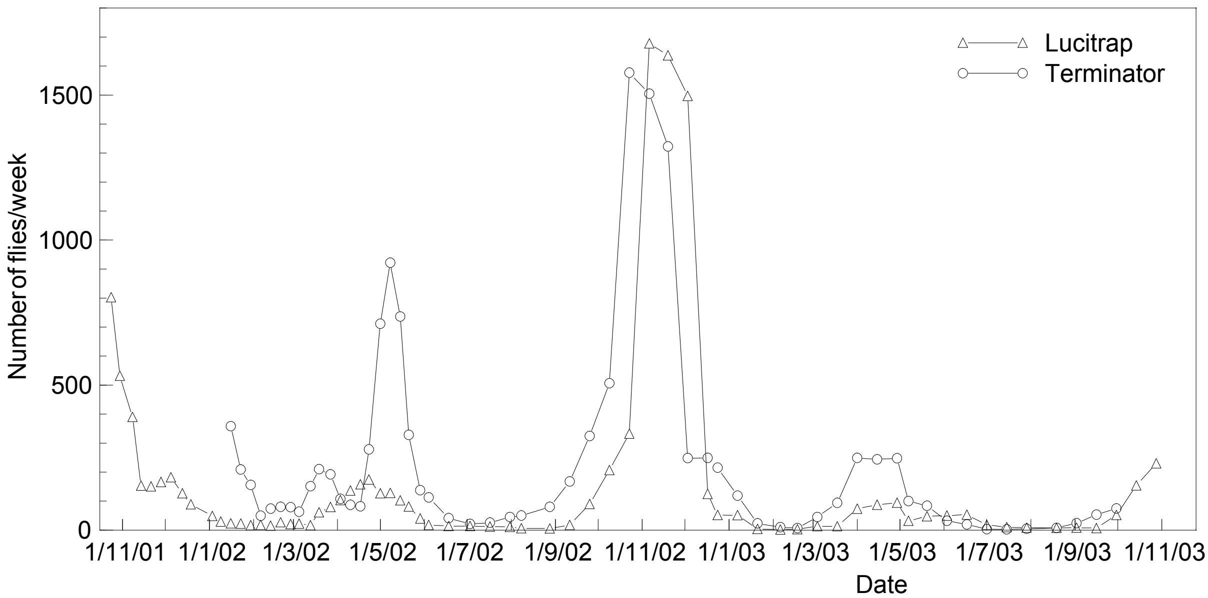

Figure 9 Average weekly *M. vetustissima* catches in the Lucitrap and Terminator trap on the feedlot.

Stable flies

Stable flies were almost exclusively caught on the sticky Alsynite trap, a commonly used surveillance tool for this fly. Fewer stable flies were caught on the Alsynite trap than other flies in the odour-laden traps (Figure 7). The Alsynite trap, which targets stable flies, caught more house flies than stable flies. This reflects the higher density of house flies compared to stable flies on the feedlot. Thus, there are indications that the stable fly populations were at low levels during the whole monitoring program. This observation is also supported by the results from animal observations (see later in report). Stable fly has two annual population peaks in the feedlot, the major peak in late autumn and the minor peak in late spring/early summer (Figure 10). Stable fly populations decline during the middle of the summer and in late winter, but the population reduction in winter occurs later than for the house and bush flies. Stable fly populations were higher in 2001/02 than 2002/03, however there is no obvious weather related explanation for this and it may be due to changes in feedlot operations.

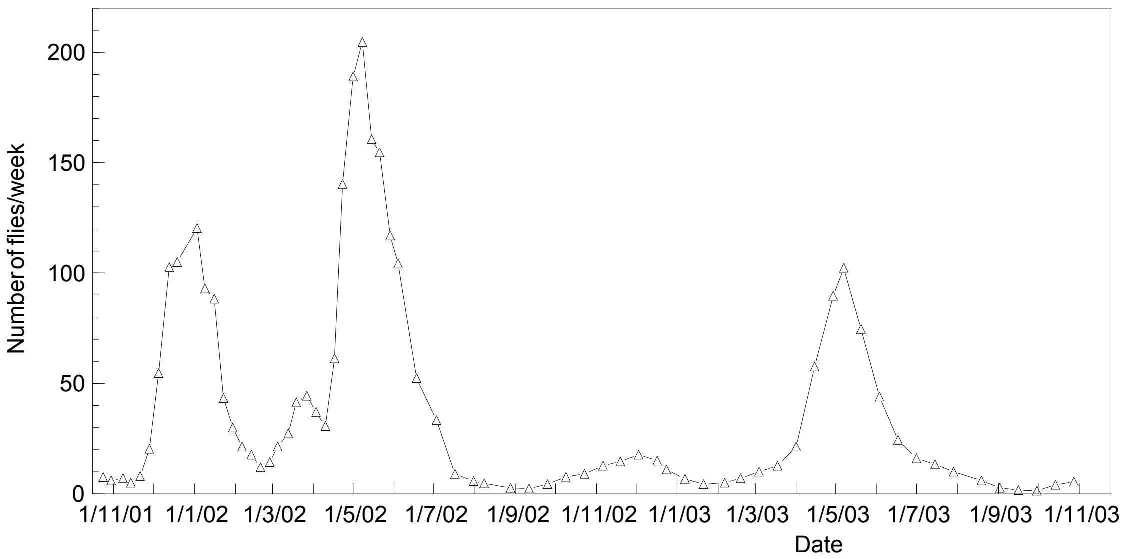

Figure 10 Average weekly *S. calcitrans* catches on the Alsynite trap on the feedlot.

Blowflies

Blowfly populations were assessed with the Lucitrap containing a general fly attractant (liver, dung, sodium sulfide and fly larvae). The seasonal populations of the major blowfly species trapped on the feedlot are shown in Figure 11. The most common species was *Chrysomya rufifacies* (hairy maggot blowfly), followed by *C. varipes* and *C. megacephala/ saffranea*. All *Chrysomya* species flies showed similar seasonal variations, with population maxima in spring and autumn, lower populations during the summer months and few trapped flies during winter. Through their dominance in the Lucitrap catch, *Chrysomya* dictate the seasonal population distribution of total blowflies as shown in Figure 7. *Calliphora augur* (bluebodied blowfly) has a completely different seasonal population distribution (Figure 11). It reached its population maxima in winter and very few *C. augur* were detected during the summer months. *C. stygia* was also caught during the winter months.

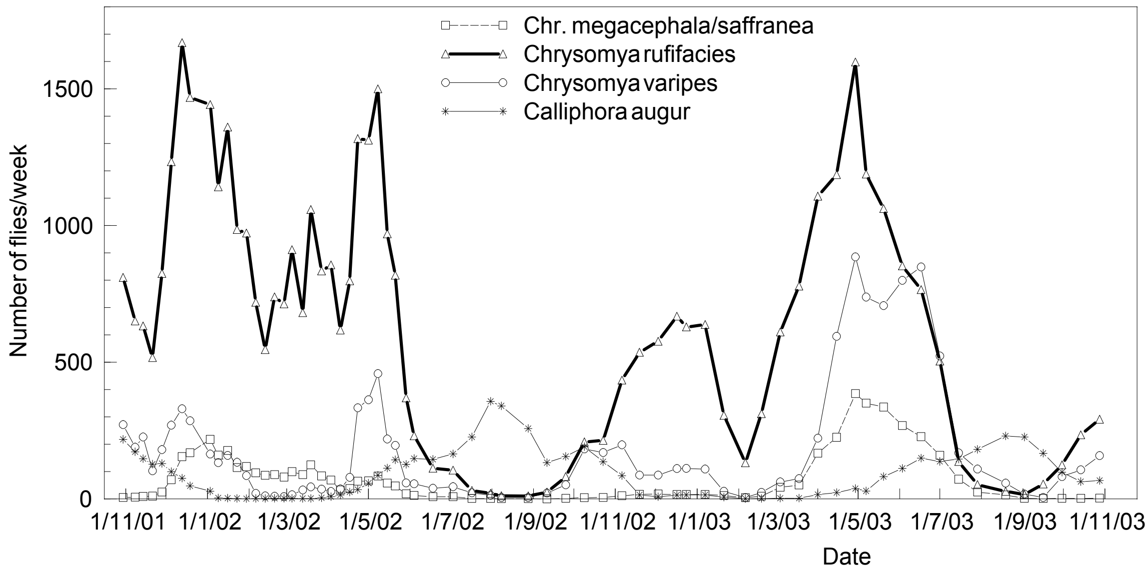

Figure 11 Average weekly blowfly catches in the Lucitrap on the SQ feedlot.

Other fly species

Other flies were caught in small numbers in the traps at the feedlot. A complete listing of trapped fly species is given in Table 2. Australian sheep blowflies (*Lucilia cuprina)* were detected in the Lucitrap with an average weekly catch of 1.3 flies over the whole monitoring period. Likewise, flesh flies (Sarcophagids) were caught in the Lucitrap (17.6 flies/week) with most being trapped during spring, summer and autumn. Milichiids were commonly found around cattle and at the manure stockpiles. Syrphids bred mainly in silage.

In summary, there is clear evidence that feedlot fly populations are influenced by seasonal changes. Air temperature is the main driver of major fly population increases and reductions. Rainfall also affected the populations of some fly species, although to a lesser extent than temperature. There was no prolonged extreme dry or wet period during the monitoring phase, thus the effect of such an event on fly populations cannot be established. The most common fly species on the feedlot, house fly, has one broad yearly population peak extending over most of the year with the exception of the coolest winter months. Minor maxima and minima in house fly populations appeared to be caused by better than average rainfall and drier, hot periods respectively. Bush fly population peaks occurred in spring (major peak) and late autumn and were short lived, lasting for only a few weeks. Stable fly has two annual population peaks in the feedlot, the major peak in late autumn and the minor peak in late spring/early summer. Stable fly populations decline during the middle of the summer and in late winter, but the population reduction in winter occurs later than for the house and bush flies. *Chrysomya* spp. provide the bulk of the feedlot blowflies and they show a similar population profile as stable flies. The bluebodied blowfly has population maxima in winter and is practically absent from the feedlot during the summer.

Comparison of feedlot sites

The locations of the trapping sites within the feedlot were selected from previously published reports and after consultation with the feedlot operators. Fly population monitoring traps were located at or near:

- Feed mill
- Dam (freshwater storage)
- Silage pits
- Sedimentation pond
- Manure stockpiles
- Cattle pens (old and new pens)
- Horse stables
- Hospital/induction area

- Outside the feedlot complex (to establish background levels)

Various traps were placed at each site to ensure anticipated target flies were caught. For the comparisons between sites, fly catches from the same trapping system are compared. However, even differences in trap catches from the same trapping system do not necessarily translate into the same quantitative differences in the fly populations at these sites. The variability in the presence and intensity of other behavioural cues for the flies, such as odour (manure, sedimentation pond, silage, cattle), moisture (animals, water troughs, ponds, dam) and visual effects (animals, vegetation), may increase or decrease the likelihood of flies being caught in traps. Thus, quantitative comparisons between fly populations at feedlot sites have to be considered in this context.

The average weekly number of house flies caught in the Terminator and Alsynite traps at each feedlot site are shown in Figure 12. The relative sizes of the trap catches at different sites are similar in both trapping systems, except for the manure stockpile catches. The Terminator trap which registered a high catch was located between the manure piles and the feedlot pens whereas the Alsynite trap was on the opposite side of the piles next to adjacent paddocks. It is possible that this difference in the traps' location may account for the observed difference. House flies were reasonably evenly distributed across the feedlot, with the highest catches at the cattle pens, the hospital, the horse stables and the manure stockpiles. Low catches were obtained at the sediment pond and the silage pits. It appears that house flies preferentially congregate in areas containing animals. The background traps caught lower numbers of house flies than any of the feedlot sites (Alsynite trap) or similar numbers as the lowest feedlot sites (Terminator trap). This seems to indicate that the house fly populations are higher inside than outside the feedlot.

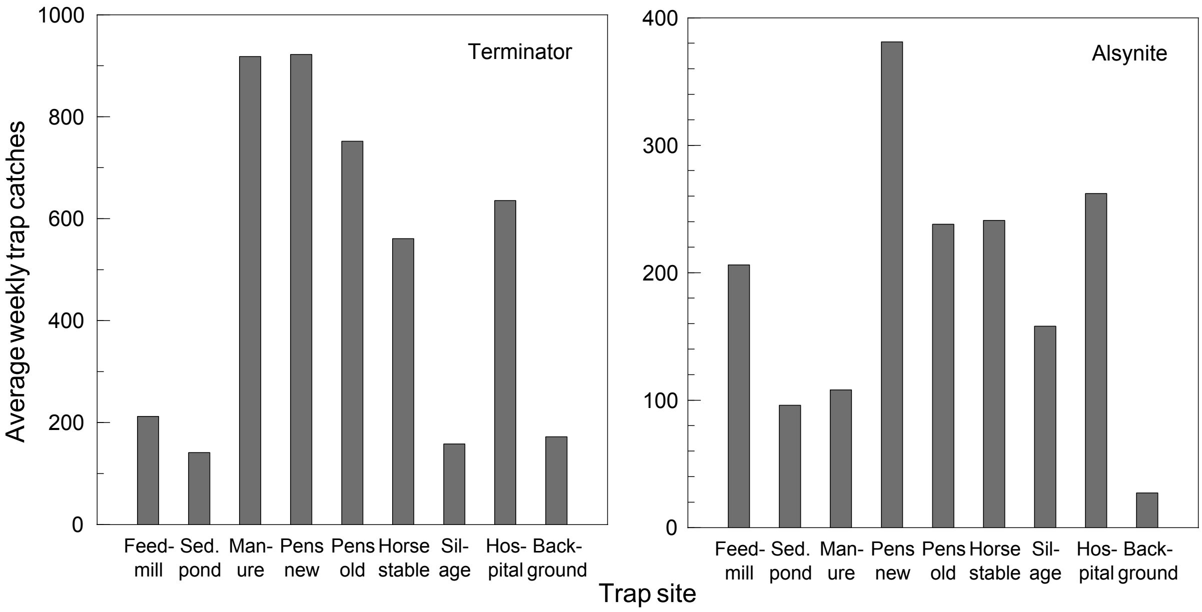

Figure 12 Average weekly *Musca domestica* catches in the Terminator and Alsynite traps for each feedlot site over the monitoring program.

The comparison between feedlot sites for *M. vetustissima* is shown in Figure 13 for the Terminator trap and the Lucitrap. Bush flies were caught at all sites but the correlation between sites was not completely consistent in the two trapping systems. The silage pits, sedimentation pond, hospital and dam had low catches. The background traps and the manure pile traps provided the highest catches. The bush fly catches at all feedlot sites were equal or lower than outside the feedlot (except the Lucitrap at the manure stockpiles).

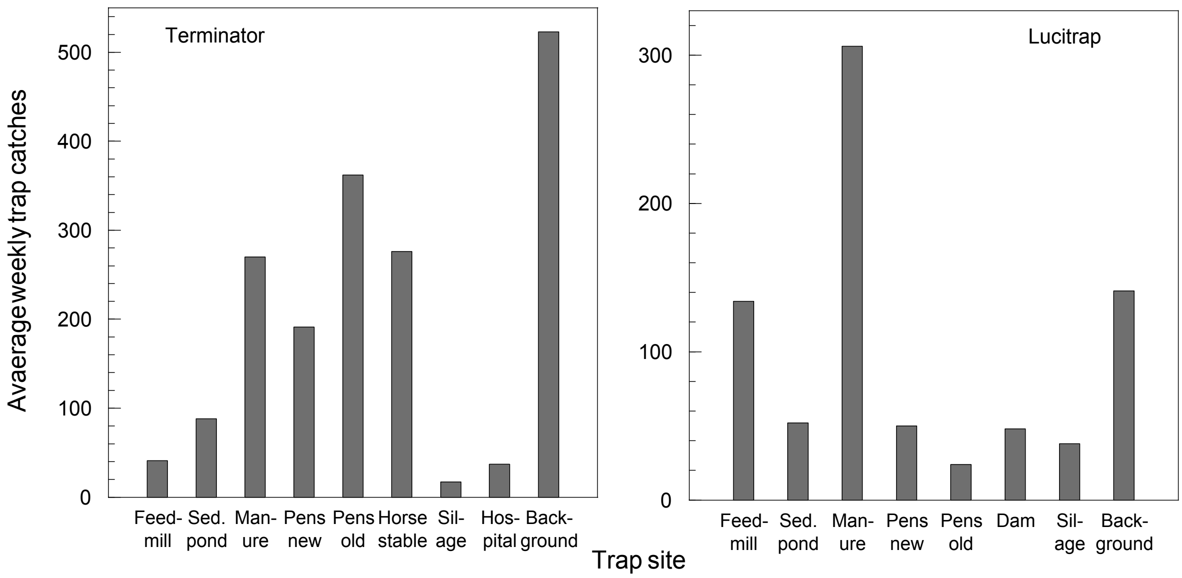

Figure 13 Average weekly *Musca vetustissima* catches in the Terminator trap and Lucitrap for each feedlot site over the monitoring program.

Trap catches for stable flies and blowflies at various feedlot sites are shown in Figure 14. The highest populations of stable flies were obtained at the manure piles and the silage pits. Very few stable flies were caught in the background traps, probably due to the close association between stable flies and animals. Blowfly catches were the highest in the background Lucitraps, followed by the manure stockpile traps. Blowflies breed in small and large animal carcasses and they, particularly *C. rufifacies,* are commonly found in Australian rural areas. The natural background level of blowflies appears to be higher than the populations at the feedlot. It is possible that within the feedlot the increased blowfly density at the manure piles is due to increased attraction to incompletely buried animals and/or to the intrinsically higher odour level in this area.

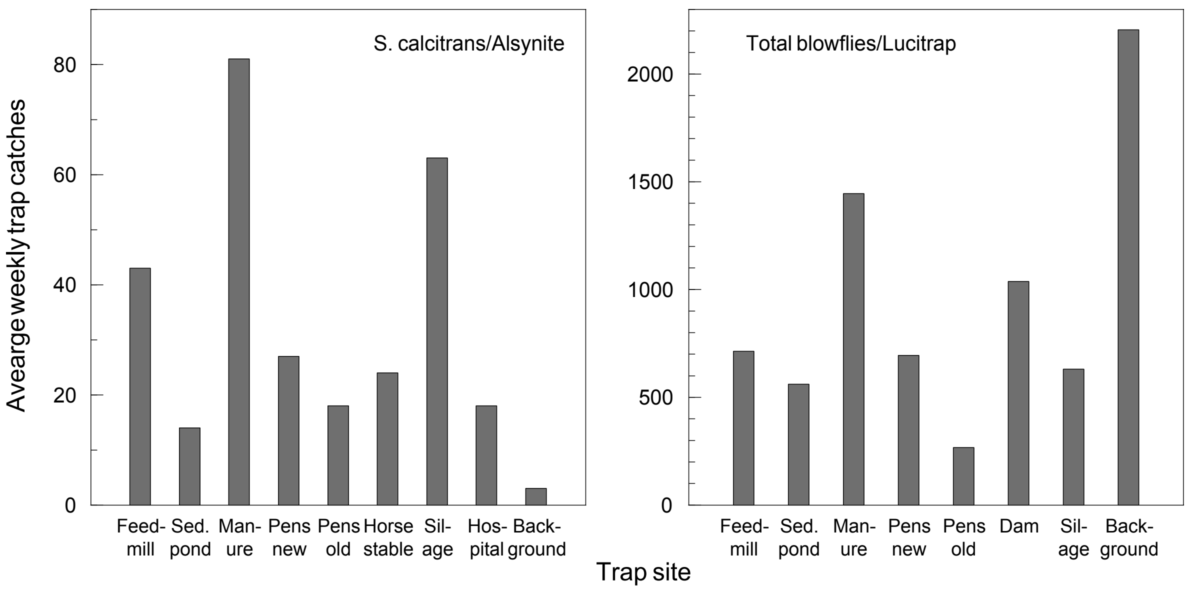

Figure 14 Average weekly catches of *S. calcitrans* in the Alsynite trap and total blowflies in the Lucitrap for each feedlot site over the monitoring program.

In summary, there were clear differences in the distribution of different fly species inside and outside the feedlot. House flies were distributed across the entire feedlot, with populations higher in the vicinity of cattle. House fly populations were higher inside than outside the feedlot. The highest bush fly catches were obtained outside the feedlot and at the manure stockpiles in the feedlot. Stable fly populations were concentrated at the manure stockpiles and the silage pits. Very few stable flies which depend on animal hosts for blood meals were caught outside the feedlot. Blowfly catches were the highest in the traps outside the feedlot, followed by the manure stockpile traps.

Feedlot management practices

The effects of insecticide applications in the feedlot on fly populations are considered in this section. Due to the potential movement of adult flies within the feedlot, these considerations are applied to total feedlot data. Other management practices which are expected to have an influence on flies in the feedlot, e.g. cleaning of cattle pens and sedimentation ponds are considered under the immature fly population monitoring.

Four major applications of insecticides and/or fly baits occurred at the feedlot during the fly monitoring period. The timing of these applications and their associations with the various fly populations are shown in Figure 15. Details of the insecticidal applications, e.g. treatment sites, are provided in Table 4. In addition to the major applications, Methomyl bait was used in the induction area and the hospital when necessary, which could be as often as weekly during the summer months, and in the feed mill several times during each season. Deltamethrin (Arrest) was also used on cattle in the feedlot during the induction of cattle from April to September. This product is used for internal parasite control, however, the residue in the manure may assist with fly control.

Table 4 Insecticide applications in the feedlot between October 2001 and October 2003

Date	Active constituent	Type	Product name	Application sites
23/01/2002	Trichlorfon	Spray	Neguvon	Feed bunks, sedimentation pond, loading ramp
23/01/2002	Cyfluthrin	Spray	Solfac	Induction shed, hospital, horse stables, feed mill, lunch room
23/01/2002	Methomyl	Bait	Dy-Fly	Induction shed, hospital, horse stables, grain pad, workshop, dam, sedimentation ponds, water troughs, tree lines
11/02/2002	Cyfluthrin	Spray	Solfac	Feed bunks, water troughs, fence lines and tree lines (new pens), loading ramp, ends of cattle pens
11/02/2002	Methomyl	Bait	Dy-Fly	Feed bunks, tree lines (new pens), hospital
28/01/2003	Trichlorfon	Spray	Dipterex 500	Feed bunks
25/04/2003	Trichlorfon	Spray	Dipterex 500	Feed bunks
As needed	Methomyl	Bait	Dy-Fly	Induction area, hospital, feedmill

An examination of the flytrap data (Figure 15) indicates that the four insecticidal treatments did not have a major impact on fly populations. The prevalent seasonal trends in fly populations after the treatment appear to be the same as pre- treatment. It is possible that the insecticides had short term effects on fly populations which were not reflected by the weekly (October 2001 to June 2002) or fortnightly (June 2002 to October 2003) monitoring program. The impact of the insecticide treatments on immature fly populations is examined in a separate section.

Work on the resistance status of the feedlot house flies (see FLOT milestone report No 5), had indicated that they were moderately resistant to diazinon (organophosphate, OP) but not or weakly resistant to cyfluthrin (synthetic pyrethroid) and azamethiphos (OP). The feedlot flies showed apparent behavioural resistance to the baits, Snip (azamethiphos and Z-9-tricosene) and Dy-Fly (methomyl and Z-9-tricosene). These findings may be congruent with infrequent insecticidal spraying and more regular use of fly baits at the feedlot.

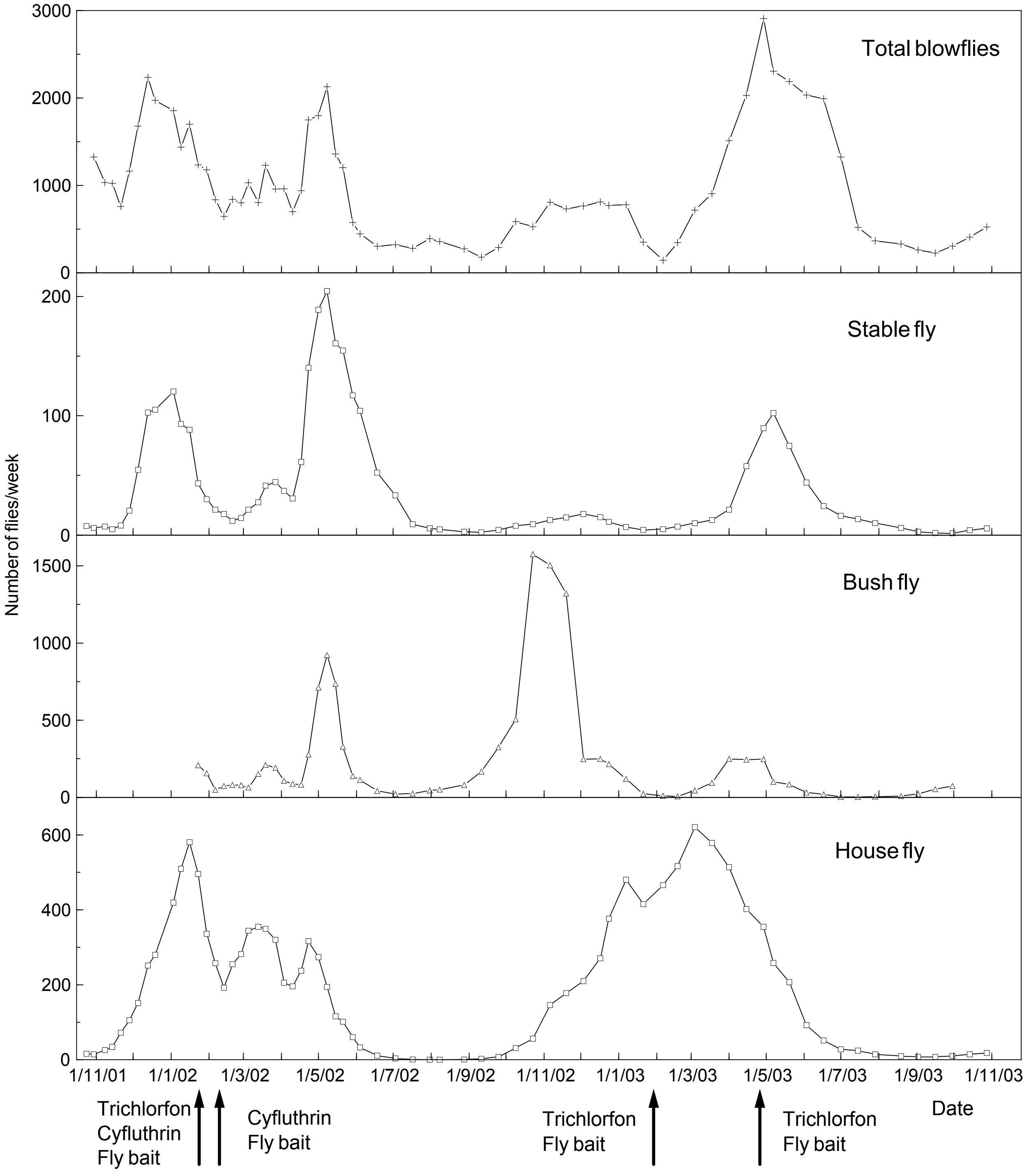

Figure 15 Insecticide applications and fly populations on the feedlot between October 2001 and October 2003.

Observations of feedlot cattle behaviour

Cattle irritated by flies will initiate actions in order to minimise their irritation. These actions aim to reduce the number of flies on cattle or prevent the flies from carrying out their annoying habits, eg collecting moisture from eyes or nose or biting to obtain a blood meal. Such fly-induced cattle behaviour includes bunching up into a tight group (to reduce the surface exposed to flies), tail swishes (to dislodge flies from back and flanks), ear flicks and head tosses (to remove flies around ears and on the head) and leg stomps (mainly to dislodge stable flies which prefer to bite on the lower parts of legs). Observations of feedlot cattle behaviour were made at each feedlot visit in order to obtain an index of fly annoyance.

The number of tail swishes, ear flicks, head tosses and leg stomps observed during one minute were recorded for 10 animals in two pens, one each in the old and new section. The tail had to be rapidly swished above the top of the animal's back to register a count. The average numbers of fly avoidance movements in the old and new pens were calculated and are shown in Figure 16. Tail swishes were the most commonly observed activity, followed by ear flicks. Head tosses and leg stomps were recorded much less frequently. However, the maximum average number of head tosses observed (3/min), still equates to 180 tosses per hour.

The seasonal patterns in the frequencies of cattle movements were similar in the old and new pens but the numbers of movements were generally higher in the new section (Figure 16). The average numbers of tail swishes/ear flicks over the whole observation period were 6.1/1.9 and 7.6/3.2 movements per minute for the old and new pens respectively. This pen difference could be attributed either to differences in fly populations or to dissimilar fly sensitivities of the animals. Populations of *M. domestica*, the major fly species, were higher at the new compared to the old pens (see Figure 12). The new pens were partly covered by shade cloth which was not present in the old pens. A higher density of flies was observed on the animals in the shade compared with animals in the open. In hot weather most animals congregated under the shade cloth and this may explain the observed increase in the frequency of animal movements. The old and new pens housed different predominant cattle breeds with dissimilar feeding regimes. The new pens largely contained long-fed cattle for the Japanese market whereas the old pens were stocked with short-fed domestic cattle. The relative sensitivity of these cattle breeds and the extent of their avoidance reactions to flies are not known. Thus, it is possible that the observed difference in fly avoidance movements could be due to either the prevalent fly populations or the animals' fly sensitivity.

The total numbers of animal movements (tail swishes + ear flicks + head tosses + foot stomps) correlate well with the average catches of *M. domestica* and *M. vetustissima* on Alsynite traps located at the new cattle pens (Figure 17). The seasonal trends in the frequency of animal movements and in the trap catches are almost identical. During most of the monitoring period, the animal movements closely reflect the house fly catches, indicating that this species is causing most of the nuisance. A swift increase in movements in September/October 2002 coinciding with high *M. vetustissima* and low house fly populations indicates clearly that bush flies also irritate feedlot cattle. It is interesting that fly avoidance by the animals was stronger in the initial than the latter parts of both seasonal *M. domestica* populations. This seems to indicate that cattle are more irritated/annoyed at the start of a fly wave (Figure 17). The close correlation between trap catches and animal movements indicate that the latter are a useful measure of fly burden in a feedlot situation. Animal movements can be readily assessed without any investments in fly monitoring technology.

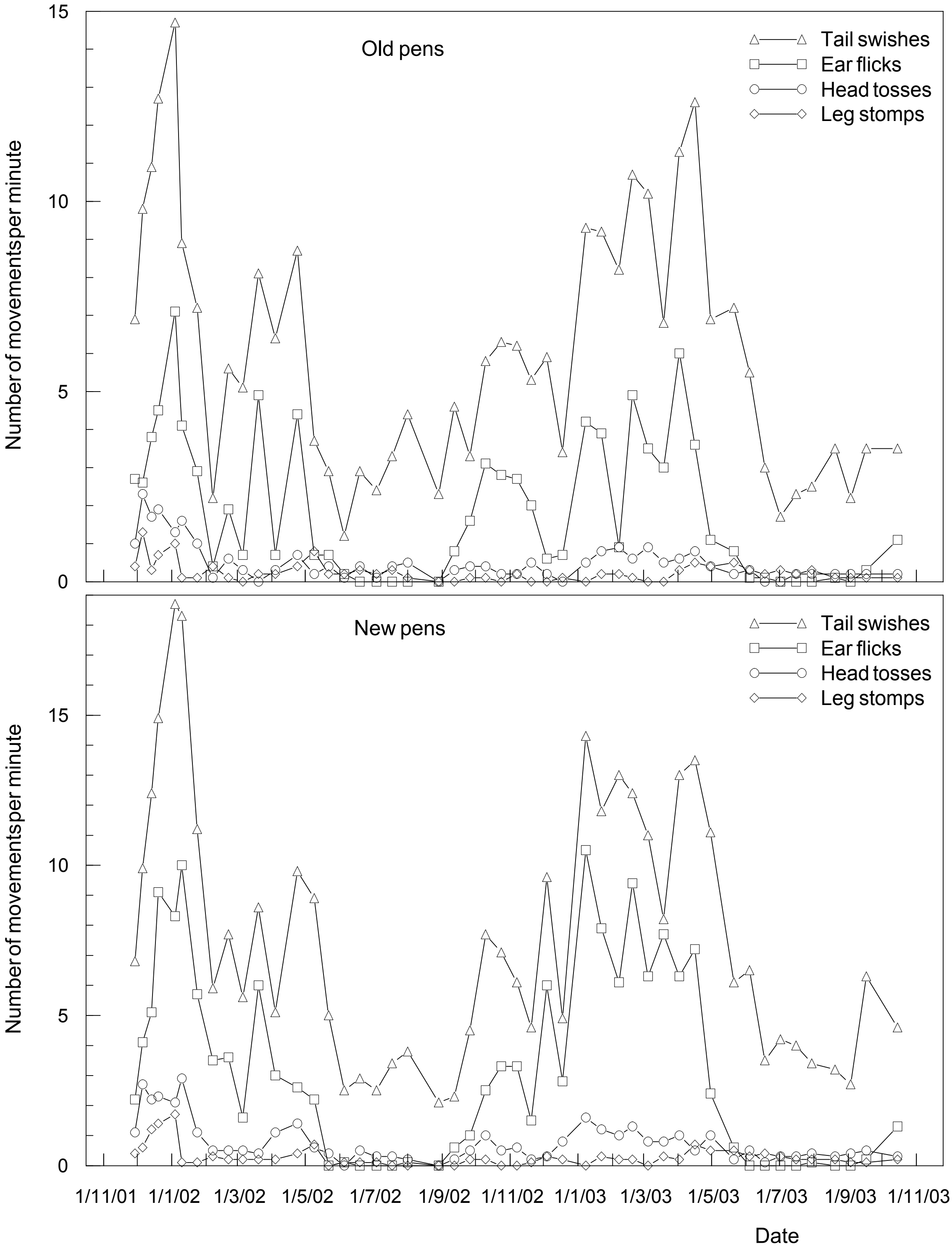

Figure 16 Average numbers of animal movements per minute in the old and new cattle pens at the feedlot over the monitoring period. Average is from 10 randomly selected animals.

It is generally assumed that leg stomps are a defensive reaction to biting stable flies. This hypothesis was confirmed by the high seasonal correlation between the number of stable flies caught and the number of leg stomps (Figure 18). The graphs for stable fly populations and number of leg stomps have similar seasonal patterns over the monitoring period. The seasonal population peaks of stable flies appear at a different time than those of the house flies and bush flies.

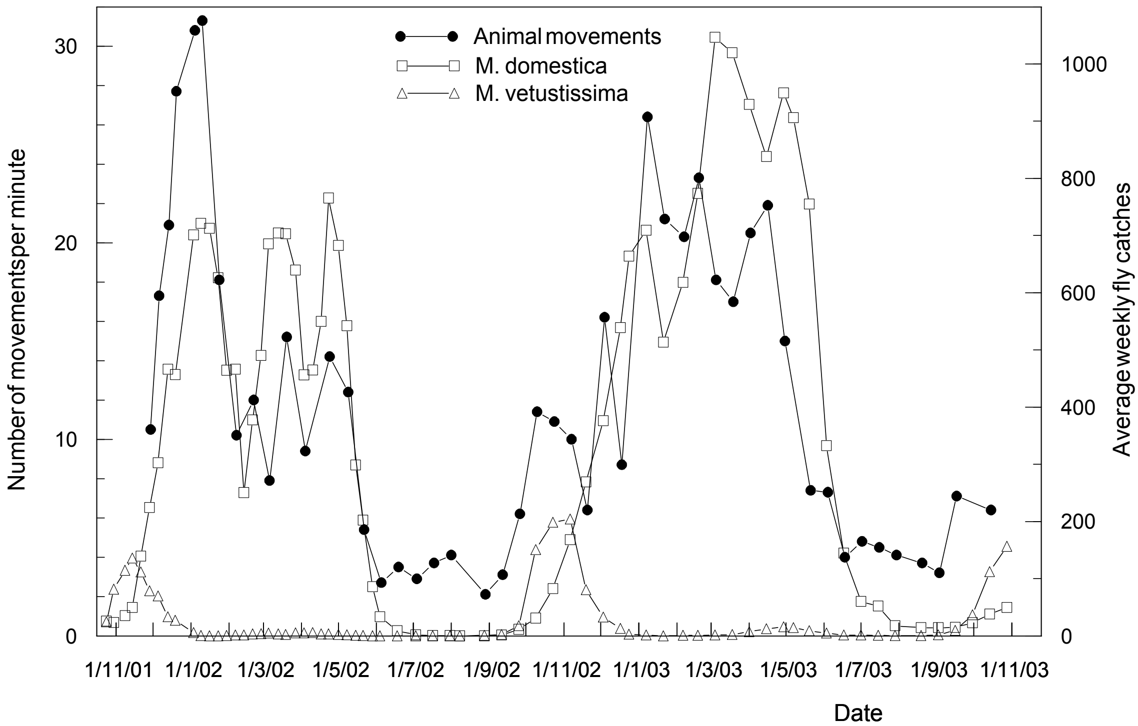

Figure 17 Average number of animal movements (tail swishes + ear flicks + head tosses + foot stomps) per minute and average number of *M. domestica* and *M. vetustissima* caught on Alsynite traps at the new cattle pens.

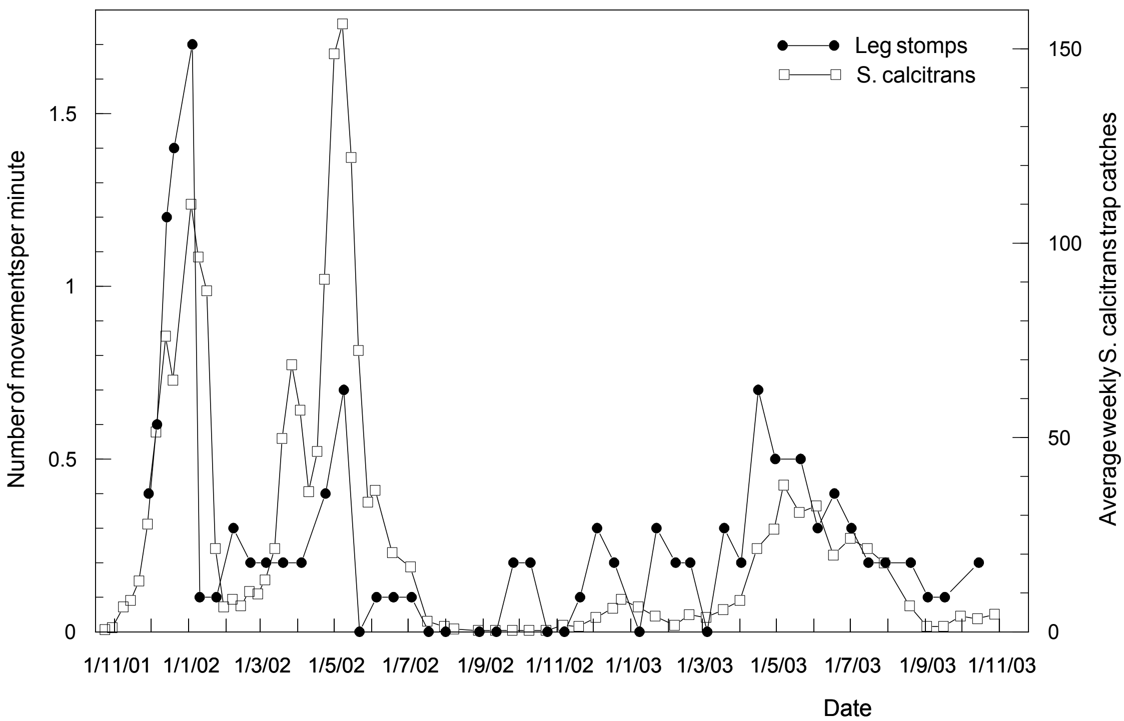

Figure 18 Average number of leg stomps per minute and average number of *S. calcitrans* caught on Alsynite traps at the new cattle pens

Immature fly population monitoring program

Adult Muscid flies lay eggs in suitable sites for the eggs to hatch (less than 1 day) and the larvae to feed (4-7 days) followed by pupation either in the same site or after migrating to a more suitable site. After another 3-4 days a fresh fly emerges from the pupa. Different fly species require different substrates in which to lay their eggs, eg manure/spilt feed for house flies, undisturbed dung for bush flies and buffalo flies and vegetable matter mixed with dung/urine for stable flies.

A program was implemented to establish which flies were breeding where, when and to what extent in the feedlot. Samples of suspected fly breeding substrates were collected from various sites around the feedlot at fortnightly intervals (with the exception of November and December 2001 when weekly collections were obtained). The target sites for immature collection included:

- Sedimentation pond
- Horse stables/yards
- Manure stockpiles
- A particular cattle pen in the older section of the feedlot, having minimal pen surface gradient (old pens)
- A particular cattle pen in the newer section of the feedlot, having optimal 3% pen surface gradient (new pens)
- Silage pits
- Hospital/induction area
- Drains

Five samples were taken from each site and abundance ratings (0 none, 1 very low, 2 low, 3 medium, 4 high, 5 very high) for larvae and pupae in each sample were recorded in the feedlot. Cattle dung, feed residues or soil where fly larvae and pupae had been detected were sampled. Within one site the five samples were taken from similar locations at each collection, eg in the cattle pens from behind the feed bunk, in the middle of the pen and under the two side and the back fences. This sampling regime allowed us to determine where fly breeding sites were and whether there were preferred locations within each site.

The samples were subsequently processed in the laboratory, with pupae and third instar larvae (about 3-6 days old) collected from each sample by sequential flotation in water and salt solution. The extracted larvae and pupae were subsequently identified and counted. Intact pupae were placed individually in gelatine capsules to determine whether a fly, a wasp or nothing emerged. Data directly related to fly breeding is discussed in this section. Details of wasp emergence from pupae are presented in the section on parasites.

Results and Discussion

The vast majority of immatures found in the feedlot were house flies, with 86% of larvae found during the entire monitoring program belonging to this species. Stable fly (10%) and *Physiphora clausa* (Otitidae) (3%) larvae were also detected on the feedlot in significant numbers, while all other larvae together accounted for less than 1% of the total. The results and discussion in this section will generally be limited to house and stable flies with a few references to *P. clausa.*

Seasonal effects on fly breeding

The average larval abundance rating and the average number of house fly and stable fly larvae recovered from the samples (across all monitoring sites) over the monitoring period from October 2001 to October 2003 are provided in Figure 19. House fly larvae were much more abundant in the feedlot samples than stable fly larvae for all samples, except for the coldest winter months when larval numbers were very small. The figure shows a tight correlation between the field observations (ratings) and the number of house fly larvae extracted from the samples in the laboratory. The smaller numbers of stable fly and *P. clausa* larvae contributed noticeably to the overall larval rating during March to May 2003 when they constituted a substantial portion of larvae found in the feedlot.

The abundance of house fly larvae showed a clear seasonal dependence. Very few larvae were detected during the coldest winter months (July/August 2002, August 2003), whereas at warmer times (November to May) large numbers of larvae were observed. For both years, there was a small decline in the larval numbers during January. These reductions were most likely caused by the hot and dry conditions which predominated in January (see Figure 7). Insecticides were sprayed in the feedlot in late January in both years (see Figure 15), but were unlikely to have caused the observed reductions as they happened towards the end of or after the decline. The numbers of house fly larvae and the larval ratings were higher during the 2002/03 seasons than the corresponding 2001/02 periods, particularly during the autumn.

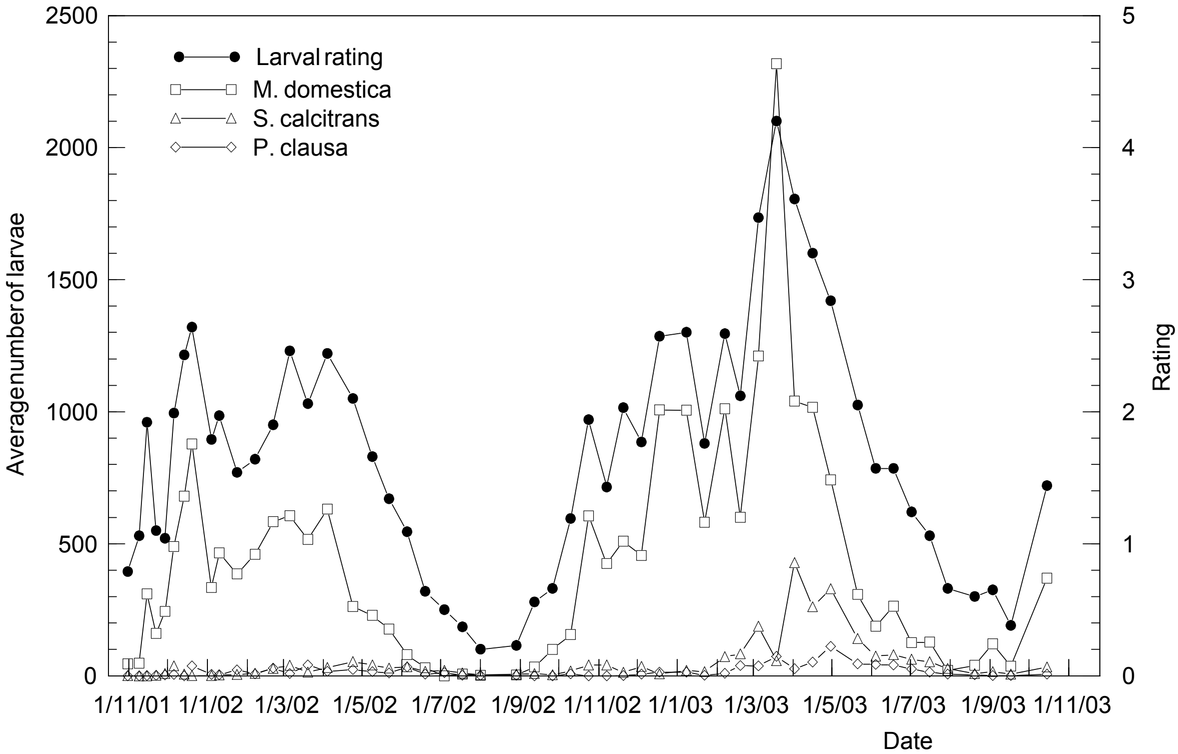

Figure 19 The average larval abundance rating and the average number of house fly, stable fly and *P. clausa* larvae recovered from feedlot samples (across all monitor sites) over the monitoring period from October 2001 to October 2003.

Stable fly larvae were most abundant during March to May 2003, followed by minor abundance peaks in April to May and October/November 2002. During the hot summers, stable fly larvae were almost absent from the feedlot but they persisted during the entire winter. This agrees with other reports which found the preferred temperature range for stable flies to be lower than that of house flies.

The results for pupae are similar to the larval findings. There is a good correlation between the abundance ratings in the field and the number of pupae extracted from the feedlot samples in the laboratory (Figure 20). The seasonal effects on the abundance of pupae are similar to the ones observed for fly larvae. Within and between season trends are the same for larval and pupal abundance.

A comparison between the seasonal effects on house fly larval and pupal abundance and trapped flies also reveals a clear correlation (Figure 21). The peaks and troughs in the house fly trap catches generally follow those of larval and pupal abundance with a couple of weeks delay. As the immature stages progress to adult flies, a lag of about one to two weeks is to be expected in hot weather, somewhat longer in cooler conditions.

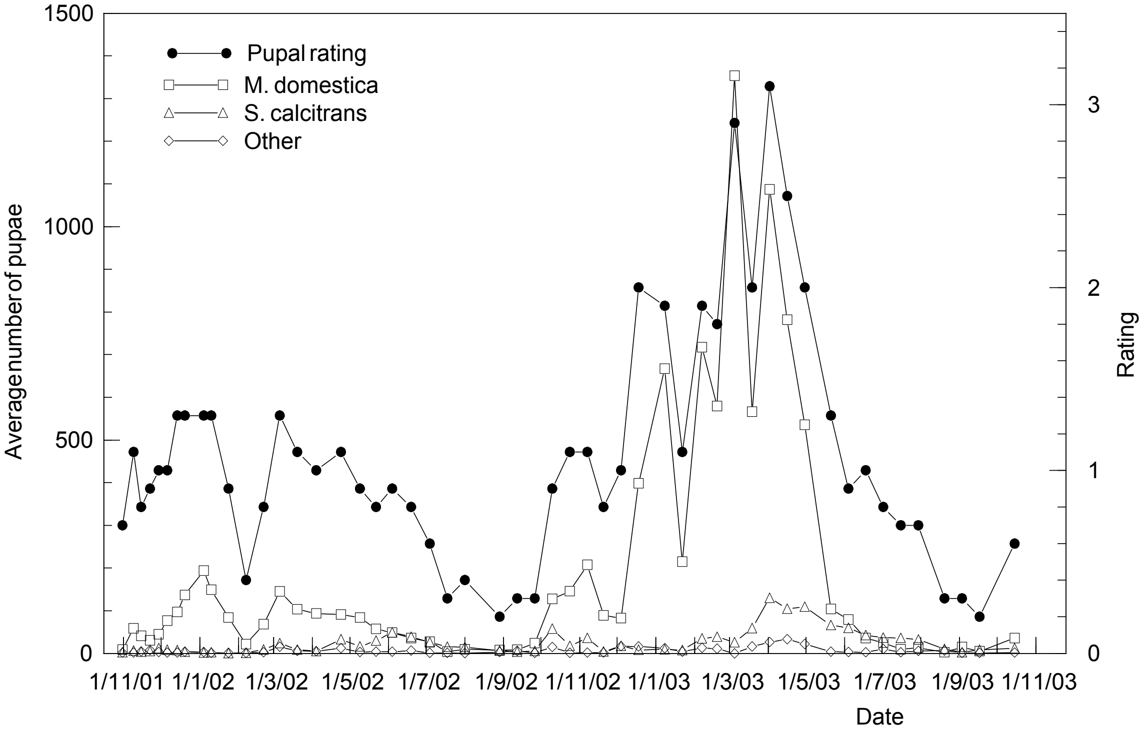

Figure 20 The average pupal abundance rating and the average number of house fly, stable fly and other pupae recovered from feedlot samples (across all monitor sites) over the monitoring period from October 2001 to October 2003.

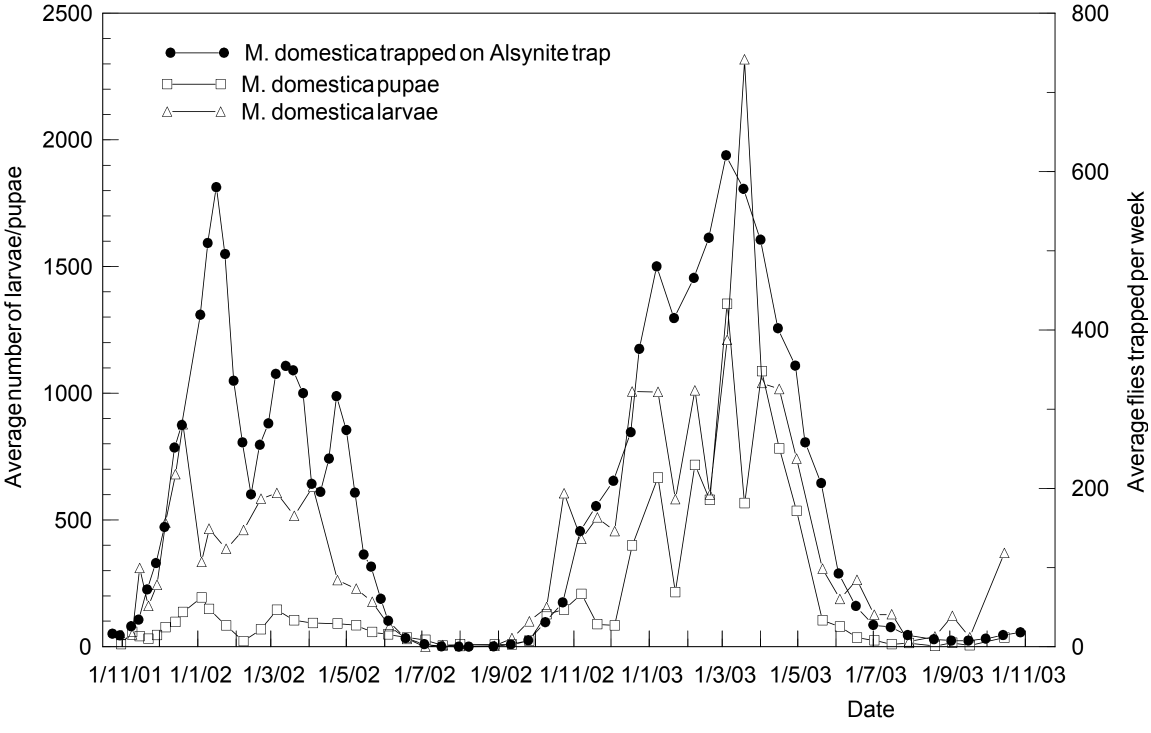

Figure 21 The average numbers of house flies trapped on Alsynite traps and house fly pupae and larvae recovered from feedlot samples (across all monitor sites) over the monitoring period from October 2001 to October 2003.

The seasonal abundance of larvae and pupae closely matched the patterns observed for adult flies. The majority of extracted larvae and pupae were house flies, which were found in elevated numbers over about 9 months of the year (October to June). Stable fly larvae and pupae were recovered at much lower numbers and their major population peak was in autumn 2003 with two minor peaks in spring and autumn 2002. During the hot summer almost no immature stable flies were found in the feedlot. It appears that the observed fluctuations in larval and pupal populations are a result of seasonal changes.

Comparison of feedlot sites

The immature fly sampling program was designed to locate the breeding sites of the various feedlot fly species. In the previous section It was demonstrated that the abundance ratings obtained in the field and the number of extracted larvae and pupae are positively correlated. The numbers of larvae extracted from the various sites were subsequently selected to evaluate feedlot fly breeding. Two of the feedlot sites, the drains and the hospital, were only monitored from January to October 2003, all other sites from October 2001 to October 2003.

The average numbers of house fly, stable fly and other fly larvae extracted from feedlot sites over the whole monitoring period are shown in Figure 22. Larvae were found in all selected sites, with average extractions of all species ranging from 150 to 850 larvae per sample. The highest average numbers of house fly larvae were recovered from the hospital and the cattle pens. The sedimentation pond, manure stockpiles, silage pit and drains produced values close to the average, whereas the yield of larvae from horse stable samples was well below the others. Stable fly larvae were found in highest numbers in the drains and the hospital. The sedimentation pond also contained above average stable fly larvae whereas the other sites were below average.

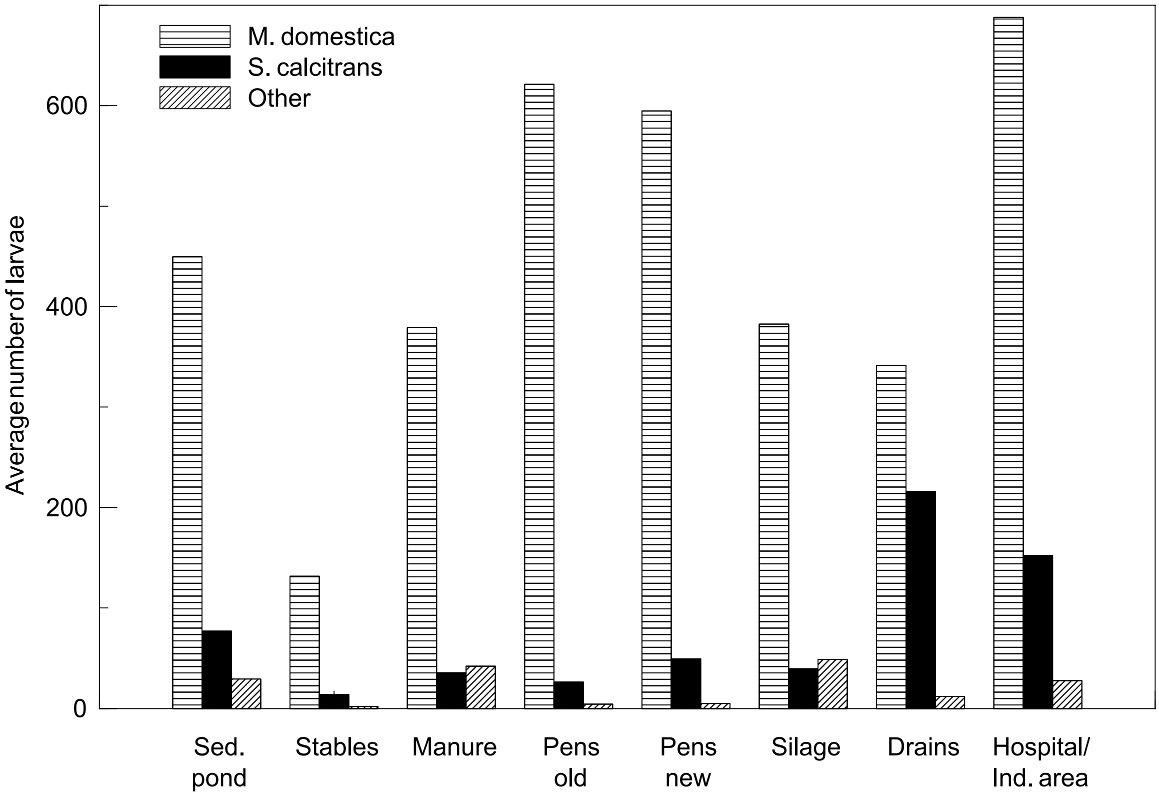

Figure 22 Average numbers of larvae extracted from various feedlot sites over the whole monitoring period.

The induction area contains a high proportion of fence lines and as cattle are only temporarily held in this area, the manure is not compacted as much as in cattle pens. The induction area is adjacent to the hospital where hay is used as feed. These factors combined provide ideal breeding grounds for a variety of fly species. The mixture of vegetation, manure and moisture in the drains and sedimentation pond also provides an ideal combination for fly breeding, particularly for stable flies. The old and new cattle pens had equally large numbers of house fly larvae. They provide suitable and obviously preferred sites for egg laying and larval development, particularly the soft, humid and undisturbed manure under the fence lines (see below). The silage pits and manure stockpiles also contribute markedly to fly breeding on the feedlot. The presence of fibre, protein and moisture at the bottom of the silage pits supports fly breeding. The silage pits were used only intermittently after November 2002 with filling delayed until January 2003 due to prolonged drought and resulting high silage prices. Pit 1 and pit 2 were again empty in March and June 2003 respectively and were not refilled for the remainder of the monitoring period. A higher number of larvae may well have been found at the silage pits if they had been continuously used.

In view of the large seasonal differences in larval numbers (as discussed in previous section), we investigated whether the overall site differences were consistent across the seasons. Average numbers of house fly and stable fly larvae extracted from samples from the different sites, grouped by seasonal quarters over the period from November 2001 to October 2003, are shown in Figure 23 (there are no averages for the drains and hospital available in the October to December quarter as sampling in these areas only started in January 2003). The numbers of house fly larvae for the sites with the highest overall averages, the hospital and cattle pens (old and new) were, compared to the other sites, consistently high across the quarters which have a high fly production (summer, autumn, spring). The medium rated sites showed seasonally variable results, eg the sedimentation pond was high in summer and spring, and the manure stockpiles were high in autumn and winter. Most of the house fly larvae in winter were found in the manure stockpiles, which appear to maintain fly production through heat generated by the composting process. Stable fly larvae were principally found in the drains and the hospital with several other sites also producing good numbers in the autumn quarter.

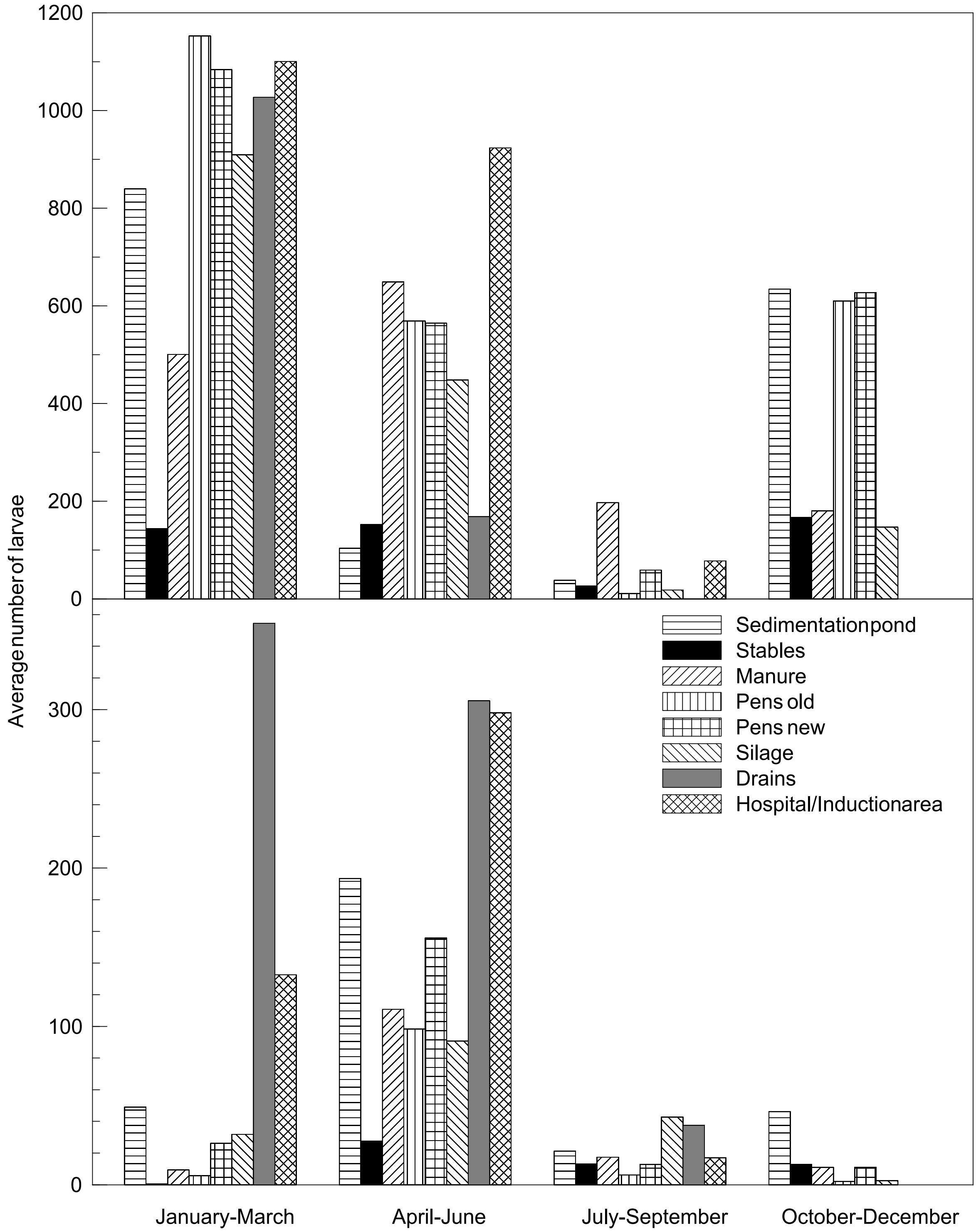

Figure 23 Average numbers of larvae of house flies (upper) and stable flies (lower) recovered from various feedlot sites grouped by quarters (no values for drains and hospital October-December).

The numbers of pupae extracted from the samples were lower than the corresponding larval numbers for all sites except for the drains and silage pits where they were similar (Figure 24). A lower number of pupae than larvae can be expected at the same site, as not all larvae will survive to pupate. The time taken for developing from larvae to pupae and the spatial movement of larvae can cause differences in larval and pupal abundance at one site. It is well documented that larvae wander off into drier matter prior to pupation and this may well account for the smaller proportion of pupae compared to larvae found in the stables, the sedimentation pond and cattle pens. The drains and the silage habitats are localised and consequently the larvae pupate within these habitats and are easier to find. The data also shows that in other areas it is more difficult to find pupae than larvae because of larval wandering and predation by ants. Thus the preferred immature fly stage to monitor is the larval stage.

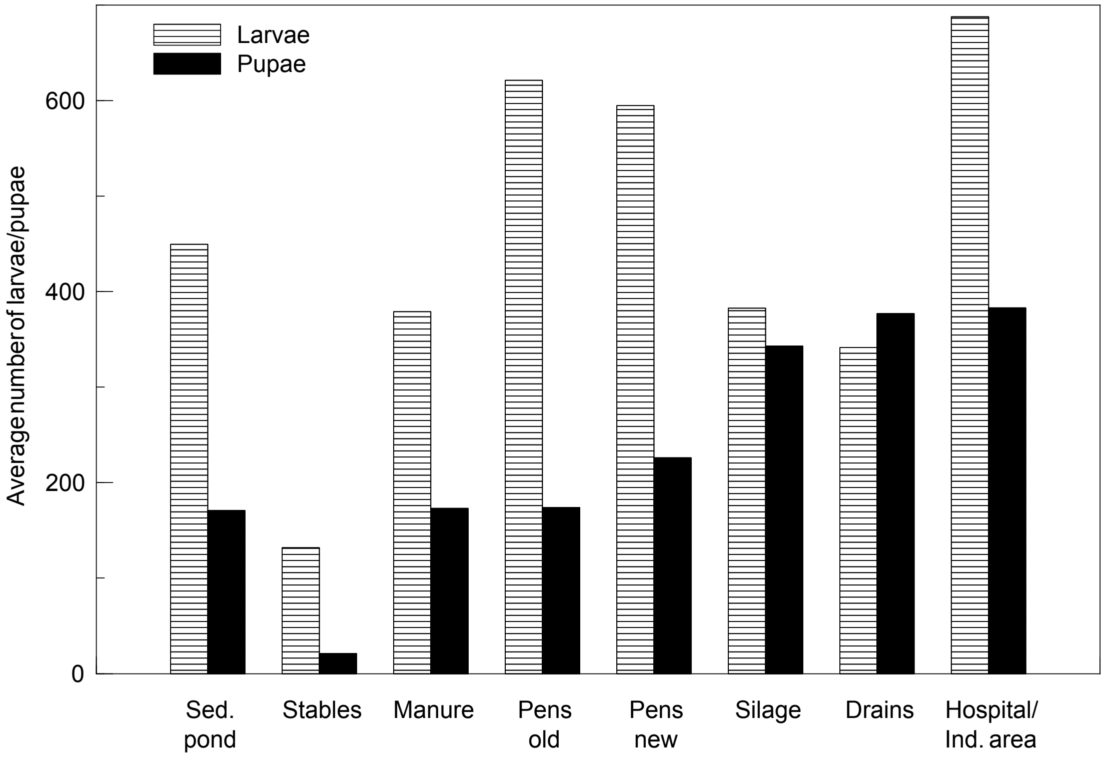

Figure 24 Number of house fly larvae and pupae from different feedlot sites over the whole monitoring period

At each feedlot site, five manure/soil samples were collected in different locations (except hospital/induction area three samples). These locations within sites were kept constant, to allow us to pinpoint preferred egg laying and developmental spots within the feedlot sites. The average numbers of larvae extracted from the different samples are given in Table 5.

Table 5 Average numbers of larvae extracted from different locations within feedlot sites.

Site	Sample					Average
	1	2	3	4	5	
Sedimentation pond	169	97	89	110	99	112
Horse stables	36	36	6	42	75	43
Manure stockpiles	59	65	100	74	166	91
Old pen	65	6	189	196	203	131
New pen	117	42	168	156	173	131
Silage	37	43	143	109	209	100
Drains	127	78	143	123	100	114
Hospital/induction area*	319	330	219	na	na	289

* Three samples only

The numbers of larvae varied greatly between samples within most feedlot sites. The variations and possible reasons are discussed separately for each site. The results for pupal extractions showed the same sample differences, thus the discussion is limited to larvae.

Sedimentation pond

In the sedimentation pond, larvae were generally only located at the liquid-solid interface which moved up and down the pond edge depending on water influx. Thus, the samples were taken from the inlet (sample 1), at the liquid-solid interface near the inlet (sample 2), half-way between inlet and outlet (sample 3), near the outlet (sample 4) and at the outlet (sample 5). Larval abundance was highest at the inlet with all other samples at or just below the average. The inlet sample gave the highest reading because it included the drain from the cattle pens/lanes which was not concreted and retained moisture.

Horse stables/yards

In the horse area the most productive fly breeding location was in the day spelling paddock, where larvae were found in a mixture of soil and hay around the feeding bins (sample 5). The other locations around the stables, the old manure stockpile (sample 1), under the troughs (2) and the fresh feed residues (4) provided average numbers whereas under the fence (3) larvae were found only in low numbers.

Manure stockpile

The highest larvae numbers in the manure piles were observed in fresh, wet deposits which originated from sedimentation ponds or catchment drains (sample 5). This sample provided almost twice as many larvae as the average manure stockpile sample. The other samples, including the currently used stockpiles (sample 1 and 3), a completed pile (sample 2) and the manure stockpile which was used for composting carcasses (sample 4) were equal to or lower than the site average.

Cattle pens

In both cattle pens, samples were taken from the following locations: near the feed bunk apron (1); in the centre of the pen (2); under the side fences (3 & 4); and under the back fence (5). The highest larval densities were consistently obtained from under the fence lines, with little difference between side and back fences. The uncompacted and often moist manure under the pen fence lines provides an ideal substrate for fly breeding. The highest larval densities were often observed in the vicinity of the water troughs which were located midway along the side fence lines. The lowest larval extracts were obtained from the centre of the pen where the highly compacted manure pad provides little support for fly breeding. The abundance of larvae in the area adjacent to the feed bunk was higher than in the middle of the pen, but still much lower than under the fence lines. The disparity between the highest and lowest larval numbers was large, up to 30 fold in the new pens.

The average numbers of larvae extracted from the new and old pens were equivalent. However, the distribution of larvae within the pens appears to be somewhat different. In the old pens 89% of the extracted larvae originated from under the fence lines compared to 76% in the new pens. More larvae were recovered from near the feed bunk (18%) and the centre (6%) in the new pen than the old pen (10% and 1% respectively). There are several plausible reasons for this observation. The new pens house long-term cattle which are fed ad lib with feed residues commonly found on the ground near the feed bunks. There are minimal feed residues in the old pens containing short-term cattle. Therefore, the environment around the feed bunks in new pens is more suitable for fly breeding and development than in the old pens. The new pens were partly covered with shade cloth under which cattle congregate during warm weather resulting in a more moist manure pad in the shade. Most larvae in the new pens were found in the uncovered areas which were not as uniformly compacted as the old pens without shade cloth.

Silage pit

The highest larvae abundance was observed at the face of the silage pits (sample 4 and 5) with intermediate and low readings halfway along the pits (sample 2 and 3) and at the mouth of the pits (sample 1) respectively. Pit 1 was usually the inactive pit resulting in lower values from this pit (sample 2 and 4) compared to pit 2 (sample 3 and 5). The combination of silage material and moisture (seeping from the stored silage) provide a good media for fly breeding. The best breeding sites were at the face of the pit, but due to uneven surface of the pits and the presence of residues and spilt silage, breeding sites were found along the length of the pits. Even in the inactive or empty pits there was still fly breeding activity for months in the remaining residue.

Drains

The drains samples were collected from: drain from sedimentation pond and silage pits to holding pond (1); as (1) but closer to holding pond (2); drain behind new cattle pens (3); drain behind old cattle pens (4); drain from new cattle pens to sedimentation pond (5). The highest numbers of larvae were recovered from the drain behind the new cattle pens. This drain was generally wet from pen runoff and poor drainage to the sedimentation pond.

Hospital/induction area

The samples for the hospital/induction area were collected from the laneway and under the fence lines (sample 1) and near the feed bunk and hayrack (sample 2) in the holding yards (hospital area), and under the laneway fence and in the drain in the induction area (sample 3). The average larval abundance in the hospital/induction area was greater than any other site. The hospital area had particularly high larval counts probably due to high amount of feed residue (hay and grain), low cattle number in pens and infrequent cleaning.

Effects of feedlot design and practices

The abundance of larvae and pupae was determined throughout the monitoring period in new and old cattle pens, in order to assess whether differences in pen design, the scraping and removal of manure from pens or the application of insecticides influenced the extent of fly breeding.

Feedlot design

There were some design and construction variations within the feedlot which allowed us to make some assessments of these features on fly breeding. The cattle pens in the newer section of the feedlot have a pen surface with a 3% slope, considered optimal by industry for drainage and odour, whereas the older section has minimal pen surface gradient. The additional pen rows which were added to the new section during 2002 had a concrete base (about 500 mm wide) under the fences, whereas the existing pens in this and the old section had a compacted earth base. The selected pen in the new section had a natural base in the first part (October 2001 to 8 January 2003) and a concrete base in the second part (22 January to 15 October 2003) of the monitoring program. In the transition phase (7 November 2002 to January 2003) two pens in the new section, one with concrete and one with earth base were monitored.

The average number of larvae recovered from the new and old pens over the whole monitoring period were identical but their distribution within the pens was different (Table 5). However, differences between the old and new pens other than design may have significantly impacted on fly breeding: cattle breeds, feed composition and residues and shade cloth (see section on cattle pens above). Most these factors appeared to assist fly breeding in the new pens. Therefore, it is possible that the anticipated beneficial effects of increased pen slope on fly breeding were cancelled by other differences or that pen slope did not have a significant effect on fly breeding. Manure accumulates under the fence line regardless of pen gradient and fence lines were identified as the major fly breeding site associated with cattle pens. Furthermore, this assessment of fly breeding was obtained during a relatively dry period when pen gradient may not have been a critical issue.

There was some evidence that a concrete base under the pen fence lines may assist in reducing under-the-fence fly breeding. In a direct comparison of larval abundance between fence lines with and without concrete (November 2002 to January 2003), the average numbers of larvae under the fence lines were 299, 323 and 225 for the old, new (earth base) and new (concrete base) pens respectively. Thirty percent fewer larvae were recovered from the concrete base fence than the earth base in pens of similar design and with the same cattle breed and feed.

Feedlot cleaning

The cattle pens, drains and sedimentation ponds were cleaned as part of the normal feedlot operation. The monitoring program included components which allowed us to assess the impact of the cleaning on fly breeding. Due to a change of feedlot ownership, there were changes to the routine feedlot cleaning protocol during the monitoring period. The cleaning activities were recorded by feedlot staff in the feedlot workbook. We obtained our information from this workbook and through our observations and notes taken at each visit. The cleaning of the selected monitoring pens in the new and old section and the sedimentation pond were of particular interest to us.

A box scraper was routinely used to skim loose manure off the pen surface throughout the feedlot. The manure in the feedlot pens was scraped into a mound in the centre of the pens and subsequently removed from the pens at varying intervals after the scraping. Manure accumulated under the fence lines was pushed and removed at the same time as the pen was scraped. The timing of the scraping and removal of manure from the new and old pens and the average number of extracted larvae for these pens are provided in Figure 25. After many, but not all, pen cleaning events, a reduction in numbers of larvae was observed. However this reduction was short-lived, commonly only observed in the first measurement following the cleaning. The reduction was often not substantial in terms of the existing immature fly populations and fly production quickly returned to its season-driven level. Our observations indicated that a build up of non-compacted manure under the fences occurred rapidly after the cleaning, thus re-establishing the flies' preferred breeding sites.

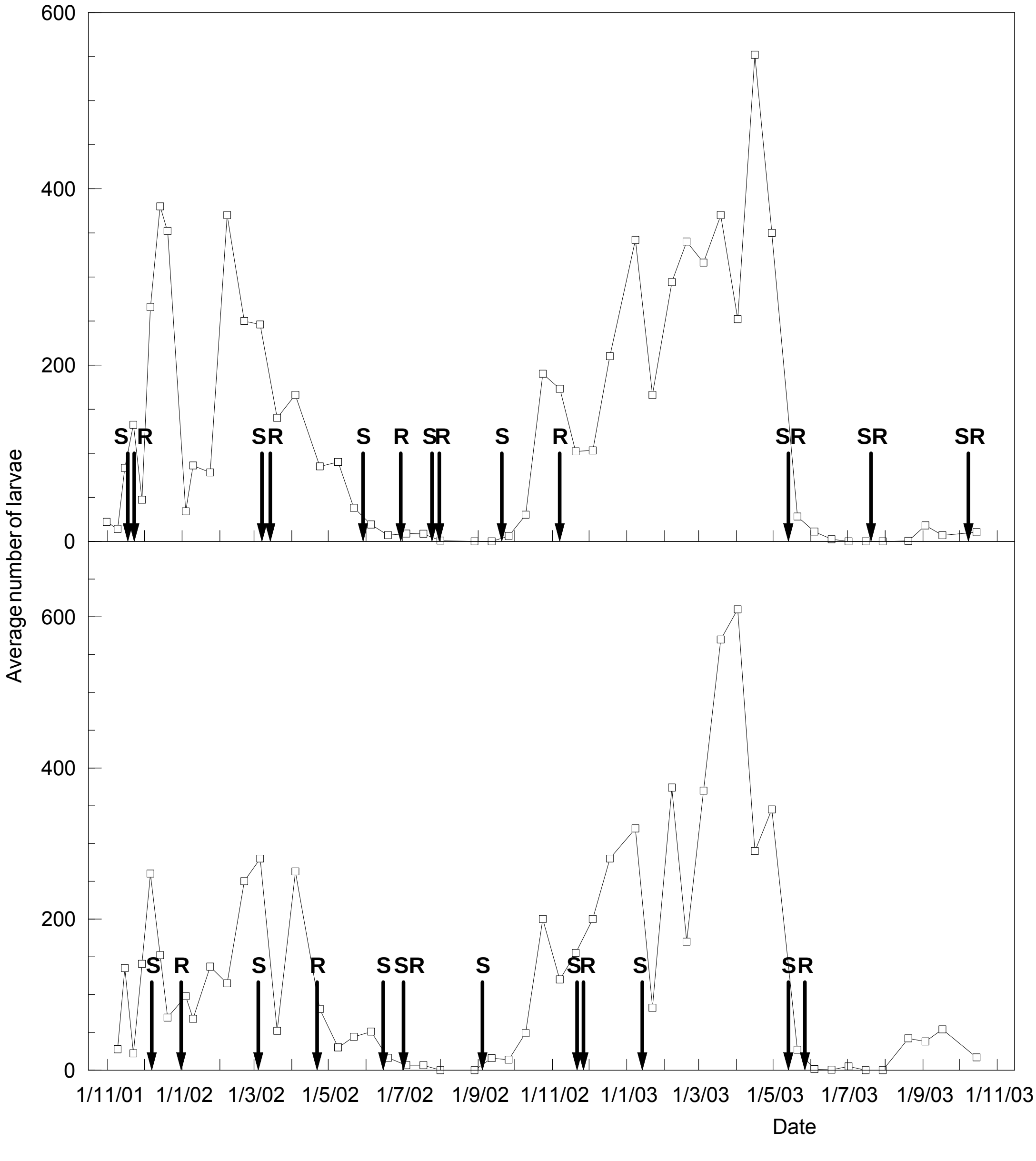

Figure 25 Average numbers of larvae and timing of cleaning (S = manure scraped, R = manure removed) in the new (upper) and old (lower) cattle pens.

A possibly successful strategy for reducing fly breeding in cattle pens would involve frequent removal of manure under the pen fences with less frequent pen clean outs. In this feedlot, current practice is to clean fence lines at the same time as pens. We have demonstrated that the majority of fly breeding in pens takes place in the uncompacted manure under the fence lines (see Table 5 and subsequent paragraphs). More frequent cleaning targeting the major breeding areas may result in better control of fly breeding than general but less frequent cleaning. It is recommended that the benefits of such modified cleaning procedures for fly control be investigated.

The scraping and cleaning of the sedimentation pond also had only limited impact on the number of fly larvae recovered from this site (Figure 26). The sedimentation pond was levelled and its base lined with gravel in February 2003 and this almost led to an elimination of fly larvae. However, recovery was quick and unprecedented numbers of larvae were extracted in March 2003.

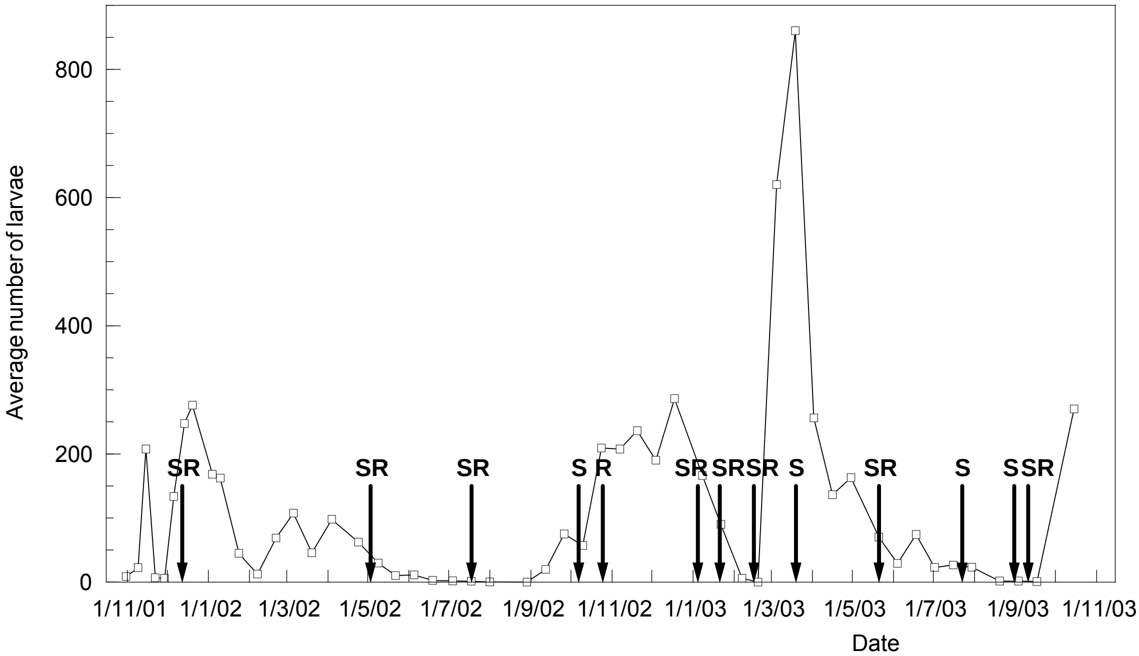

Figure 26 Average numbers of larvae and timing of cleaning (S = manure scraped, R = manure removed) in the sedimentation pond.

Insecticidal treatments

The insecticidal treatments and their application sites in the feedlot are provided in Table 4. Treatments were infrequent and generally applied when there was a perceived need rather than on a routine basis. With regards to the treatments, Cyfluthrin spray (Solfac) is an adulticide and will not directly affect fly larvae. Trichlorfon (Neguvon) is effective against both adult and immature flies. Fly baits attract and kill adult house flies only. It has been demonstrated in the previous section that the insecticide treatments did not have a major impact on adult fly populations on the feedlot. In this section, we consider the impact of the chemical treatments on larvae at the site of application.

All of the insecticide treatments targeted the feed bunks and some also included the pen fence lines. The larval abundance in the new or old pens was not substantially reduced by any of the treatments (Figure 27). The major control of larvae abundance was provided by seasonal conditions. The chemical treatments may have resulted in minor, short term reductions (February 2002 treatment) or accelerated seasonally induced reductions (April 2003). Similar observations were made for the sedimentation pond which was sprayed with insecticides in early 2002. As noted earlier, our weekly (October 2001 to June 2002) or fortnightly (July 2002 to October 2003) population monitoring may not have detected reductions which persisted for less than one monitoring interval. It appears that insecticidal treatments had little if any impact on fly breeding or fly populations on the feedlot.

Failure of pesticide treatments on immature stages is largely due to lack of contact. Larvae are usually covered by substrates so they are untouched by the spray treatments. Pupae are impervious to pesticides, so they will not be killed. If adults emerge from pupal cases while pesticide residual is still active, then mortality can occur. Contact is also a problem with adult populations.

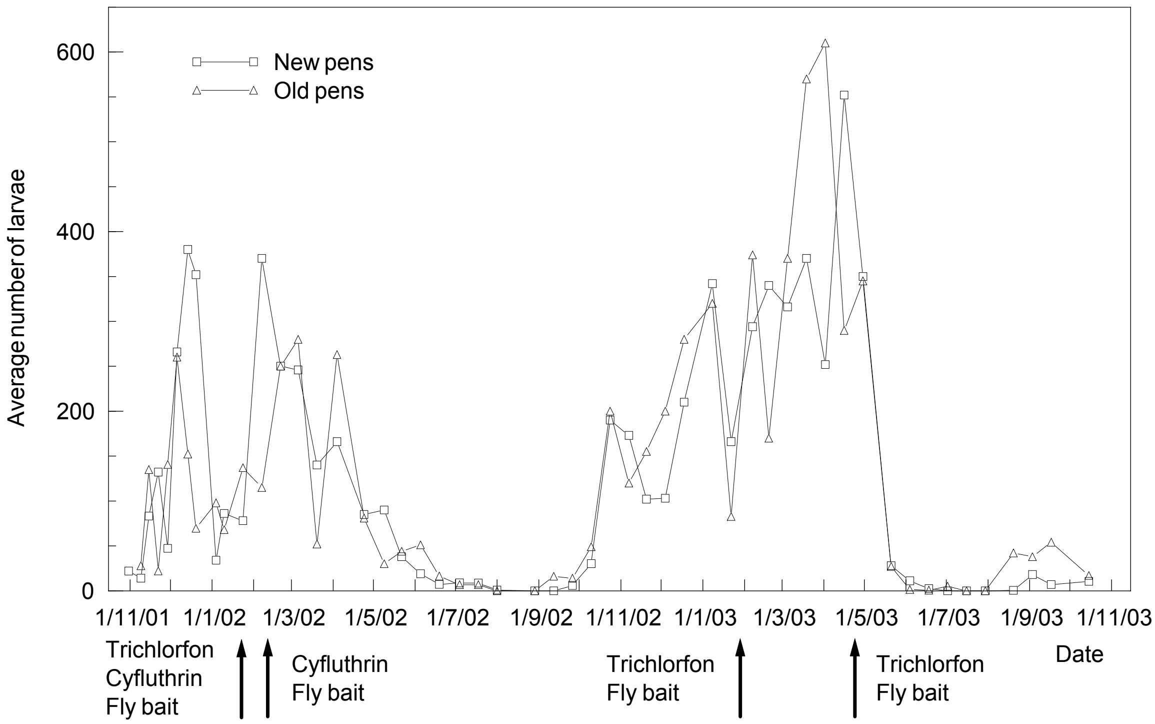

Figure 27 Average numbers of larvae and timing of insecticidal treatments in the new and old cattle pens

Parasite populations monitoring program

In an intact ecosystem a variety of natural enemies of flies will be present. Such enemies include predators (birds, beetles, some flies, spiders, mites), parasitoids (wasps) and pathogens (fungi, bacteria, nematodes, viruses). These natural enemies lower fly populations. For effective and sustainable fly management, selective control measures for target species with minimal effect on natural enemy populations should be used. Insecticides, a common tool used for fly control, will generally also kill the insect parasitoids. Most parasitoids are more susceptible to insecticides than their fly hosts. The effect of insecticides on parasitoids is compounded by the fact that most parasitoids have a longer life cycle than the flies, resulting in a slower population recovery. Parasitoids provide biological control of flies and augmenting their numbers through releases of commercially cultured species can enhance their impact. Parasitic wasps are commercially produced in the US for the control of flies in intensive livestock industries.

The feedlot monitoring program was designed to determine which of the natural enemies of flies occurred where, when and to what extent. The program targeted parasitic wasps, mites and entomopathogenic fungi through different sample collections on the feedlot and subsequent processing in the laboratory.

Parasitic wasps

Globally over 50 chalcid species of wasps in 18 genera and 5 families have been recorded as parasites of nuisance flies. Of these, wasps in the family Pteromalidae dominate pupal parasitoids and several species are commercially mass cultured and sold for augmentative and inundative control. The classification and genera of wasps identified from the feedlot are shown in Table 6.

Table 6 Classification of parasitic wasps found on the feedlot

Superfamily	Family	Genus	Wasp egg numbers per fly pupa
Chalcidoidae	Pteromalidae	*Spalangia*	Single
		Muscidifurax	Single
		Trichomalopsis	Multiple
	Chalcididae	*Dirhinus*	Single
Proctotrupoidae	Diapriidae	Unidentified	Multiple

The parasitic wasps of interest kill fly pupae by stinging them. They lay their eggs inside fly pupae and the resulting wasp larvae devour the immature flies before they can develop into adults. The wasp larvae subsequently develop inside the fly pupal cases until they emerge as adult wasps after several weeks. One or several wasps can emerge from one fly pupa. Adult wasps also sting and kill fly pupae and feed on pupal contents, but no eggs are laid; or eggs are laid but wasps die before reaching the adult stage. This has been termed dudding by American workers. Dudding results in death of many fly pupae and can cause an underestimation of parasitism unless the cause of pupal death is determined.

Parasitic wasps were collected in the feedlot using two independent methods. Firstly, through controlled exposure of house fly pupae to the feedlot wasp populations (= sentinel pupae) and secondly through appropriate processing and examination of the fly pupae collected for the immature fly population program (see section on immature flies).

Sentinel pupae consisted of 30 newly pupated laboratory-raised house fly pupae placed into screened containers and partially buried under manure at different feedlot sites. These sites included the water troughs and feed bunks in the old and new cattle pens, the evaporation pond, the mouth of the silage pit, the water troughs of the horse stables and the manure piles. The mesh size of the screen allowed parasitic wasps to enter the containers to deposit their eggs inside the pupal cases. At the end of the exposure period (one or two weeks), all intact sentinel pupae were individually placed into gelatine capsules and stored for at least 8 weeks at 27C. Flies would have emerged at the end of the feedlot exposure period, if the pupae were not parasitised or damaged by heat or predators. The wasps, which have a longer development phase than house flies, emerged from the pupae during the storage time and were trapped inside the capsules. The wasps were collected, identified (species, sex) and counted. The percentage of sentinel pupae parasitised during their exposure in the feedlot was then calculated.

Pupae extracted from the feedlot samples for the immature fly population monitoring were further processed as follows: Up to 100 pupae from each collection site were placed individually in gelatine capsules. If the total number of pupae was less than 100, all pupae were encapsulated. If collections exceeded 100 pupae, only 100 were encapsulated and the remainder were placed together into a plastic vial (bulk sample). The capsules were processed in the same way as the sentinel pupae, but the species of non-emerged pupae, emerged flies and emerged wasps were determined after a two-month development period. The number of non-emerged flies, emerged flies and wasps was calculated from the identified sample (≤100) and the total number of pupae per site.

The species of parasitic wasps detected on the feedlot from October 2001 to October 2003 are provided in Table 7. The table also indicates with which detection method the wasps were found.

Table 7 Species of parasitic wasps and source of detection on the feedlot

Species	Detected in	
	Sentinel pupae	Feedlot pupae
Spalangia cameroni	Yes	Yes
Spalangia endius	Yes	Yes
Spalangia nigroaenea	Yes	Yes
Spalangia drosophilae	No	Yes
Muscidifurax raptor	Yes	Yes
Trichomalopsis sp.	Yes	Yes
Dirhinus sp.	Yes	No
F. Diapriidae	Yes	Yes

Sentinel pupae

The average percentages of sentinel house fly pupae from which flies emerged or which were parasitised after being exposed for one or two (after 4 June 2002) weeks in the feedlot are shown in Figure 28. Fly emergence was generally quite high (average 81%) with a few observations of lower emergence, particularly in winter. Low emergence could be caused either by parasitism or by pupal death from temperature or moisture extremes. In spite of careful placement of the sentinel pupae, they were occasionally disturbed or destroyed by birds, cattle, machinery, ants, mice or rain.

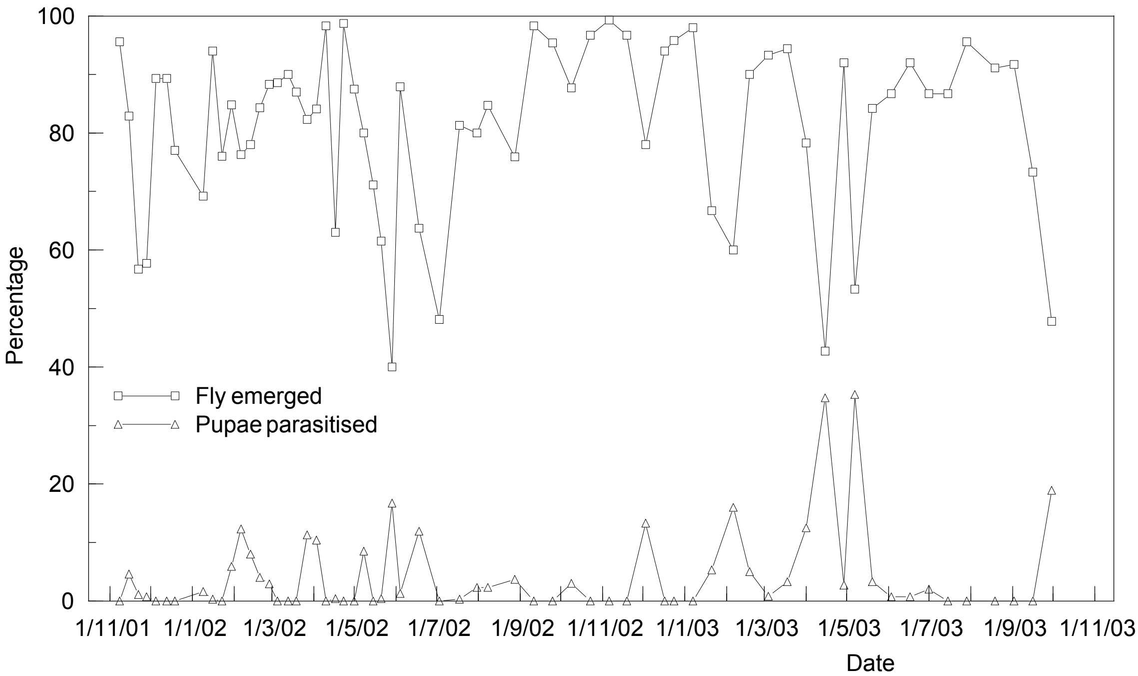

Figure 28 Percentage of sentinel house fly pupae emerged or parasitised by wasps after one or two (after 4/6/02) weeks exposure in the feedlot.

Parasitism was generally between 0% and 20%, but it reached 35% on two occasions. On 26 exposures (41% of 64 exposures) no wasps were detected in the sentinel pupae. A total of 530 pupae (4.2% of the 13,000 exposed pupae) were parasitised and 606 wasps emerged. Most pupae yielded only a single parasitic wasp, but multiple wasp emergence was observed for *Trichomalopsis* sp. and Diapriidae, yielding 1-12 and 3-15 wasps per pupa respectively.

The numbers of each species of parasitic wasps emerged from the sentinel pupae are given in Table 8. The most common wasp parasites in sentinel pupae were *M. raptor* and *S. cameroni*.

Table 8 Numbers of parasitic wasps recovered from sentinel pupae exposed on the feedlot during the monitoring period October 2001 to October 2003.

Species	No of wasps*	
Muscidifurax raptor	281	
Spalangia cameroni	211	
Diapriidae	58	(6)
Trichomalopsis sp	24	(7)
Dirhinus sp. (Chalcididae)	19	
Spalangia endius	7	
Spalangia nigroaenea	6	

* Number of pupae in brackets for multiple wasp emergence

A quarterly breakdown of numbers of the more abundant parasitic wasp species recovered from sentinel pupae is given in Figure 29. Most parasitic wasps were detected in the first half of the calendar year. *M. raptor* was found in all quarters and it was the most abundant species except in the first quarter when it was surpassed by *S. cameroni*. *S. cameroni* was only detected in the first half of the year, *Dirhinus* sp. in spring and summer and Diapriidae in autumn and winter. Of the species not shown in Figure 29, *Trichomalopsis* sp were found twice (November 2001, January 2002), S*. endius* twice (May 2002, July 2003) and *S. nigroaenea* once (May 2002).

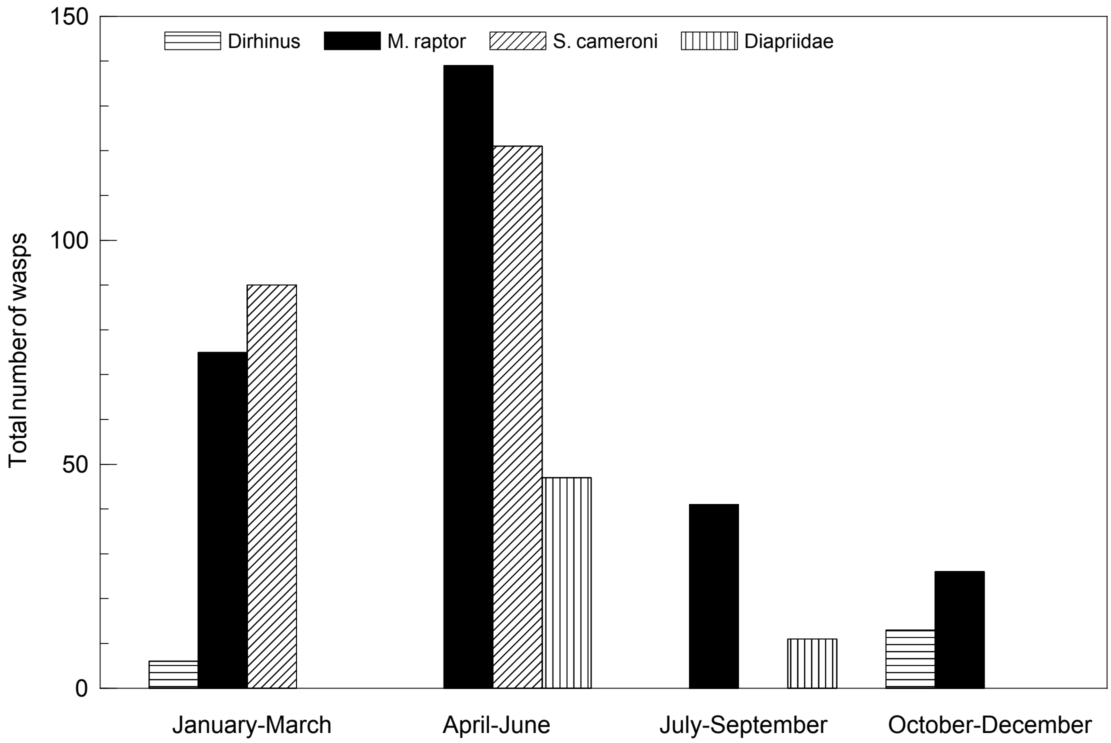

Figure 29 Numbers of parasitic wasp species recovered from sentinel pupae each quarter of the monitoring period (November 2001 to October 2003).

Feedlot fly pupae

The pupae extracted from the feedlot manure and soil samples for measuring the immature fly populations were also used to establish the extent of wasp parasitism in the feedlot. The average numbers of fly pupae (by species) extracted at each collection from October 2001 to September 2003 are shown in Figure 20 (p. 31). For each feedlot site and collection, 100 (or all if total <100) pupae were placed individually into gelatine capsules and incubated for at least eight weeks, enough time for parasitic wasps to emerge. Each capsule yielded either a fly (viable pupae), one or several wasps (parasitised pupae) or nothing (no emergence). The pupae, flies and wasps were subsequently identified. This allowed us to calculate percentage parasitism, fly emergence and non-emergence and to determine which fly species was parasitised by which wasp.

Level of parasitism

The viability of the extracted house fly pupae is shown in Figure 30. The most common outcome was non-emergence, with an average over the entire monitoring period of 60% for house fly. Thus, six of ten pupae were not viable when kept under ideal conditions (constant temperature, dry, no physical disturbance). The percentage of non-emergence might have been higher if the pupae had been left in the feedlot. House flies emerged from an average of 30% of the collected pupae. The emergence rate was typically between 25 and 35%. However, it dropped to below 20% in the coldest winter months (with a minimum of 2.5% in July 2002). Higher than average emergence was observed during September and

October 2002 and 2003, April 2002 and January and August 2003. Survival of fly pupae is influenced by abiotic and biotic factors, with temperature being an important abiotic factor.

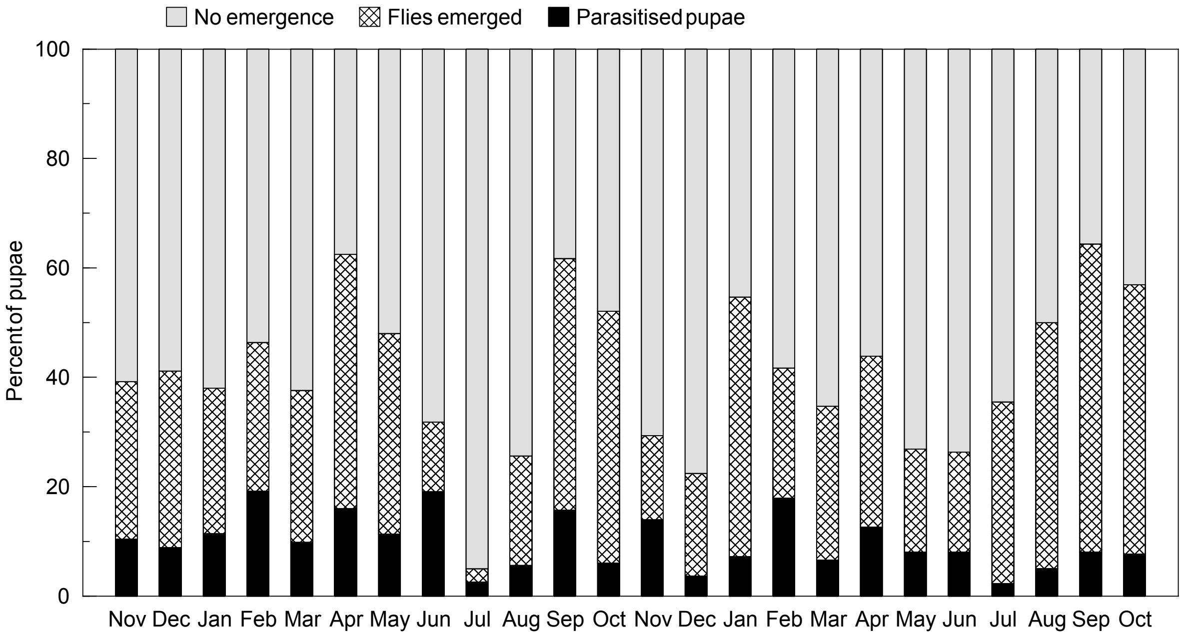

Figure 30 Monthly averages of percent parasitism, fly emergence and non-emergence of house fly pupae from November 2001 to October 2003.

Parasitic wasps emerged from an average of 10.3% of the feedlot house fly pupae. If all parasitised pupae produced a wasp and not counting the non-emerging pupae, parasitic wasps reduced the emergence of house flies by 26%. However, the actual suppression of fly emergence by parasitic wasps is likely to be higher because wasps are also known to sting pupae to feed on them (dudding) or eggs are laid but no wasps emerge. Such pupae will produce neither a fly nor a wasp and thus are classified as non-emerged pupae in our assessment. The levels of parasitism and fly emergence were low during the winter months. It appears that the cold weather reduces viability of both host and parasite.

The viability of stable fly pupae is shown in Figure 31. The overall averages for non-emergence (65%), emergence (24%) and parasitism (11%) are similar to the house fly values. The variability of the data is higher, most likely due to the smaller numbers of stable fly pupae retrieved in many collections. Overall, parasitic wasps prevented at least 36% of the viable stable fly pupae from maturing to a fly. The seasonal profile of parasitism in stable fly is different from the house fly. The higher values of parasitism were generally recorded during the cooler winter months.

The average level of parasitism for all other fly species was 13% over the whole monitoring period and thus also similar to the two major fly species. The non-emergence and emergence for other species was 55% and 33% respectively, thus the wasps achieved a 28% reduction in emergence.

The percentage of parasitised pupae across all species was 11%. With a corresponding non-emergence of 59%, the average reduction in fly emergence achieved by parasitic wasps laying an egg into a viable fly pupa was 27% across all fly species. As mentioned previously the actual control of fly emergence by wasps is probably higher because wasps also feed on fly pupae. Parasitic wasps are clearly one of the important biological control agents for fly pupae in this feedlot.

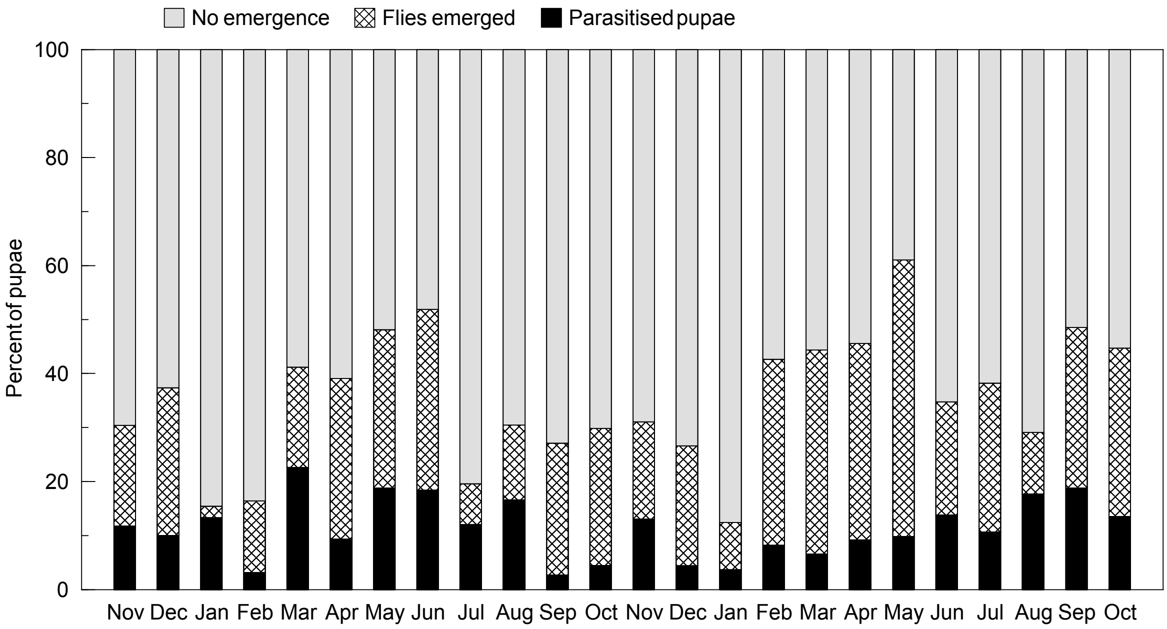

Figure 31 Monthly averages of percent parasitism, fly emergence and non-emergence of stable fly pupae from November 2001 to October 2003.

Species of parasitic wasps

The numbers of wasps emerged from house fly and stable fly pupae and the proportion of female wasps are given in Table 9. A total of 8844 wasps emerged from the extracted feedlot pupae. Half of these wasps were *S. endius,* followed by *S. nigroaenea* and *S. cameroni*. *Spalangia* spp. constituted 90% of all parasitic wasps emerged from feedlot pupae. *M. raptor* made up 9% of the wasps and *Trichomalopsis* sp and Diapriidae were found in low numbers. *Trichomalopsis* sp. was only detected three times with an average of 10 wasps emerging per pupa. Between 86% and 92% of the wasps emerged from *M. domestica* pupae for all species except *Trichomalopsis*. This emergence pattern matches well with the ratio of extracted house fly to stable fly pupae (88:12), indicating that the wasps equally parasitise both fly species. About two thirds of all emerged wasps were female with a similar sex ratio across all species, except for *Trichomalopsis* sp. where only one male wasp was found.

Spalangia spp. and *M. raptor* wasps also emerged from *P. clausa* pupae (not included in Table 9). Diapridae were found on three occasions in *Atherigona* sp. pupae and *S. drosophilae* once in Drosophilae. *S. endius* emerged once from a Calliphorid and once from a Sphaerocerid pupa.

Table 9 Total numbers of parasitic wasps recovered from house fly and stable fly pupae, percentage of wasps from house fly pupae and sex of wasps during the monitoring period November 2001 to October 2003.

Species	No of wasps			% Ex *M.*	%
	Ex. *M. domestica*	Ex. *S. calcitrans*	Total	*domestica*	female wasps
Spalangia endius	3792	630	4422	86	69
Spalangia nigroaenea	1697	212	1909	89	60
Spalangia cameroni	1400	202	1602	87	62
Muscidifurax raptor	695	62	757	92	65
Trichomalopsis sp	87	55	142	61	99
Diapriidae	1	0	20*		65
All species	**7672**	**1161**	**8852**	**87**	

* 19 from 2 *Atherigona* sp. pupae

The species of wasps found in the feedlot pupae were basically the same as in the sentinel pupae, however, the proportion of the species was distinctly different. The feedlot pupal data demonstrates that *Spalangia* spp. are the dominant parasitic wasps in this feedlot. *M. raptor* and *S. cameroni* were the most common wasps in the sentinel pupae. *S. endius* was the most common species in the feedlot pupae, but was hardly present in sentinel pupae. This difference is probably due to variable aptitude of parasitic wasp species to locate buried pupae and to differences in pupal age. Wasps parasitise pupae in the field when the pupae are at a preferred stage of development, usually between 1 and 3 days. Sentinel pupae are all of the same age and they might be right for some parasite species, but not others. Also, because the pupae are together in one container, one wasp might parasitise more pupae than would be possible if pupae were more scattered in the feedlot substrate. Sentinel containers tend to favour parasitism by *Muscidifurax* spp. and that is what was shown in this data. This comparison also indicates that feedlot pupae are the better method of establishing wasp parasitism in a cattle feedlot.

Seasonal effects on parasitism

The seasonal distribution of the major wasp species recovered from house fly and stable fly pupae is shown in Figure 32. Wasp populations showed basically the same pattern as fly populations: population peaks during summer and troughs during winter. *S. endius* was the most abundant species in most months, with broad population peaks from October to June. *S. nigroaenea* and *S. cameroni* populations increased about two to three months later than *S. endius* but disappeared about the same time (June). *S. cameroni* was the most common species in the small population of surviving wasps during winter 2003. The presence of *M. raptor* was inconsistent in 2001/02 (only January and June 2002 provided reasonable numbers) but it had a population pattern similar to *S. nigroaenea* in 2002/03. There was no clear difference in seasonal patterns of wasp populations which had emerged from house flies or stable flies respectively.

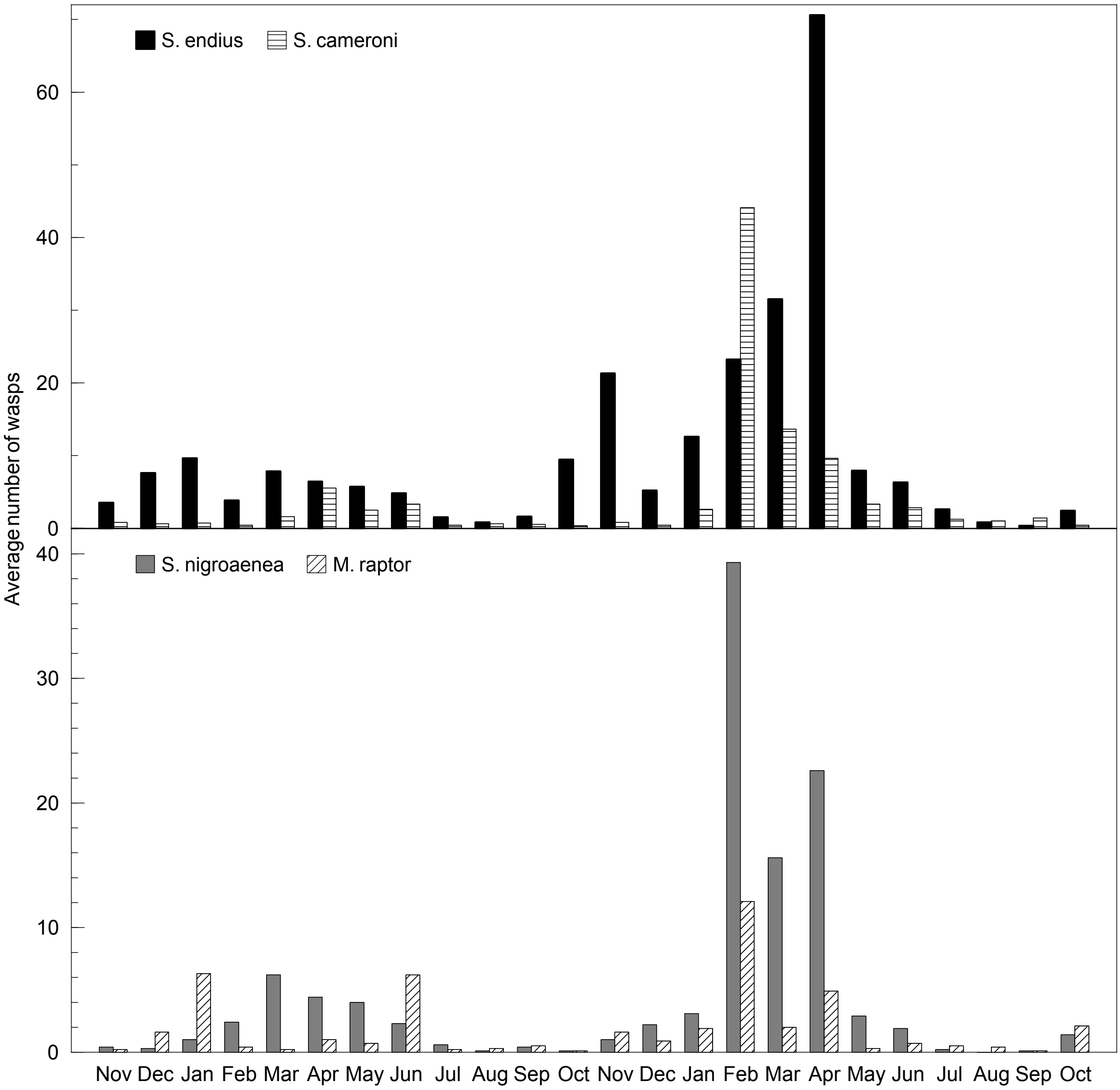

Figure 32 Average numbers of parasitic wasp species recovered from feedlot pupae grouped by month over the monitoring period.

The recovery of high numbers of wasps coincided with high numbers of pupae. The percentage of pupae which were parasitised varied greatly between collections (data not shown). The monthly average percentage of parasitism for house fly and stable fly pupae is shown in Figure 33. The level of parasitism is similar in house flies and stable flies in many months, but there are a few differences. During the cold months of July and August the level of parasitism is low for house flies, but remains close to the average for stable flies (in 2003 this trend continued into spring). The level of parasitism is generally not correlated with the number of pupae extracted from the feedlot samples (Figure 33). The variability between the months is as high as or higher than between low and high pupae populations. Some of the variability may arise from small extracted pupae sample sizes during the winter months, particularly for the stable fly. Low parasitism levels were obtained in October and December 2002 and January 2003 when fly populations started to increase. This is an indication of a lag period between the build up of fly and wasp populations.

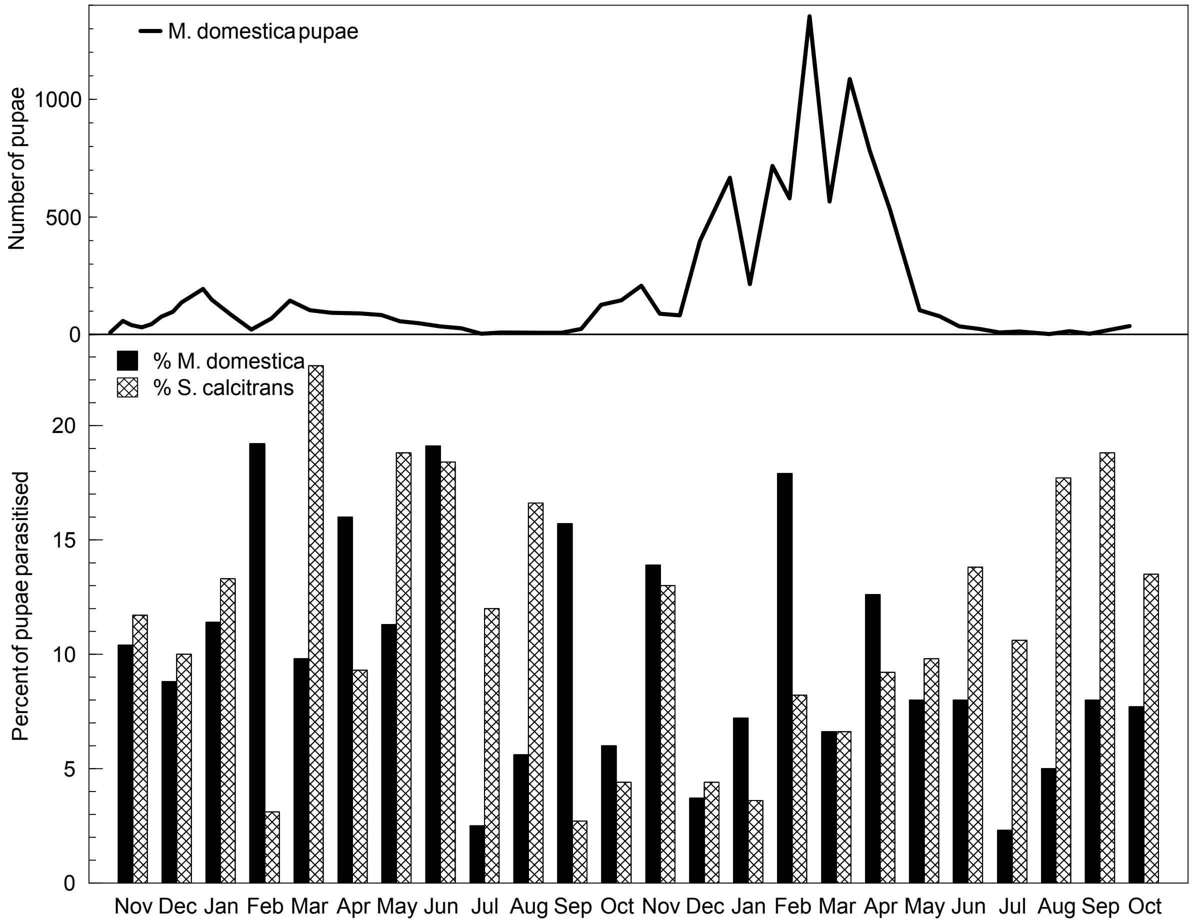

Figure 33 Monthly average percent of house fly and stable fly pupae parasitised (lower graph) and number of extracted house fly pupae (upper) from November 2001 to October 2003.

Comparison of feedlot sites

The average numbers of wasps emerged from house fly and stable fly pupae from different feedlot sites are shown in Figure 34. Due to changes in the sampling sites this comparison is based on pupae collections from January to October 2003. The highest numbers of wasps were recovered from the silage pits (average total wasps 100.3), followed by the hospital (62.9), new cattle pens (48.1), the manure piles (40.2), the drains (36.9), the sedimentation pond (31.0) and the old cattle pens (22.8). The horse stables produced very few wasps (2.8).

S. endius was the most common species found at all sites, showing that the most important parasitic wasp species was present across the entire feedlot. *S. cameroni* provided a higher than average portion of wasps at the stables (low total numbers) and the silage pits and a low portion at the sedimentation pond. *S. nigroaenea* preferred the silage area, hospital, the drains and the sedimentation pond, whereas *M. raptor* was more prominent in the hospital than in the other sites.

The percentage of parasitism in house fly and stable fly pupae at various feedlot sites is shown in Figure 35. All feedlot sites showed parasitism rates of between 7% and 16%. The hospital and stables had the highest rates (16% and 13% respectively) and the sedimentation pond and manure piles the lowest rates (7% and 8%). The fly emergence rates at the feedlot sites varied from 22% and 43%, with the highest rates at the cattle pens and the lowest at the sedimentation pond.

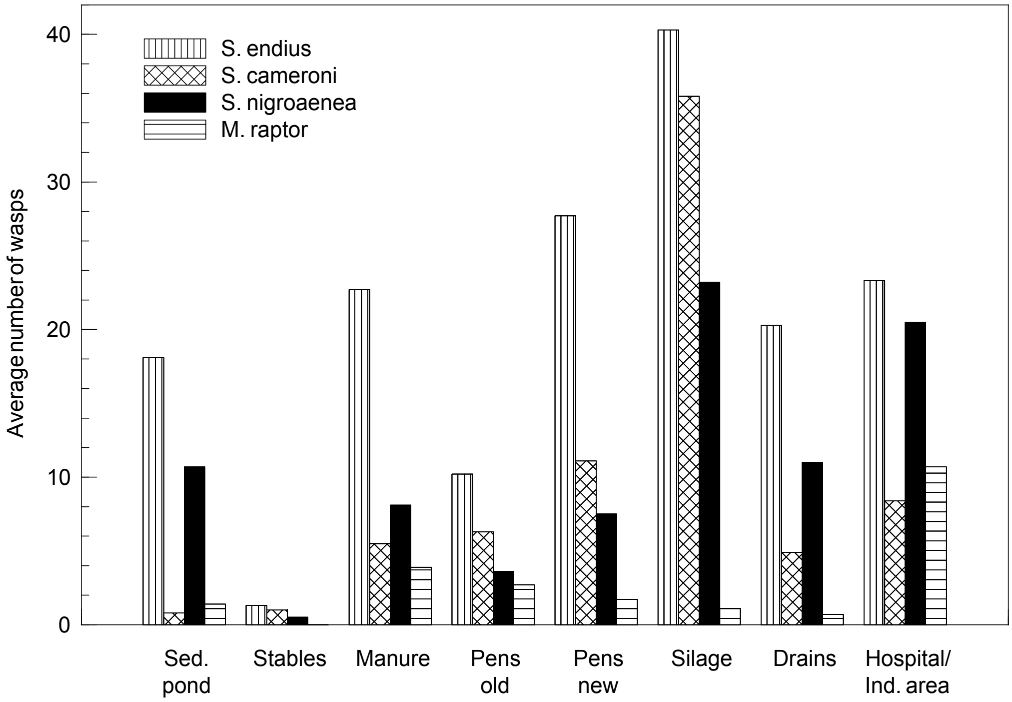

Figure 34 Average numbers of parasitic wasps recovered from various feedlot sites (January to October 2003)

The four major species of wasps were found at all monitored feedlot sites, indicating wasp presence and activity throughout the feedlot. The highest numbers of wasps were recovered from samples from the silage pits, the hospital and the cattle pens.

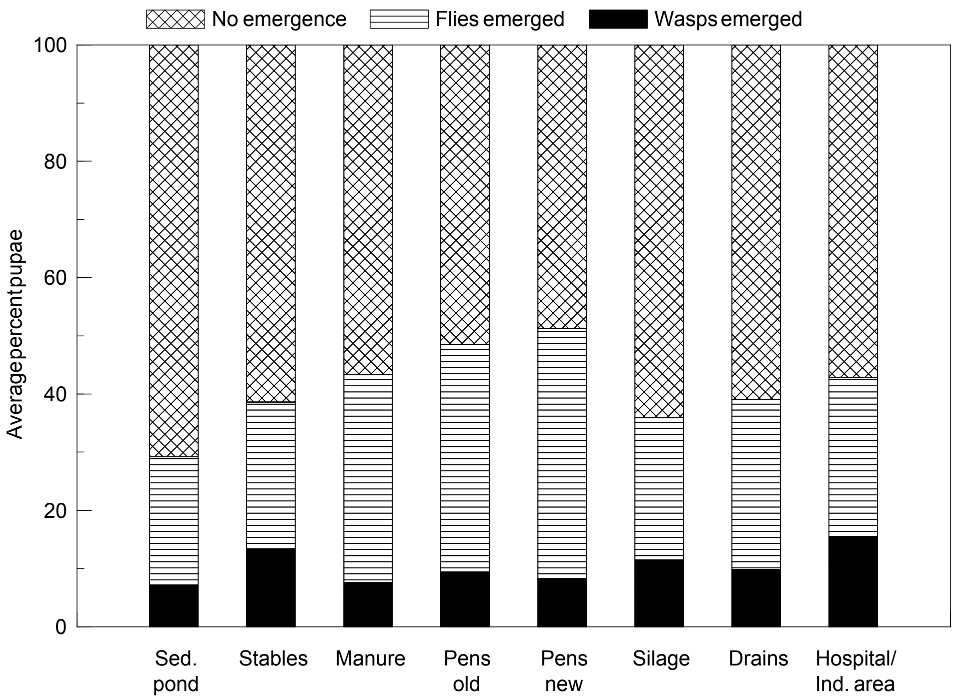

Figure 35 Site averages of percent parasitism, fly emergence and non-emergence of house fly pupae and stable fly pupae from January to October 2003.

Effects of feedlot practices on fly pupal parasitism

Scraping and removal of manure from cattle pens had only short-term impact on the recovery of larvae and pupae (see Effects of feedlot design and practices). This cleaning process disturbed or removed immature wasps from the pens with the manure. It could be expected that the rate of parasitism in pupae produced following the cleaning process may be lower compared to the pre-cleaning rate. However, no correlation between percentage of parasitised pupae and the cleaning processes was observed in the new and old cattle pens (Figure 36). Besides the seasonal difference in the level of parasitism, there were only one or two occasions (new pens November 2001, old pens November 2002) when rapid reductions in this level closely followed a cleaning event. Most of the observed reductions appear to be unrelated to the cleaning events.

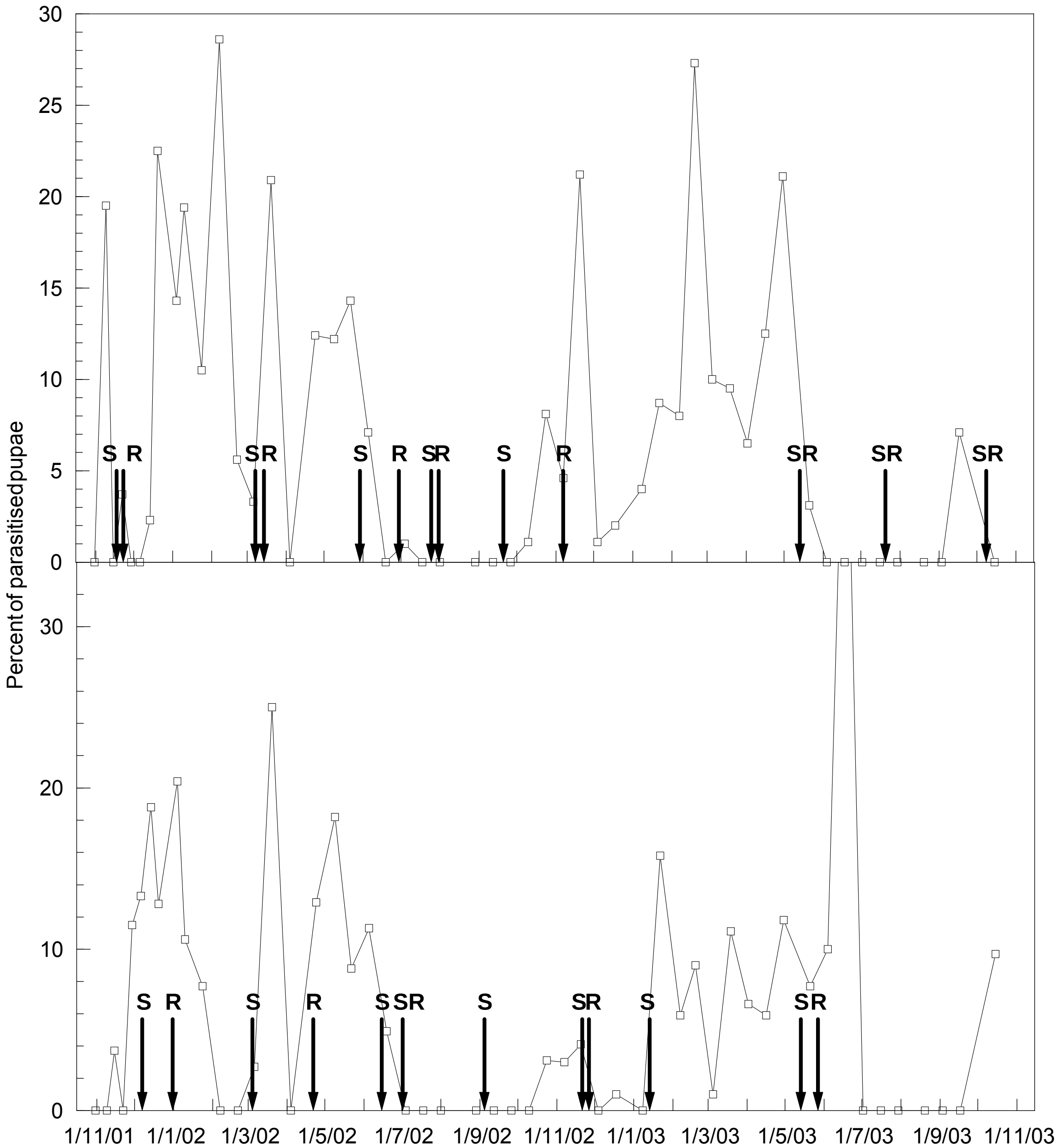

Figure 36 Average percent of parasitised pupae and timing of cleaning (S = manure scraped, R = manure removed) in the new (upper) and old (lower) cattle pens.

The application of insecticides can be expected to have a detrimental effect on parasitism of fly pupae. Insecticidal sprays used against adult flies will also kill parasitic wasps. Due to the longer life cycle of wasps compared to flies, a population recovery will take longer for wasps than for flies. Consequently, the level of parasitism may drop following insecticidal applications. There was some evidence that the level of parasitism was lowered by two applications of insecticides within three weeks in late January and early February 2002, with some but not all of the parasitism levels during the next months being lower than the preceding values (Figure 37). The chemical treatments in February and April 2003 did not appear to have substantially changed the level of parasitism in the subsequent weeks.

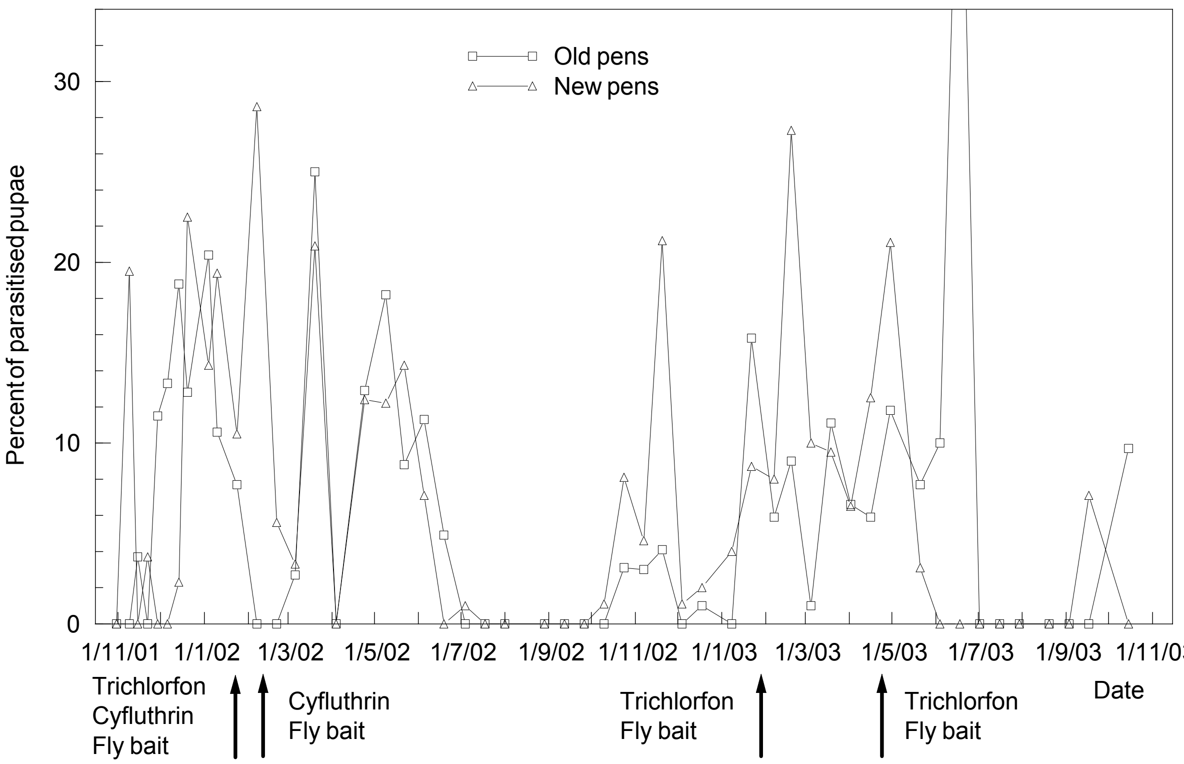

Figure 37 Average percent of parasitised pupae and timing of insecticide applications in the new and old cattle pens.

Conclusions

Parasitic wasps emerged from 11% of all fly pupae collected at the feedlot. From a further 59% of the pupae nothing emerged, thus the average reduction in fly emergence achieved by parasitic wasps by laying an egg into a viable fly pupa was at least 27%. The actual control of fly emergence by wasps is higher because not all wasp larvae will successfully develop into an adult and wasps also feed on fly pupae. Both events will produce neither a fly nor a wasp. Parasitic wasps are clearly one of the important biological control agents for fly pupae in this feedlot.

Eight species of parasitic wasps emerged from fly pupae collected at the feedlot. About 90% of these wasps were *Spalangia* spp., with *S. endius* the most common species (50% of all wasps). Other wasp species included *M. raptor* and *Trichomalopsis* sp. and wasps of the family Diapriidae. Only a single parasitic wasp emerged from most pupae, but multiple wasps (maximum 15) emerged from a few pupae. Multiple wasp emergence was observed with *Trichomalopsis* sp. and Diapriidae.

More wasps were recovered during the summer/autumn period than through winter/spring. High numbers of wasps were obtained when the numbers of pupae were high. The percentage of parasitised pupae varied between collections, was lower during the coolest winter months and was not correlated with the numbers of pupae. *S. endius* was the most common wasp at almost every monitoring event.

The four major species of wasps were found at all monitored feedlot sites, indicating wasp presence and activity throughout the feedlot. The highest numbers of wasps were recovered from samples from the silage pits, the hospital and the cattle pens. The majority of pupae and thus wasps in the pens were found under the fence lines. The levels of parasitism in fly pupae were the highest in the hospital and the stables (16% and 13% respectively) and the lowest in the sedimentation pond and manure piles (7% and 8%).

There was no evidence that scraping and/or cleaning cattle pens had a substantial impact on the levels of parasitism. Two insecticidal treatments within three weeks (January/February 2002) appeared to lower the level of parasitism over the subsequent month, but no such reduction was observed after the 2003 applications (January and April).

The level of parasitism was higher in the feedlot pupae (11%) than the sentinel pupae (4.3%). This difference could be due to presentation of pupae (in gauze-covered containers for sentinel pupae versus natural feedlot pupae in manure/soil), the timing of the start of exposure (once a fortnight versus continuous) or a difference in the attractiveness between colony and field produced pupae.

The species of wasps found in the feedlot pupae were basically the same as in the sentinel pupae, however, the proportion of the species was distinctly different. The feedlot pupal data demonstrates that *Spalangia* spp. are the dominant parasitic wasps in this feedlot. *M. raptor* and *S. cameroni* were the most common wasps in the sentinel pupae. *S. endius* was the most common species in the feedlot pupae, but was hardly present in sentinel pupae. This difference is probably due to variable aptitude of parasitic wasp species to locate buried pupae and to differences in pupal age. This comparison also indicates that feedlot pupae are the better method of establishing wasp parasitism in a cattle feedlot.

The parasitic wasps detected on the feedlot are the same species found in similar American and European studies. The presence of these wasps provide Australian feedlots with the opportunity to use parasitic wasps for biological control of nuisance flies. A variety of the parasitic wasp species found on the Australian feedlot are commercially cultured in the US for the control of flies in intensive livestock industries. The know-how of producing and applying the parasitoids on feedlots has already been established in US facilities. With the knowledge that these species are endemic in Australia, such cultures could be set up in this country. It is recommended that the production and application of parasitic wasps for nuisance fly control on feedlots be initiated and their effectiveness in Australia be investigated.

Mites associated with feedlot flies

As well as the parasitic wasps a number of other arthropods occurring in dung can limit fly populations. Predaceous mites for example can feed on house and stable fly eggs and larvae. Several hundred species of mites from four orders have been recorded from accumulations of livestock dung worldwide. A number of these mites closely associated with coprophagous flies, such as *M. domestica*, have been studied for their biocontrol potential. For the intensive livestock industries, these mites have largely been reported as species from the families Macrochelidae, Uropodidae and Parasitidae due to their high potential for biocontrol of Diptera. Little is known about other species attaching to dung-breeding flies, although some are known to carry entomopathogenic fungi.

As well as preying on various arthropod life stages the mites can attach themselves to adult flies and beetles to transport populations from one area to another. This sort of behaviour is called phoresy. For the Macrochelids the adult females attach to an insect, while for the Uropidae and Parasitidae the nymphs generally attach. These mites do little harm to the transporting hosts, although there is evidence that some feed on the haemolymph of their host.

Some phoretic mites have developed specialized attachment devices (eg Uropodids) while others remain unmodified (eg. Parasitids, Macrochelids). Other mites have developed a closer association with their hosts and a number of parasitic forms have evolved. Invertebrate ectoparasites such as the Trombidiids and Erythraeids are parasitic in the larval stage, while the adults and nymphs are predatory.

A number of native and exotic species of mites, including *Macrocheles* spp., *Glyptholaspis* sp. and *Parasitus* sp. are known to attack *Musca* sp in Australia. Members of the genus *Macrocheles* can be found in decaying organic matter in most regions of the world and their biology and behaviour, particularly *M. muscaedomesticae* is well documented. Macrochelid and probably other mites can respond to the odour of manure and flies. As the manure dries and becomes less attractive the mites tend to leave and attach to flies to be carried to fresh substrate.

Samples of flies were examined for phoretic and parasitic mites on a number of occasions during our study, particularly at times of peak fly numbers. At least two species of mites, the Macrochelid mite, *Macrocheles* sp., and an unidentified Trombidiid species, have been found on *M. domestica* and *S. calcitrans*, generally in low numbers. Aggregations in manure of what appear to be Uropodids have also been seen, however no systematic examination of manure was carried out for mites.

There was some evidence that mites detached from dead trapped flies. The infestation rate of live flies was 3.9% (20 mites from 513 flies) whereas comparable samples of dead flies only provided 4 mites from 597 flies (0.7% infested). Therefore the only trapped dead flies examined for mites were those from sticky Alsynite or yellow sheets on which the mites were also retained. Flies preserved in 70% alcohol appeared to retain mites and were also examined. If any mites detached they could be recovered in the sediment.

The percentage of *M. domestica* and *S. calcitrans* trapped on sticky sheets from which mites were recovered are shown in Figure 38 and Figure 39. (percent values only shown for samples of >100 flies). Mites were found in most samples and the blank values in both figures are due to the small sample size (< 100 flies). In general the levels of mite infestations on both fly species were similar, with the average from February 2002 to October 2003 being 3.8% and 3.2% for house and stable flies respectively.

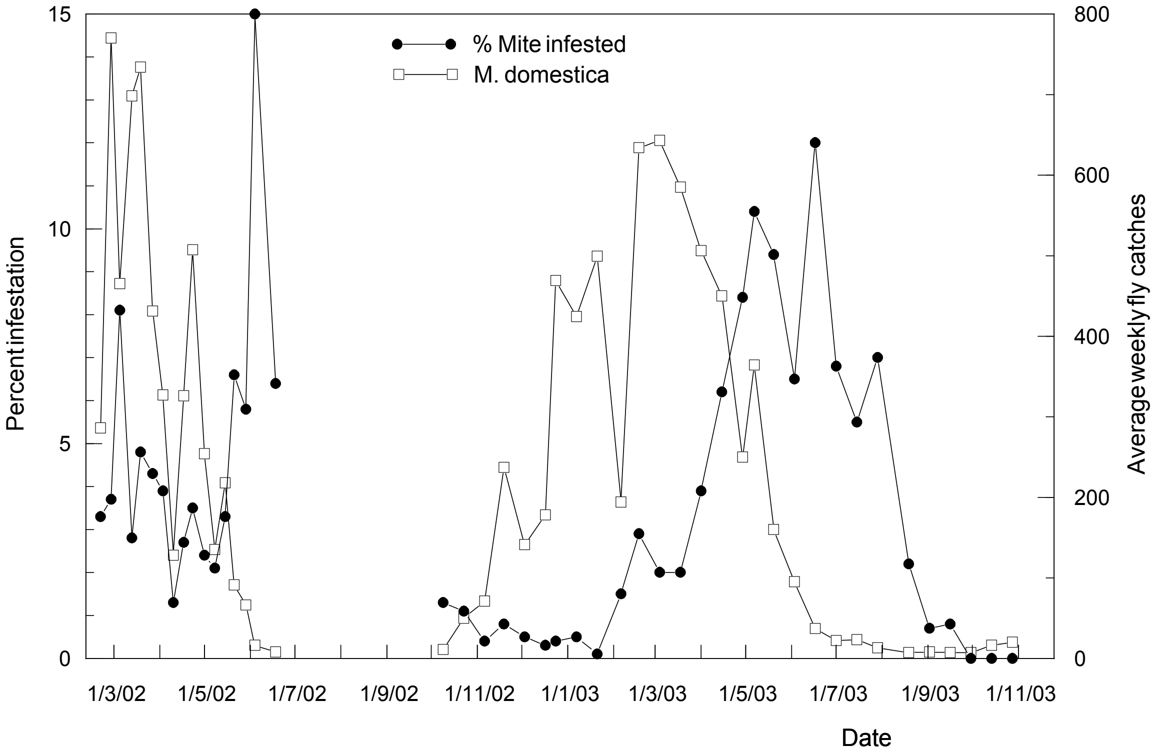

Figure 38 Percent phoretic and parasitic mite infestation on house flies from February 2002 to October 2003 (percentage shown only when total fly numbers on sticky traps >100)

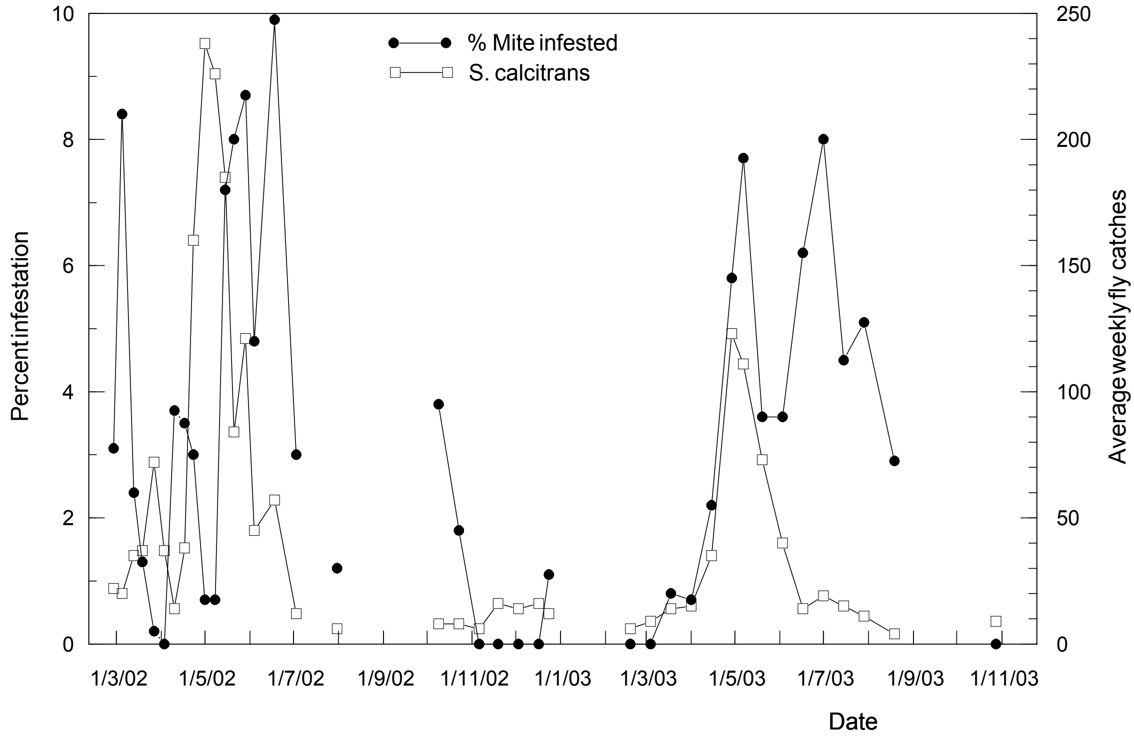

Figure 39 Percent phoretic and parasitic mite infestation on stable flies from February 2002 to October 2003 (percentage shown only when total fly numbers on sticky traps >100)

For *M. domestica,* peaks in infestation levels occurred in autumn /early winter in 2002 and 2003. Major peaks occurred after house fly numbers started to decline. Mites on *M. domestica* tended to be predominately unidentified "red" Trombidiid mites with small numbers (<2%) of *Macrocheles* sp. largely found between April to May each year. There was considerable variation in infestation levels between the sites for the Trombidiids. The silage pit showed consistently higher than average percentage of infested flies, reaching a maximum of 44% in May 2003. As for the wasps, such largely undisturbed substrates are likely to favour such population increases.

For *S. calcitrans* peaks in infestation levels also occurred in Autumn/early winter in both years. Mites on stable flies were predominately *Macrocheles* sp. (>75%) with smaller numbers of red Trombidiid mites. As for the house flies there was considerable variation in infestation levels between the sites with a maximum of 15% recorded at the manure piles.

The contribution of the various mites in the biocontrol of fly populations associated with livestock has not been generally established and to date, no mites have been produced commercially. In laboratory studies, predaceous mites such as the Macrochelids can kill up to 36 house flies per day per mite by feeding on eggs and early instar larvae. In an early field study, there were up to 45% fewer flies when mites were present. Apart from maintaining natural mite populations by judicious use of pesticides and a range of cultural practices, no additional studies are envisaged.

Entomopathogenic fungi

There has been an increasing interest during the last 30 years in the exploitation of naturally occurring organisms such as bacteria, viruses and fungi for the control of invertebrate pests. Most research has concentrated on the control of insect pests of crops and pastures, although the potential for microbial control of a wider range of insect pests is recognised. Fungi are unique among the microbial insect pathogens in that they primarily infect their hosts through the external cuticle. Thus they lend themselves to a greater variety of application methods, and hence a wider selection of target pests.

Current research being conducted by a DPI&F group is investigating the potential for fungal control of cattle ticks, buffalo flies, sheep lice and sheep blowflies. Results to date are very promising. Preliminary overseas research has investigated the potential for fungal control of nuisance flies in intensive animal houses with positive results.

Therefore a brief survey was conducted on the level of fungal infection in samples of pupae and flies collected in this project. Samples of non-emerged pupae from different sites at Aronui were examined either by microscopy or sterile isolation techniques, and the presence of fungi recorded. Sterile isolations were carried out with the adult flies and the types of fungi growing from flies were recorded. However, only selected entomopathogenic fungi were isolated and kept in pure culture for subsequent testing against *M. domestica*.

Fungi in pupae

A number of the non-emerged pupae collected from Aronui in mid April 2003 were investigated for the presence of fungi. Twelve *M. domestica* pupae and one *S. calcitrans* pupa collected from the drain site and nine *M. domestica* from the manure site were examined under the microscope. Thirty pupae from a range of sites were used for fungal isolations. The results of this investigation are summarised in Table 10.

Table 10 Origin, method of investigation and results of fungal isolations from feedlot pupae

Site	Investigation type	Total pupae investigated	Pupae with fungi present
Drain	Microscope	13	12
Manure	Microscope	9	0
Silage	Isolation	11	5
Drain	Isolation	6	2
Hospital/Induction	Isolation	5	2
Old Pens	Isolation	8	2

The microscopic examination of some pupae revealed partly or fully developed flies covered in fungal hyphae. In other pupae the larvae had been completely consumed by the fungus. (see photo of pupa with fungi in colour plates). Some of the fungi growing inside the pupae were clearly saprophytic, but others could have been parasitic. Further investigation would have to be carried out to test whether some of the fungi were capable of attacking the larvae. None of the common entomopathogenic fungi used as biopesticides were seen, though an as yet unidentified species of fungus did dominate.

Fungi in adult flies

The results from the fungal isolations of feedlot flies are shown in Table 11.

Table 11 Fungal isolations from adult feedlot flies

Date collected	Number of flies investigated	Number of flies with fungi present	Percent infected
3/1/2002	33 (dead)	21	63%
10/1/2002	11 (live)	7	64%
10/1/2002	149 (dead)	48	32%
16/2/2003	100 (dead)	57	57%
19/3/2003	31 (dead)	12	39%

A large number of fungi were recorded from the flies with many being common saprophytes. Only fungi from a few selected entomopathogenic genera were isolated and kept in pure culture.

Two of the most common fungi developed for commercial applications in insect control are *Beauveria bassiana* and *Metarhizium anisopliae,* both of which have been used in a number of DPI&F fly control research projects. The fly isolations yielded five isolates of *Beauveria bassiana* and eight isolates of *Metarhizium anisopliae.* Selected isolates of each species were tested for virulence against *M. domestica*. The results of these assays are shown in Figure 40 and Figure 41. In one bioassay, spores were formulated in an aqueous carrier and applied to the abdomen (2µl per fly, Figure 40). In the other bioassay, flies were allowed to self-contaminate by feeding on a mixture of spores and sugar (Figure 41). In both assays all isolates caused 100% fly mortality within 6 days with the most effective isolates killing 100% of flies within 4 days.

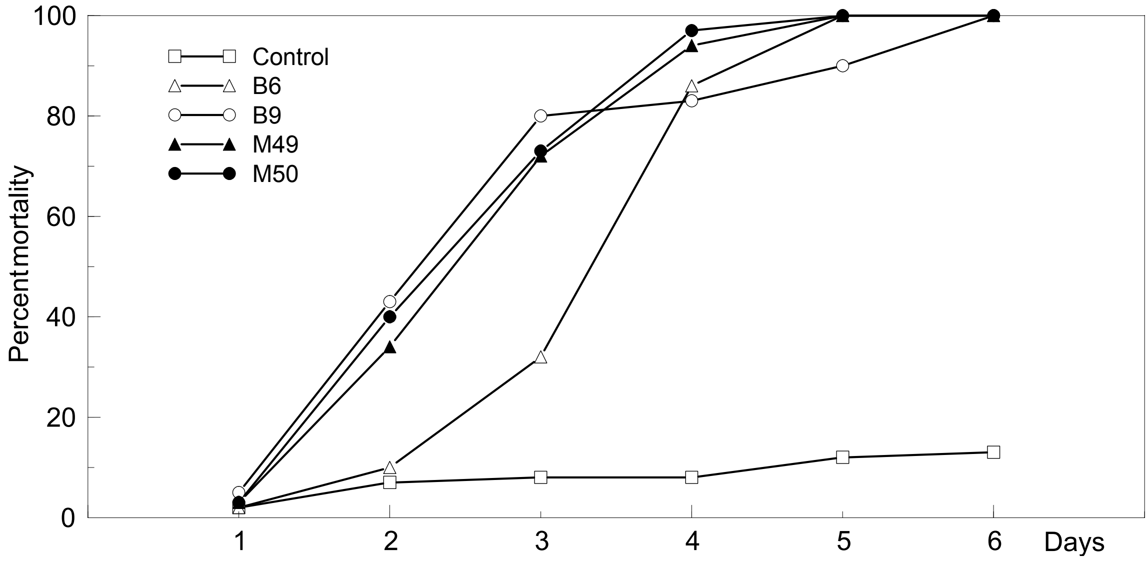

Figure 40 Mortality of *M. domestica* after topical application of *B. bassiana* and *M. anisopliae* isolates obtained from feedlot flies

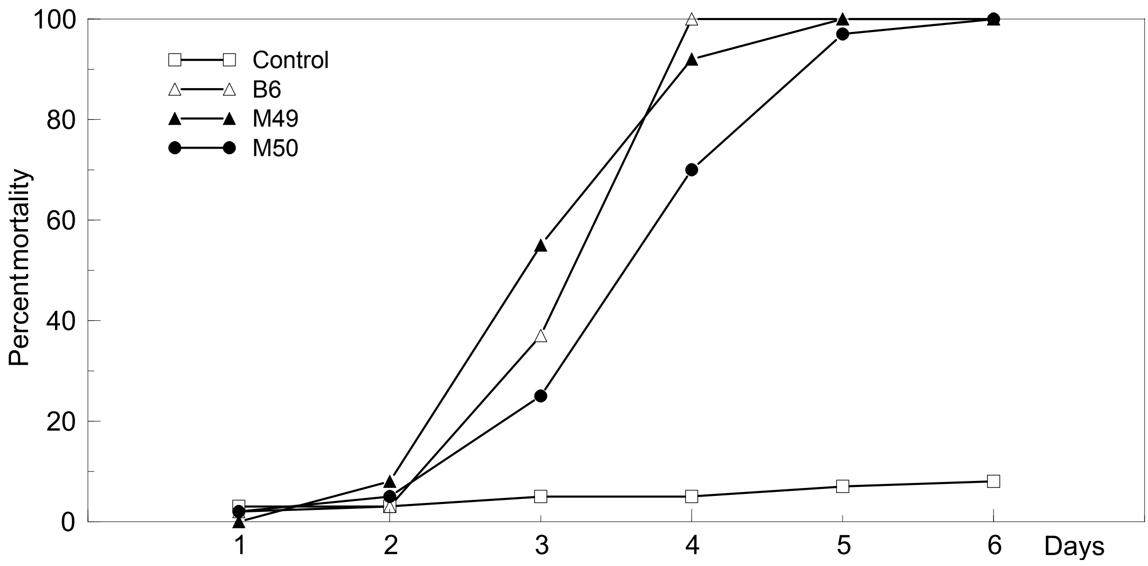

Figure 41 Mortality of *M. domestica* fed with sugar contaminated with *B. bassiana* and *M. anisopliae* isolates obtained from feedlot flies

Some of these isolates have also been tested against adult and immature stages of sheep blowfly and have shown high virulence. The studies reported here into fungi and feedlot flies really just provided a brief snapshot, yet the results indicate that there is a potential for controlling nuisance flies with endemic species of fungi. Therefore it is recommended that further studies be conducted to explore the development of local species of entomopathogenic fungi as an IPM tool for the management of nuisance flies in cattle feedlots.

Fly and parasite population monitoring in other feedlots

In addition to the comprehensive fly and parasite population monitoring carried out in a SQ feedlot, a snapshot of these populations was also obtained on two additional feedlots located in different climatic regions, namely in central NSW (CNSW) and central Queensland (CQ). Information on the feedlots is provided in Table 12.

Table 12 Information on feedlots in central NSW and central Queensland used for fly and parasite population monitoring

	Feedlot	
	CNSW	CQ
Average number of cattle over month prior to monitor	18,000 head	17,000 SCU
Domestic trade	35%	54%
Short fed Japanese export	40%	46%
Long fed Japanese export	25%	-
Major grain	Wheat, barley, corn (high moisture)	Sorghum, corn, barley
Grain processing	Steam flaking	Steam flaking; dry roll & ensile (corn)
Perceived fly nuisance over past month (1 very low, 10 very high)	4-6	9
Chemical treatments over past month	None	Baits (induction and hospital)
Average temperature over past month (daily min/max)	15.7/29.0C	19.7/31.8
Rainfall over past month	50 mm	33 mm
Rainfall over past week	2.6 mm	17 mm
Date of monitor	14-16 January 2003	25-27 March 2003

Management practices over the month prior to the monitoring included routine pen and under fence cleaning in both feedlots and catch drain cleaning at the CNSW feedlot. Both feedlots have large compacted manure stockpiles (and some windrows at CNSW) and compost their carcasses.

Adult fly population monitoring

The mean trap catches obtained on these feedlots in January and March 2003 respectively, and the average weekly catches from January to March 2003 in the southern Queensland feedlot (with continuous fly monitoring) are given in Table 13. The trapping periods in the additional feedlots were selected at times with abundant flies, whereas fly populations in southern Queensland were intermediate for house flies and low for other flies in the first quarter 2003 (see Figure 4). Thus, the snapshot trapping provides information on fly species and their relative proportion in the population rather than absolute comparisons of population sizes between the feedlots.

Table 13 Average fly numbers and percentage composition of total trap catch in various traps in three feedlots

Fly species	Trap	Average number of flies/ % trap composition					
		CNSW[a]		SQ[b]		CQ[c]	
M. domestica	Lucitrap	999	39%	202	26%	1592	61%
	Alsynite	53	21%	532	98%	606	93%
	Terminator	929	88%	940	93%	7626	88%
M. vetustissima	Lucitrap	420	16%	9	1%	496	19%
	Terminator	109	10%	36	4%	729	8%
S. calcitrans	Alsynite	202	79%	8	1%	4	0.6%
Blowflies	Lucitrap	1095	43%	567	72%	466	18%
	Terminator	5	0.5%	33	3%	199	2%
All flies	Lucitrap	2550		790		2616	
	Alsynite	257		541		652	
	Terminator	1055		1010		8619	

[a] Central NSW: 14-16 January 2003
[b] Southern Queensland: Average weekly catch January-March 2003
[c] Central Queensland: 25-27 March 2003

The major fly species, *M. domestica, M. vetustissima, S. calcitrans* and blowflies were found in all monitor feedlots. *M. domestica* was the most abundant species in all feedlots and its numbers were particularly high in central Queensland with an average Terminator trap catch of >7000 compared with about 1000 in the other feedlots. Bush flies were trapped in higher numbers in the CNSW and CQ feedlots than the SQ feedlot, where the bush fly populations were low during the hot summer months (Figure 9). The clearest differences between the feedlots were seen with *S. calcitrans* catches. The mean catches on the Alsynite trap, which targets *S. calcitrans*, were 202, 8 and 4 stable flies for the CNSW, SQ and CQ feedlots respectively. The CNSW *S. calcitrans* catch constituted 79% of the total Alsynite trap catch compared to 1% or less for the other feedlots. The lower temperatures at CNSW (see Table 12) could favour stable fly populations at CNSW over the Queensland feedlots. Stable flies are usually most abundant during the cooler periods in Queensland as demonstrated in the continuous SQ feedlot monitor (Figure 10).

Blowflies were also caught in all feedlots with the highest catch in CNSW. Most of the blowflies were *Chrysomya rufifacies* in the CQ and SQ feedlot, whereas in CNSW there were about equal numbers of *C. rufifacies* and *C. varipes*. Other flies caught in the two feedlots included *Hydrotaea spinigera* (high numbers in CNSW), *Physiophora clausa* (high numbers in CQ), *H. rostrata*, F. Syrphidae and *Atherigona* sp. These flies had all previously been detected in the SQ feedlot.

The major fly species, house flies, stable flies, bush flies and blowflies were found in all three monitored feedlots located between central New South Wales and central Queensland. There were differences in their relative abundance between the feedlots: House fly was the most common fly in all feedlots and stable fly was more abundant in the CNSW feedlot than the Queensland feedlots during these one-off collections. The highest trap catches were obtained in the CQ feedlot which also scored the higher nuisance fly rating by its manager (see Table 12).

The average numbers of fly avoidance movements observed on cattle in the three feedlots is given in Table 14. The numbers of movements were similar in all feedlots, with the exception of leg stomps which were more than ten times higher at the CNSW than the Queensland feedlots. Leg stomps are elicited by stable flies and they were in much greater abundance at the CNSW feedlot.

Table 14 Average number of animal movements (per minute) in three feedlots

Movement	Feedlot		
	CNSW	SQ	CQ
Tail swishes	13.2	10.4	10.1
Ear flicks	3.6	5.7	4.5
Head tosses	1.3	0.9	0.5
Leg stomps	1.1	0.1	0.0
Total	19.1	17.2	15.1

Immature fly population monitoring

The average larval and pupal rating, the numbers of extracted larvae and pupae and the species composition of the extracts are provided in Table 15 for the three feedlots. The CQ feedlot had the highest larval rating and numbers of larvae extracted. House fly larvae were the most common larvae in all feedlots and they constituted >90% of the larvae in both Queensland feedlots. Stable fly larvae made up 13%, 6% and 1% of the extraction in the CNSW, SQ and CQ feedlots, respectively. Most of the other fly larvae were *P.* clausa in the CNSW and CQ feedlots. The pupal ratings and the numbers of pupae were similar in all three feedlots. The species composition of the pupal extracts were generally similar to the larval extracts, but there were some differences: In the CQ feedlot a higher percentage of other pupae, mostly *P. clausa*, was observed and in CNSW the stable fly/house fly ratio was higher for pupae than larvae.

Table 15 Average larval and pupal ratings and numbers and percent composition of extracted larvae and pupae in three feedlots

Indicators		Feedlot					
		CNSW[a]		SQ[b]		CQ[c]	
Larval rating		2.7		2.8		4.3	
Number of larvae extracted	*M. domestica*	562	77%	1121	92%	1727	91%
	S. calcitrans	97	13%	72	6%	11	1%
	Other flies	72	10%	30	2%	161	8%
	Total	731		1223		1899	
Pupal rating		2.4		1.9		2.2	
Number of pupae extracted	*M. domestica*	307	54%	683	94%	315	60%
	S. calcitrans	220	39%	29	4%	4	1%
	Other flies	41	7%	9	2%	204	39%
	Total	568		721		523	

[a] Central NSW: 15 January 2003; [b] Southern Queensland: Average January-March 2003
[c] Central Queensland: 26 March 2003

The larval rating and abundance, including the species distribution, correlate well with the values for the adult flies in the same feedlot (Table 13). The species distribution in the pupae is also similar to larval and adult data, but the quantitative differences between the feedlots were not observed. This may well be due to the timing of these one-off monitors compared to the status of the fly wave, e.g. high numbers of adults and larvae but preceding the increasing numbers of pupae. The one-off monitors were carried out at a time when the feedlot operators deemed their fly numbers to be high.

The abundance of larvae at different sites was also compared across the three feedlots (Table 16). The sites with high larval density were consistent across feedlots: the silage pits, drains and hospital (no collection in CNSW) rated within the first three sites in all feedlots. Above average numbers of larvae were also extracted from cattle pen samples in SQ and CQ. The averages for the cattle pens at CNSW were not as high, because the pen slope was much higher at this feedlot and high larvae numbers were only obtained at the back fence, where manure had accumulated. The horse stable in the CNSW feedlot and the sedimentation pond in CQ also produced high larval extracts. House fly larvae were found at all sites and they comprised the highest portion of the species on the sites near animals (pens, stables). Above average numbers of stable fly larvae were found in the drains, sedimentation pond and manure piles in CNSW, in the drains and hospital in SQ and in the hospital area in CQ. *P. clausa* (the majority of the other flies) were largely limited to the manure piles, silage pits and drains.

Table 16 Average larval ratings and numbers and percent composition of extracted larvae for different sites in three feedlots

Site		Feedlot					
		CNSW[a]		SQ[b]		CQ[c]	
Sedimentation pond	Larval rating	2.8		2.2		4.4	
	M. domestica	293	42%	1391	96%	1865	98%
	S. calcitrans	211	30%	46	3%	0	0%
	Other flies	201	29%	14	1%	35	2%
	Total	705		1451		1900	
Horse stables	Larval rating	3.3		1.2		3.0	
	M. domestica	1005	98%	125	99%	307	99%
	S. calcitrans	21	2%	1	1%	3	1%
	Other flies	0	0%	1	1%	0	0%
	Total	1025		127		310	
Manure piles	Larval rating	1.6		2.3		4.3	
	M. domestica	81	57%	981	92%	1937	97%
	S. calcitrans	23	16%	14	1%	0	0%
	Other flies	39	27%	74	7%	63	2%
	Total	142		1070		2000	
Old pens	Larval rating	2.4		3.0		4.4	
	M. domestica	724	96%	1502	99%	2335	98%
	S. calcitrans	8	1%	12	1%	0	0%
	Other flies	21	3%	9	1%	45	2%
	Total	754		1523		2380	
New pens	Larval rating	2.0		3.0		5.0	
	M. domestica	605	98%	1514	96%	3000	100%
	S. calcitrans	0	0%	57	4%	0	0%
	Other flies	15	2%	1	0%	0	0%
	Total	620		1572		3000	
Silage pit	Larval rating	3.6		3.4		4.6	
	M. domestica	1027	87%	1251	89%	1147	55%
	S. calcitrans	8	1%	40	3%	0	0%
	Other flies	140	12%	113	8%	953	45%
	Total	1175		1403		2100	
Drains	Larval rating	3.0		3.4		4.5	
	M. domestica	195	28%	1027	73%	2159	92%
	S. calcitrans	411	59%	354	25%	0	0%
	Other flies	89	13%	23	2%	191	8%
	Total	695		1404		2350	
Hospital	Larval rating	--	--	4.0		4.5	
	M. domestica	--	--	1100	89%	1069	93%
	S. calcitrans	--	--	133	11%	81	7%
	Other flies	--	--	10	1%	0	0%
	Total	--	--	1243		1150	

Parasite populations monitoring

Parasitic wasps

The viability of the extracted house fly pupae collected from the three feedlots is shown in Table 17. The level of parasitism is similar in all feedlots, ranging from 9% to 12% which is close to the two-year average of 11% in the SQ feedlot. The CNSW and SQ feedlots also had similar fly emergence rates, whereas fewer flies emerged from the CQ pupae. The parasitic wasps killed at least 21%, 23% and 35% of flies developing in the CNSW, SQ and CQ feedlots respectively.

Table 17 Viability of pupae collected on three feedlots

Viability	Feedlot		
	CNSW	SQ	CQ
No emergence	56%	57%	65%
Flies emerged	35%	33%	23%
Wasps emerged	9%	10%	12%

The species and numbers of parasitic wasps and the percentage that emerged from house fly pupae at the three feedlots are given in Table 18.

Table 18 Numbers of parasitic wasps and percentage emerged from *M. domestica* pupae collected on three feedlots

Species	Total numbers of wasps/ % ex. *M. domestica*					
	CNSW (n=3973)		SQ (n=5657)		CQ (n=4181)	
Spalangia endius	195	50%	178	95%	149	73%
Spalangia nigroaenea	66	72%	160	98%	55	0%
Spalangia cameroni	92	65%	154	98%	266	41%
Muscidifurax raptor	1	100%	42	100%	72	100%
All species	354	58%	534	97%	542	53%

The major parasitic wasp species were identical in all feedlots. *S. endius* was the most common wasp in the CNSW and SQ feedlots, *S. cameroni* the most abundant in the CQ feedlot. The wasp species detected at low abundance in the SQ feedlot during the two-year study were not detected in this one-off monitor at the CNSW and CQ feedlots. *Spalangia* spp. were the principal wasp parasites of flies in Australian feedlots from central NSW to central Queensland.

In the SQ feedlot, house fly pupae made up a large fraction of the population and consequently most wasps (97%) emerged from house fly pupae. In the CNSW and CQ feedlots house fly pupae constituted 54 to 60% of the population (see Table 15) and a corresponding percentage of wasps emerged from these pupae. This demonstrates that the wasps parasitise a variety of fly pupae to about the same extent. In CNSW, 36% of the wasps emerged from *S. calcitrans* pupae which made up 39% of the pupal population. In the CQ feedlot, 46% of the wasps emerged from other pupae (39% of population) with most of these being *P. clausa*. The ratios of female to male wasps were 64:36, 64:36 and 48:52 for CNSW, SQ and CQ feedlots respectively.

Mites associated with feedlot flies

In the CNSW feedlot, three species of mites were found on *M. domestica*. Two of these species, belonging to the families Trombidiidae (1.9%) and Macrochelidae (0.1%), detected on sticky traps, were similar to those found on SQ flies. Groups of small white nymphal mites (Pygmephoridae) were also detected on 6.5% of flies. Due to their small size, these mites were only found after microscopic examination of netted flies, preserved in 70% alcohol. Only Macrochelidae (0.2%) were seen on *S. calcitrans* recovered from sticky traps.

In CQ, only a single species of mite (Trombidiidae, 2.4%) was found on *M. domestica* from sticky traps. Examination of netted flies also revealed a single species of Trombidiidae (2.4%). No mites were found on *S. calcitrans*, however only a small number of flies were available for examination.

SUMMARY AND CONCLUSIONS

A comprehensive program to monitor fly and parasite population at a southern Queensland (SQ) feedlot was designed and implemented. The population monitoring program targeted adult flies and their immature stages (larvae and pupae) and biological control organisms that adversely affect both adult and immature fly stages. The natural enemies included parasitic wasps (lay their eggs inside fly pupae and devour the immature fly), predatory mites (feed on fly eggs and larvae and attach to adult flies) and entomopathogenic fungi (spores germinate on the fly cuticle and the growing fungi penetrate the cuticle to access food resources). A snapshot of fly and parasite populations was also obtained on two additional feedlots located in different climatic regions, namely in central NSW (CNSW) and central Queensland (CQ).

The sampling systems for adult flies were traps containing odour attractants and sticky traps. The major trapping systems were the Terminator trap (house flies, bush flies), Lucitrap (blowflies, house flies, bush flies) and the Alsynite trap (stable flies, house flies). The impact of adult flies on feedlot cattle was assessed through quantitative observations of cattle behaviour, such as tail swishes, ear flicks, head tosses and leg stomps.

Flies in their immature stages were collected by core sampling manure, feed and soil in strategic places. An abundance rating for larvae and pupae at these sites was recorded. Larvae and pupae were subsequently extracted from the samples by the use of appropriate flotation techniques.

Parasitic wasps were obtained from sentinel fly pupae exposed in the feedlot and from collected feedlot pupae after an appropriate development period. Mites and fungi were isolated from adult and immature flies collected on the feedlot.

The results presented in this report cover the fly and parasite population monitoring activities from November 2001 to October 2003.

Adult fly populations

Over 1.6 million flies were caught on the SQ feedlot over the two-year period and just less than half of these were blowflies. The most commonly trapped species were house flies (*Musca domestica*, 38% of total fly catch) and hairy maggot blowflies (*Chrysomya rufifacies*, 27%). Other common species trapped were the bush fly (*M. vetustissima*, 15%), stable fly (*Stomoxys calcitrans*, 1.3%), the small hairy maggot blowfly (*C. varipes*) and the bluebodied blowfly (*Calliphora augur*).

Seasonal effects on fly catches

There was clear evidence that feedlot fly populations are influenced by seasonal changes (Figure 42). Air temperature was the main driver of major fly population increases and reductions. Rainfall also affected the populations of some fly species, although to a lesser extent than temperature. There was no prolonged extreme dry or wet period during the monitoring phase, thus the effect of such an event on fly populations was not established. The most common fly species on the feedlot, the house fly, had one broad annual population peak extending over most of the year with the exception of the coolest winter months (Figure 42). Minor maxima and minima in house fly populations appeared to be caused by better than average rainfall and drier, hotter periods respectively. Bush fly population peaks occurred in spring (major peak) and late autumn and were short lived, lasting for only a few weeks. The stable fly has two annual population peaks in the feedlot, the major peak in late autumn and the minor peak in late spring/early summer. Stable fly populations decline during the middle of the summer and in late winter, but the population reduction in winter occurs later than for the house and bush flies. *Chrysomya* spp. provide the bulk of the feedlot blowflies and they show a similar population profile to stable flies. The bluebodied blowfly has population maxima in winter and is practically absent from the feedlot during the summer.

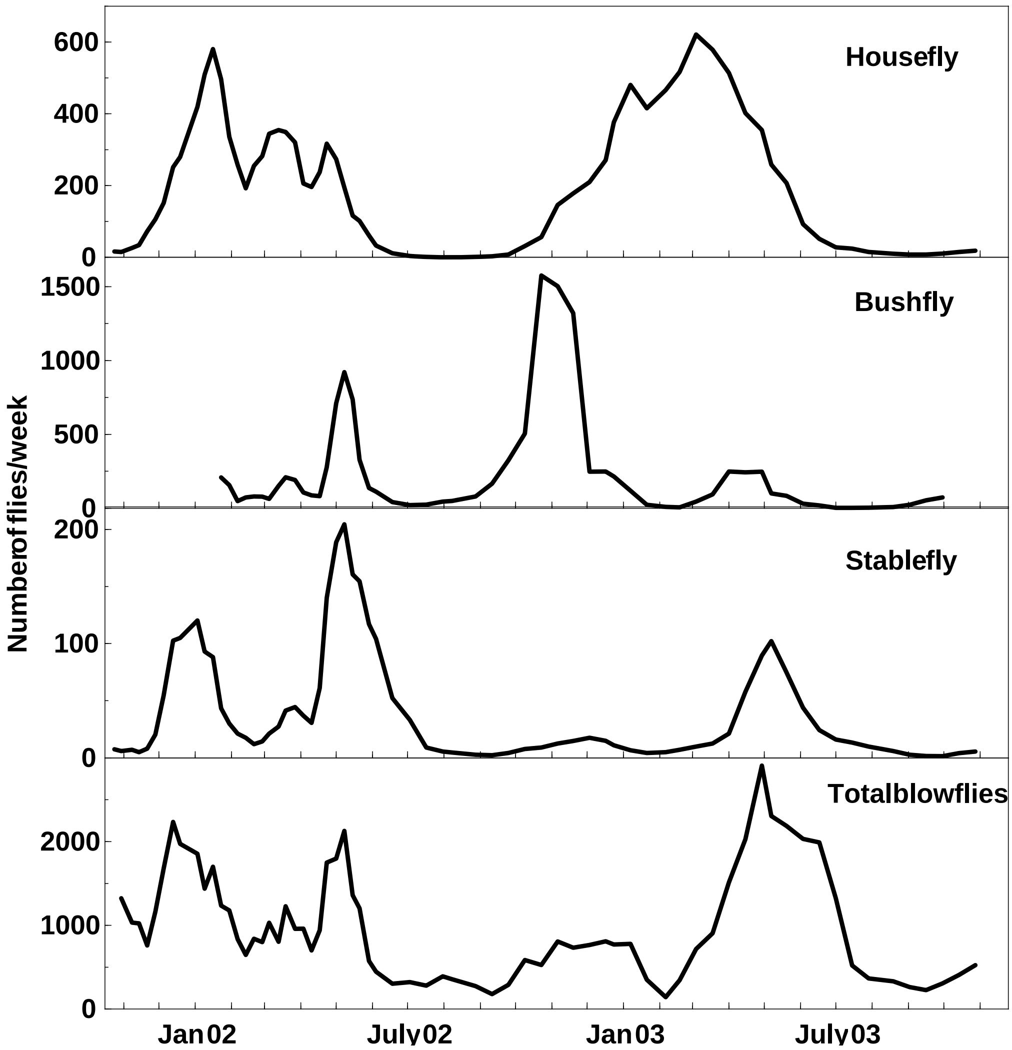

Figure 42 Average weekly trap catches for house flies, bush flies, stable flies and total blowflies from November 2001 to October 2003.

Comparison of feedlot sites

Fly traps were placed at or near the following sites within the feedlot:

- Feed mill
- Dam (freshwater storage)
- Silage pits
- Sedimentation pond
- Manure stockpiles
- Cattle pens
- Vegetation between pens
- Horse stables
- Hospital/induction area
- Outside the feedlot complex (to establish background levels)

The distribution of various fly species inside and outside the feedlot was distinctly different. House fly populations were higher inside than outside the feedlot and they were distributed across the entire feedlot, with populations higher in the vicinity of cattle. The highest bush fly catches were obtained outside the feedlot and at the manure stockpiles in the feedlot. Stable fly populations were concentrated at the manure stockpiles and the silage pits. Very few stable flies, which depend on animal hosts for blood meals, were caught outside the feedlot. Blowfly catches were the highest in the traps outside the feedlot, followed by the manure stockpile traps.

Feedlot management practices

The four major insecticide applications during the monitoring period did not have a major impact on adult fly populations. The prevalent seasonal trends in fly populations after the treatment appeared to be the same as pre-treatment. It is possible that the insecticides had short term effects on fly populations which were not reflected by the weekly or fortnightly monitoring program. Fly bait was used in the induction area, the hospital and the feed mill when perceived necessary, which could be as often as weekly during the summer months.

The results of the resistance tests of the feedlot house flies, moderately resistant to diazinon (organophosphate, OP) but no or low-level resistance to cyfluthrin (synthetic pyrethroid) and azamethiphos (OP) and behavioural resistance to fly baits, are congruent with infrequent insecticidal spraying and more regular use of fly baits at the feedlot.

Observations of feedlot cattle behaviour

Cattle irritated by flies will initiate actions in order to minimise their irritation. These actions aim to reduce the number of flies on the animal or prevent the flies from carrying out their annoying habits, e.g. collecting moisture from eyes or nose or biting to obtain a blood meal. Such fly-induced cattle behaviour includes bunching up into a tight group, tail swishes, ear flicks, head tosses and leg stomps. Observations of feedlot cattle behaviour were made at each feedlot visit in order to obtain an index of fly annoyance.

Tail swishes were the most commonly observed activity (average over monitoring period 6.9/minute, highest average 19/min.), followed by ear flicks (2.6 and 11/min.). Head tosses and leg stomps were recorded much less frequently with the highest averages at 3 and 1.7/min respectively.

The frequency of the animal movements correlated well with the number of house and bush flies caught in the traps over the monitoring period, e.g. frequent movements coincided with high fly populations. Likewise, the number of leg stomps correlated well with the stable fly populations, confirming the hypothesis that leg stomps are primarily a defensive reaction to biting stable flies.

The close correlation between animal movements and fly populations make formalised observations of cattle a valid tool for assessing feedlot fly populations. Counts of one or several of these movements on a number of animals (5 to 10) over a specified time (e.g. 1 minute) will give an indication of prevalent fly populations associated with this movement.

Immature fly populations

The vast majority of immatures found in the feedlot were house flies, with 86% of larvae found during the entire monitoring program belonging to this species. Stable fly (10%) and *Physiphora clausa* (Otitidae) (3%) larvae were also detected on the feedlot in significant numbers, while all other larvae together accounted for less than 1% of the total.

Tight correlations between the larval and pupal density ratings (field observations) and the number of fly larvae and pupae extracted in the laboratory were obtained.

Seasonal effects

The seasonal abundance of larvae and pupae closely matched the patterns observed for adult flies. House fly larvae were found in elevated numbers over about 9 months of the year (October to June). Stable fly larvae and pupae were recovered at much lower numbers and their major population peak was in autumn 2003 with two minor peaks in spring and autumn 2002. During the hot summer almost no immature stable flies were found in the feedlot. It appears that the major fluctuations in larval and pupal populations are a result of seasonal conditions.

A close correlation between larval/pupal abundance and trapped flies across the seasons was also observed. The peaks and troughs in the house fly trap catches generally follow those of larval and pupal abundance with a couple of weeks delay. As the immature stages progress to adult flies, a lag of about one to two weeks is to be expected in hot weather, somewhat longer in cooler conditions.

Feedlot sites

Larvae were found in all selected sites, with average extractions of all species ranging from 150 to 850 larvae per sample (Figure 43). The highest average numbers of house fly larvae were recovered from the hospital/induction area and the cattle pens. The sedimentation pond, manure stockpiles, silage pit and drains produced values close to the average, whereas the yield of larvae from horse stable samples was well below the others. Stable fly larvae were found in highest numbers in the drains and the hospital. The sedimentation pond also contained above average numbers of stable fly larvae whereas the other sites were below average.

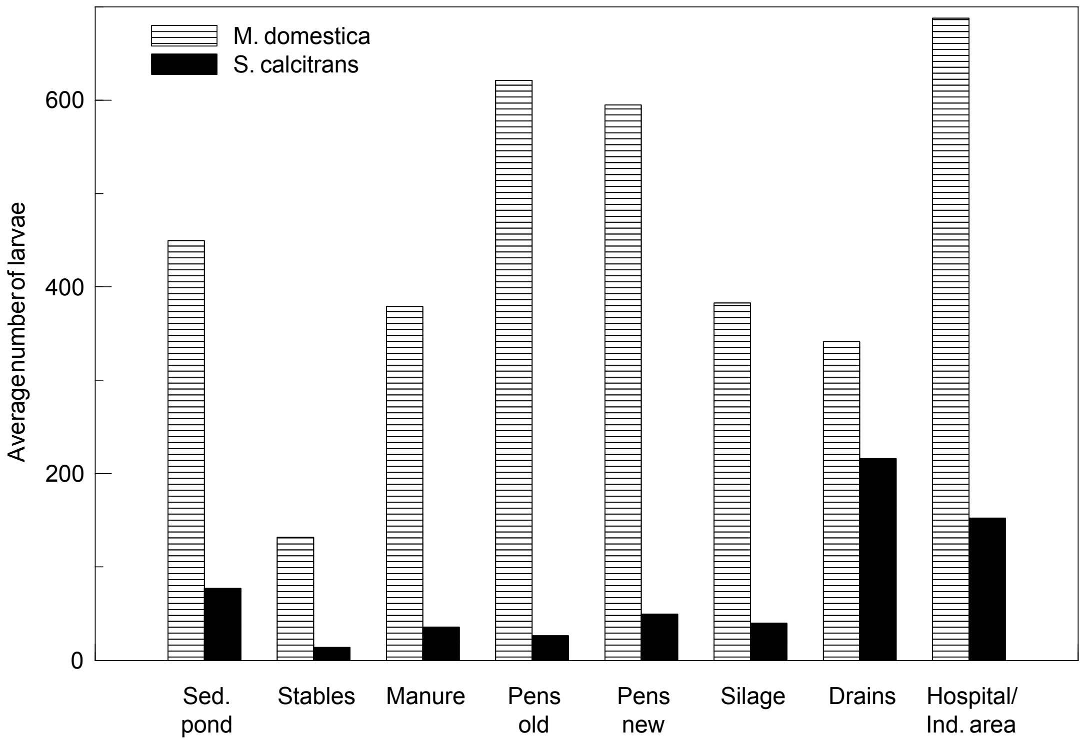

Figure 43 Average numbers of larvae extracted from various feedlot sites

The ranking of feedlots sites by larval production was reasonably consistent across seasons. The highest yielding sites, the hospital and cattle pens, were consistently high compared to the other sites. The sedimentation pond was high in summer and spring and low in autumn and winter. The manure stockpiles, although overall an average fly breeding site, produced most of the house fly larvae in winter.

The highest numbers of larvae were found where a mixture of vegetation, manure and moisture was present. These factors combined, provide ideal breeding grounds for a variety of fly species. The hospital/induction area, under the fence lines in cattle pens, drains and silage pits all provide such ideal substrates for fly development.

At each feedlot site, five manure/soil samples were collected in different locations, to pinpoint preferred egg laying and developmental spots within the feedlot sites. The larval abundance varied greatly between different locations. In the hospital/induction area, the hospital yards had particularly high larval counts probably due to high amounts of feed residue (hay and grain), low cattle numbers and infrequent cleaning. In cattle pens, the highest ratings were consistently obtained under the fence lines which produced between 76 and 89% of the larvae from this site. The larval abundance adjacent to the feed bunk was higher than in the middle of the pen, but still much lower than under the fence lines. In the sedimentation pond, larvae were generally located at the liquid-solid interface which moved up and down the pond edge depending on water influx. The sedimentation pond inlet, including the drain, gave the highest reading. In the drains, the highest numbers of larvae were observed in areas with poor drainage. The highest larval abundance in the manure piles was observed in fresh, wet deposits removed from sedimentation ponds or catchment drains, followed by the manure stock pile used for composting carcasses. The ratings of the other manure piles were considerably lower, particularly the larval ratings. The pit face gave the highest rating in the silage pits. In the horse area the most productive fly breeding location was in the day spelling paddock, where larvae and pupae were found in a mixture of soil and hay around the feeding bins.

These findings indicate that major fly breeding is concentrated to relatively small pockets in the feedlot. A potentially successful **strategy for reducing fly breeding in the cattle feedlot would involve a more targeted and more frequent cleaning of these major fly breeding areas**. For example, in the cattle pens the manure under the pen fences should be removed more frequently than only during the normal complete pen clean out which occurred every two to three months at the SQ feedlot; in the hospital the mixing of hay and manure should be minimised and/or the area should be cleaned more frequently; in the sedimentation pond the solid/liquid interface should be kept as small as practical; in the silage pits the presence of spilled silage should be minimised. Such strategies may result in better control of fly breeding than the current processes and they should be part of an IPM system for fly control in cattle feedlots**. It is recommended that the benefits of more frequent, targeted cleaning procedures for fly control be investigated**.

Effects of feedlot design and practices

Cattle pens in the newer section of the feedlot have a pen surface with a 3% slope, considered optimal by industry for drainage and odour control, whereas the older section has minimal pen surface gradient. The average numbers of larvae recovered from the new and old pens over the whole monitoring period were identical but their distribution within the pens was different. However, differences between the old and new pens other than design, such as cattle breeds, feed rations and residues, stocking rates and shade cloth, may have significantly impacted on fly breeding. Most of these factors appeared to assist fly breeding in the new pens. Therefore, it is possible that the anticipated beneficial effects of increased pen slope on fly breeding were negated by other differences or that pen slope did not have a significant effect on fly breeding. Manure accumulated under the fence lines regardless of pen gradient and fence lines were identified as the major fly breeding site associated with cattle pens. Furthermore, this assessment of fly breeding was obtained during a relatively dry period when pen gradient may not have been a critical issue.

There was some evidence that a concrete base under cattle pen fence lines may assist in reducing under-the-fence fly breeding. Thirty percent fewer larvae were recovered from concrete base than from earth base fence lines in pens of similar design and with the same cattle breed and feed rations.

Manure scraping and removal from cattle pens and fence lines was generally performed on a routine basis at two to three month intervals. After many, but not all, pen cleaning events, a reduction in numbers of larvae was observed. However this reduction was short-lived, commonly observed only in the first measurement following the cleaning. The reduction was often not substantial in terms of the existing immature fly populations and fly production quickly returned to its season-driven level. Our observations indicated that a build up of non-compacted manure under the fences occurred rapidly after the cleaning, thus re-establishing the flies' preferred breeding sites. Similar observations were made for the sedimentation pond. As mentioned above, a more targeted and more frequent cleaning of major fly breeding sites should assist in fly control.

Insecticidal treatments were infrequent and generally applied when there was a perceived need rather than on a routine basis. Fly baits, which attract and kill adult house flies only, were also used when deemed necessary. All of the insecticide treatments targeted the feed bunks and some also included the pen fence lines. The larval abundance in pens was not substantially reduced by any of the treatments. The chemical treatments may have resulted in minor, short-term reductions. It appears that insecticidal treatments had little if any impact on fly breeding or fly populations on the feedlot.

The results of the resistance tests of the feedlot house flies, moderately resistant to diazinon (organophosphate, OP) but not or weakly resistant to cyfluthrin (synthetic pyrethroid) and azamethiphos (OP) and behavioural resistance to fly baits, are congruent with infrequent insecticidal spraying and more regular use of fly baits at the feedlot.

Of the flies trapped on the feedlot, only house flies and stable flies breed on the feedlot, whereas all others predominantly breed outside the feedlot and presumably are attracted to the feedlot by its odours. Minimising feedlot odours may reduce its attractiveness to flies breeding outside the feedlot and thus lower their populations in the feedlot. Bush flies breed in undisturbed cattle dung and as our study has confirmed, the feedlot environment is unsuitable for their breeding. It is interesting to note that not a single buffalo fly was caught in any trap on the feedlot which was located in an area where they would commonly be found on grazing cattle. Buffalo flies also breed in undisturbed cattle dung and spend all of their adult life on animals. Blowflies breed in carcasses and this study has shown that this takes place primarily outside the feedlot. However, it is crucial that feedlot carcasses are completely covered when they are buried in composting piles to prevent blowfly breeding on the feedlot.

Parasite populations

Parasitic wasps

Parasitic wasps were collected in the feedlot using two independent methods. Firstly, through controlled exposure of house fly pupae to the feedlot wasp populations (= sentinel pupae) and secondly through appropriate processing and examination of the fly pupae collected for the immature fly population program.

Sentinel pupae

Parasitism of sentinel pupae was generally between 0% and 20%, but it reached 35% on two occasions. Fly emergence occurred in 81% of the sentinel pupae. A total of 530 pupae (4.2% of the 13,000 exposed pupae) were parasitised and 606 wasps emerged. Most pupae yielded only a single parasitic wasp, but multiple wasp emergence was observed a few times. The most common wasp parasites in sentinel pupae were *Muscidifurax raptor* and *Spalangia cameroni*.

Feedlot fly pupae

The percentage of parasitised pupae collected in the feedlot was 11%, while a fly emerged from 30% and nothing emerged from 59% of the pupae. The rates of parasitism and viability were consistent for house fly, stable fly and other feedlot pupae. Not counting the non-emerging pupae, parasitic wasps reduced the emergence of flies by 27%. However, the actual suppression of fly emergence by parasitic wasps is higher because wasps also sting pupae to feed on them (dudding) or eggs are laid but no wasps emerge. Such pupae will produce neither a fly nor a wasp and thus are classified as non-emerged pupae in our assessment. Parasitic wasps are clearly one of the important biological control agents for fly pupae in this feedlot.

Eight species of parasitic wasps emerged from fly pupae collected at the feedlot. About 90% of these wasps were *Spalangia* spp., with *S. endius* the most common species (50% of all wasps). Other wasp species included *M. raptor* and *Trichomalopsis* sp. and wasps from the family Diapriidae. Only a single parasitic wasp emerged from most pupae, but multiple wasps (maximum 15) emerged from some pupae. Multiple wasp emergence was observed with *Trichomalopsis* sp. and Diapriidae. Between 86% and 92% of the wasps emerged from *M. domestica* pupae for all wasp species except *Trichomalopsis*. This emergence pattern matches well with the ratio of extracted house fly to stable fly pupae (88:12), indicating that the wasps equally parasitise both fly species. About two thirds of all emerged wasps were female with a similar sex ratio across all species, except for *Trichomalopsis* sp. with 99% females. The species of wasps found in the feedlot pupae were basically the same as in the sentinel pupae, however, the proportion of the species was distinctly different.

Wasp populations followed basically the same seasonal pattern as fly populations: population peaks during summer and troughs during winter. *S. endius* was the most abundant species in most months, with broad population peaks from October to June. *S. nigroaenea* and *S. cameroni* populations increased about two to three months later than *S. endius* but disappeared about the same time (June). *S. cameroni* was the most common species in the small population of surviving wasps during winter 2003. The presence of *M. raptor* was inconsistent in 2001/02 (only January and June 2002 provided reasonable numbers) but it had a population pattern similar to *S. nigroaenea* in 2002/03. There was no clear difference in seasonal patterns of wasp populations which had emerged from house flies or stable flies respectively.

The percentage of pupae parasitised varied greatly between collections. The average percentage of parasitism for house fly and stable fly pupae was similar in many months, but there were a few differences. During the cold months of July and August the level of parasitism was low for house flies, but remained close to the average for stable flies (in 2003 this trend continued into spring). The level of parasitism was generally not correlated with the number of pupae extracted from the feedlot samples.

The four major species of wasps were found at all monitored feedlot sites, indicating wasp presence and activity throughout the feedlot. The highest numbers of wasps were recovered from the silage pits, the hospital and the cattle pens. All feedlot sites showed parasitism rates of between 7% and 16%. The hospital and stables had the highest parasitism rates (16% and 13% respectively) and the sedimentation pond and manure piles the lowest rates (7% and 8%).

There was no evidence that scraping and/or cleaning cattle pens had a substantial impact on the levels of parasitism. Two insecticidal treatments within three weeks (January/February 2002) appeared to lower the level of parasitism over the subsequent month, but no such reduction was observed after the 2003 applications (January and April).

The level of parasitism was higher in the feedlot pupae (11%) than the sentinel pupae (4.2%). This difference could be due to presentation of pupae (containers versus manure/soil), the age of the pupae or a difference in the attractiveness between colony and field produced pupae.

The species of wasps found in the feedlot pupae were basically the same as in the sentinel pupae, however, the proportion of the species was distinctly different. The feedlot pupal data demonstrates that *Spalangia* spp. are the dominant parasitic wasps in this feedlot. *M. raptor* and *S. cameroni* were the most common wasps in the sentinel pupae. *S. endius* was the most common species in the feedlot pupae, but was hardly present in sentinel pupae. This difference is probably due to the variable ability of parasitic wasp species to locate buried pupae and to differences in pupal age. This comparison also indicates that feedlot pupae are the better method of establishing wasp parasitism rates in a cattle feedlot.

The parasitic wasps detected on the feedlot are the same species found in similar American and European studies. The presence of these wasps provides Australian feedlot managers with the opportunity to use parasitic wasps for biological control of nuisance flies. Several of the parasitic wasp species found on the Australian feedlots are commercially cultured in the US for the control of flies in intensive livestock industries. The know-how of producing and applying the parasitoids on feedlots has already been established in US facilities. With the knowledge that these species are endemic in Australia, such cultures could be set up in this country. **It is recommended that the production and application of parasitic wasps for nuisance fly control on feedlots be initiated and their effectiveness in Australia be investigated**.

Mites associated with feedlot flies

As well as the parasitic wasps a number of other arthropods occurring in dung can limit fly populations. Predaceous mites for example can feed on house and stable fly eggs and larvae. A number of these mites closely associated with coprophagous flies, such as *M. domestica*, have been found to have high biocontrol potential against Diptera. For the intensive livestock industries, these mites have largely been reported as species from the families Macrochelidae, Uropodidae and Parasitidae. A number of native and exotic species of mites, including *Macrocheles* sp. *Glyptholaspis* sp. and *Parasitus* sp. are known to attack *Musca* sp in Australia.

Samples of flies were examined for phoretic and parasitic mites on a number of occasions during our study, particularly at times of peak fly numbers. At least two species of mites, the macrochelid mite, *Macrocheles* sp., and an unidentified trombidiid species, have been found on *M. domestica* and *S. calcitrans*, generally in low numbers. Aggregations in manure of what appear to be Uropodids have also been seen, however no systematic examination of manure was carried out for mites.

The average mite infestation level was 3.8% and 3.2% for house and stable flies respectively. Peaks in infestation levels occurred in autumn/early winter in both years. Major peaks occurred after fly numbers started to decline. Mites on *M. domestica* tended to be predominately unidentified "red" trombidiid mites with small numbers (<2%) of *Macrocheles* sp. largely found between April to May each year. The silage pit showed consistently higher than average percentage of infested flies, reaching a maximum of 44% in May 2003. As for the wasps, such largely undisturbed substrates are likely to favour population increases. Mites on stable flies were predominately *Macrocheles* sp. (>75%) with smaller numbers of red trombidiid mites. As for the house flies there was considerable variation in the stable fly infestation levels between the sites with a maximum of 15% recorded at the manure piles.

The contribution of the various mites in the biocontrol of fly populations associated with livestock has not been generally established and to date, no mites have been produced commercially. In laboratory studies, predaceous mites such as the Macrochelids can kill up to 36 house flies per day per mite by feeding on eggs and early instar larvae. In an early field study, there were up to 45% fewer flies when mites were present. Apart from maintaining natural mite populations by judicious use of pesticides and a range of cultural practices, no additional studies are envisaged.

Entomopathogenic fungi

Bacteria, viruses and fungi can also limit fly populations and probably play a role in a feedlot situation. Fungi are unique among the microbial insect pathogens in that they primarily infect their hosts through the external cuticle. The potential for microbial control using fungi has been well recognised. Two of the most common fungi developed for commercial applications in insect control are *Beauveria bassiana* and *Metarhizium anisopliae*.

A large number of fungi were recorded during our studies from adult flies and pupae with many being common saprophytes. Only fungi from a few selected entomopathogenic genera were isolated and kept in pure culture. In laboratory bioassays, four *B. bassiana* and *M. anisopliae* isolates caused 100% fly (*M. domestica)* mortality within 6 days with the most effective isolates killing 100% of flies within 4 days. These isolates were highly effective in killing house flies, making them potential candidates for the development of a fungal biopesticide for flies. Some of these isolates have also successfully killed adult and immature stages of sheep blowfly.

Our preliminary studies on fungi in feedlot flies indicate that there is a potential for controlling nuisance flies with endemic species of fungi. Researchers in the United States have also made progress in their investigation of fungal control of nuisance flies. DPI&F has an established fungal biopesticides group with current research projects on a number of livestock pests including buffalo flies, ticks and blowflies. **It is recommended that further studies be conducted to explore the development of local species of entomopathogenic fungi as an IPM tool for the management of nuisance flies in cattle feedlots.**

Fly and parasite population monitoring in other feedlots

In addition to the comprehensive fly and parasite population monitoring carried out in a SQ feedlot, a snapshot of these populations was also obtained on two additional feedlots located in different climatic regions, namely in central NSW (CNSW) and central Queensland (CQ).

The major nuisance flies, house flies, stable flies, bush flies and blowflies were the same in all three monitored feedlots located from central New South Wales to central Queensland. There were differences in their relative abundance between the feedlots: House fly was the most common fly in all feedlots while stable fly was more abundant in the CNSW feedlot than the Queensland feedlots during these one-off collections. The highest trap catches were obtained in the CQ feedlot which also scored the highest nuisance fly rating, by its manager.

The CQ feedlot had the highest larval rating and numbers of larvae extracted. House fly larvae were the most common larvae in all feedlots and they constituted >90% of the larvae in both Queensland feedlots. Stable fly larvae made up 13%, 6% and 1% of the extraction in the CNSW, SQ and CQ feedlots respectively. Most of the other fly larvae were *P. clausa* in the CNSW and CQ feedlots. The larval rating and abundance, including the species distribution, correlate well with the values for the adult flies in the same feedlot.

The level of parasitism was similar in all feedlots, ranging from 9% to 12% which was close to the two-year average of 11% in the SQ feedlot. The CNSW and SQ feedlots also had similar fly emergence rates, whereas fewer flies emerged from the CQ pupae. The parasitic wasps killed at least 21%, 23% and 35% of flies developing in the CNSW, SQ and CQ feedlots respectively (Figure 44).

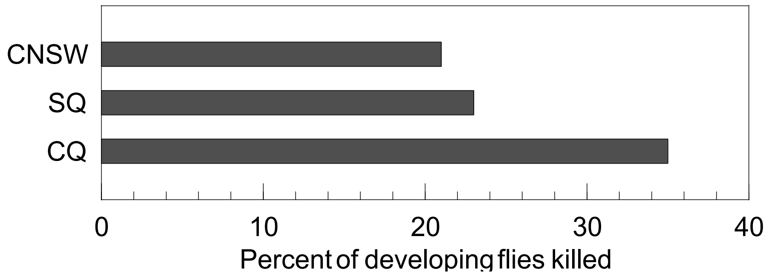

Figure 44 Percent of developing flies killed by parasitic wasps in three feedlots

The major parasitic wasp species were identical in all feedlots. *S. endius* was the most common wasp in the CNSW and SQ feedlots, *S. cameroni* the most abundant in the CQ feedlot. *Spalangia* spp. were the principal wasp parasites of flies in three Australian feedlots from central NSW to central Queensland.

In the CNSW feedlot, three species of mites were found on *M. domestica*. Two of these species, belonging to the families Trombidiidae (1.9%) and Macrochelidae (0.1%), detected on sticky traps, were similar to those found on SQ flies. Groups of small white nymphal mites (Pygmephoridae) were also detected on 6.5% of flies. In CQ, only a single species of mite (Trombidiidae, 2.4%) was found on *M. domestica* captured with sticky traps and nets.

This study has provided an extensive set of data on nuisance fly and parasite populations on three Australian feedlots. It has provided information on which fly species, and when and where they are present in the feedlot. The major fly breeding sites and the seasonal variations in fly breeding were established. The presence and activity of parasitic wasps, predatory mites and entomopathogenic fungi were also documented. These natural enemies of flies play an important role in limiting fly populations in cattle feedlots and this should be taken into consideration when devising fly control strategies. On the basis of this Australian data and information on nuisance fly ecology and control from other sources (mainly from USA) guidelines for integrated fly control in cattle feedlots and recommendations were developed. The guidelines and recommendations are presented in the final project report to MLA and the guidelines and information on nuisance flies, their parasites and predators were also published in extension material targeted at the feedlot industry.

COLOUR PLATES

Common flies trapped on Australian feedlots

Trapping systems used on Australian feedlots

Muscid larvae and fungal pathogen from Australian feedlots

Parasitic wasps detected on Australian feedlots

Mites associated with flies on Australian feedlots