"Bait bins", time series analysis and *Lucilia cuprina*

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Summary
This ten year study investigates the seasonality of the blowfly Lucilia cuprina in far-western New South Wales by using time series analysis. The effect of using bait bins as a management tool was also investigated by using interrupted (intervention) time series analysis. Lucilia cuprina showed a strong seasonal abundance. There was a positive correlation between sheep strike and the previous month's L. cuprina numbers, and a negative correlation between strike and the population numbers of L. cuprina from two month's previous. Sheep strike was correlated with the previous month's rainfall. The results from the interrupted time series analysis indicated that there were no significant effects of bait bins on L. cuprina population numbers, or on the incidence of sheep strike.

Keywords
Time Series, blowfly, *Lucilia cuprina*, seasonality, population cycles.

Introduction

In far-western New South Wales, the blowfly *Lucilia cuprina* appears only at certain times of the year. Physical factors, such as temperature and rainfall, are thought to directly affect population density by influencing the rate of development, activity of the flies and mortality of larvae and pupae (Fuller, 1934; Waterhouse, 1947). These seasonal conditions also influence vegetation biomass which in turn affects food supply of adult flies and developing larvae via availability and decomposition of carrion and sheep susceptibility to strike, as well as shelter for adults and pupae (Fuller, 1934; Whitten *et al.*, 1977; Anderson *et al.*, 1984; Wardhaugh and Morton, 1990; McLeod and Anderson, 1992). Knowledge of the seasonal variability of blowfly species and the influences on their population densities is important in developing management strategies against blowfly strike. If graziers can be pre-warned of impending fly risks they can work to prevent flystrike, by reducing susceptibility of sheep and trapping blowflies (Anderson *et al.*, 1990), rather than treating strikes after they appear. By limiting prospective breeding sites, early implementation of management practices can retard the critical initial population build up at the start of the season and reduce future blowfly populations (Barton, 1982; Anderson *et al.*, 1984; Anderson *et al.*, 1990). This study investigates the seasonality of *L. cuprina* by using time series analysis. The effect of using bait bins as a management tool at Fowler's Gap is also investigated by using interrupted (intervention) time series analysis.

Methods

Description of the Study Site
The field work was conducted at the University of NSW's Fowler's Gap Arid Zone Research Station, located 110 km north of Broken Hill in western New South Wales (latitude 31°05'S, longitude 141°40'E). It has an area of 39,000 hectares and lies within the sheep pastoral zone. Fowler's Gap is climatically representative of much of southern Australia's arid zone with hot summers and mild winters (Bell, 1972). Temperatures during winter drop below 0^0C on average only 7 - 10 times a year, and daytime temperatures in summer generally exceed 30^0C with an average of 40 days above 35^0C (Bell, 1972). The average annual rainfall is approximately 200 mm. Rainfall tends to fall equally over summer and winter, although the winter rainfall is more reliable (Bell, 1972).

The station's sheep flock comprises strong-wooled merino breeding ewes and wethers. The size of the flock fluctuated between 4500 and 8000 adult sheep during the course of this study. Ewes were

joined in mid-January, and lambs were born in July. Flocks were regularly inspected (usually on a monthly basis) in the paddock by station staff for flystrike (mainly overt strike). Close inspection occurred when the flocks were mustered at shearing (November), crutching (May) and marking (August-September).

Population Sampling and Standardisation of Trap Catches

Five permanent trapping sites were set up around the study area. The Western Australia trap (Vogt and Havenstein, 1974) was used for population sampling. Traps were baited with 500g of liver, 40g of sodium sulphide and 1 L of water. Fresh baits were always used to reduce the possibility of variation in attractiveness of the bait (Vogt *et al.*, 1983). The sites were trapped for 24 hours, twice per month for the duration of the study. All sites, but one, were trapped since September 1982 during the studies of Anderson (1984), Anderson *et al.* (1984) and Anderson (1991). The remaining site was established in 1985.

To account for the differences in weather conditions during each sampling period, trap catches were standardised using the formulas of Vogt *et al.* (1983 and 1985) and Vogt (1988). Only ambient temperature was used. The formula assumed a twelve-hour trapping day.

Weather Data

Daily temperature and relative humidity were continuously recorded on a hygrothermograph placed in a Stevenson's screen at the homestead meteorological station. Daily rainfall was recorded at the homestead. Wind speed and solar radiation were measured hourly. Wind direction and cloud cover were recorded at 0900h and 1500h during trapping sessions.

Time Series Analysis

A time series of nearly ten years was constructed for *L. cuprina* (Figure 1). The time plots of *L. cuprina* abundance were continuous except for a break of 14 months between June 1985 and September 1986 and a short break from February to April 1984.

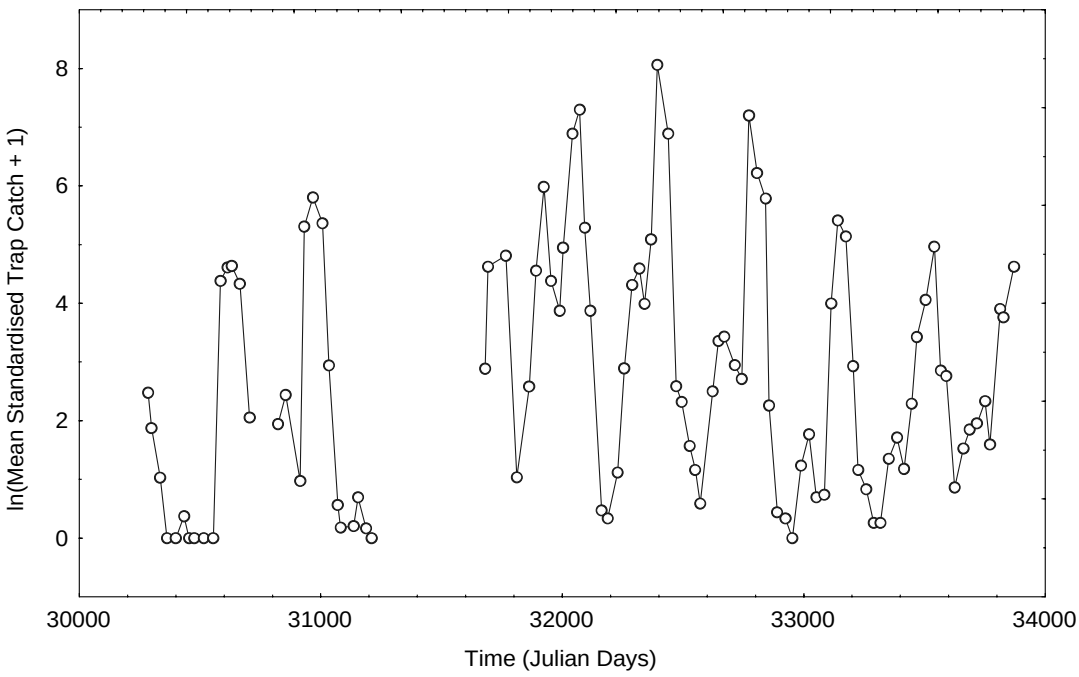

Figure 1. Time plot for *Lucilia cuprina*. The time series starts in November 1982 and finishes in September 1992.

Population Fluctuations and Seasonality

Autocorrelation functions (ACF) and partial autocorrelation functions (PACF) of the $\log_e$ transformed mean standardised trap catch +1 were used to examine the pattern of the fluctuations in blowfly abundance. ACF's can be used to distinguish between random fluctuations in abundance

and fluctuations involving some periodic behaviour (Nisbet and Gurney, 1982). Only data from the period September 1986 to September 1992 were used in the ACF analysis since these data represent the largest unbroken time series. If the ACF indicated serial dependence or seasonal dependence the time series were differenced to examine the underlying dependency patterns. A PACF is similar to an ACF except that the autocorrelations within the lag are partialled out. This makes it easier to examine particular serial dependencies for individual lags since they are no longer confounded by other serial dependencies (Box and Jenkins, 1976).

Spectral Analysis

Spectrum analysis is useful for uncovering cyclical patterns of different lengths within a time series (Bloomfield, 1976; Shumway, 1988). Prior to analysis the time series was made stationary. In addition, as the time series was relatively short (n = 73) and odd in number (Fourier analyses require an even number of data points) the series' were padded (with 56 points) and the last valid data point (September 1992) was excluded from Fourier analyses. Because a large number of padding points were used, the time series' were tapered prior to spectrum analyses using the split-cosine-bell tapering transformation. This transformation generally leads to a reduction of leakage in the spectral density plots (Bloomfield, 1976).

Cross-Correlation

The cross-correlation function is the bivariate analogue of the autocorrelation function and can be used to indicate inter-dependence between variates. Three cross-correlograms were calculated for the time series'; 1) *L. cuprina* and monthly rainfall, 2) *L. cuprina* and observed monthly sheep strike, 3) monthly rainfall and observed monthly sheep strike.

The time series for *L. cuprina* and sheep strike were made stationary by detrending the series' before analysis. If seasonal trend is not removed it is likely that strong seasonal patterns in the data will tend to overwhelm the cross-correlation making interpretation of underlying dependencies between data series very difficult (Diggle 1990). The rainfall data did not require transformation since it essentially represented a random process with zero trend.

Interrupted (Intervention) Time Series Analysis

Interrupted time series analysis is a method for examining the effect of one or many discrete events on the values of a time series. In the context of the present study, the establishment of bait bins at Fowler's Gap in July 1987 represented a discrete event which has been claimed to reduce blowfly population numbers and the incidence of sheep strike (Anderson *et al.*, 1990; Anderson *et al.*, 1992). The time series from July 1982 to June 1985, then from September 1986 to June 1987 represent times when there were no bait bins at the study site, while the time series starting in July 1987 and ending in September 1992 represent times when bait bins were present.

There are three main types of impacts; 1) permanent abrupt, 2) permanent gradual, and 3) temporary abrupt (McDowell *et al.*, 1980). Since the bait bins were present for the whole time series after July 1987 the potential impact of the bait bins must be considered permanent. Furthermore, it was not possible to *a priori* distinguish between an abrupt and gradual impact effect, therefore both types of impact were modelled. If the effect of the bait bins was abrupt, the impact pattern would be characterised by an immediate shift in the mean of the time series. In contrast, if the impact pattern is gradual the final permanent impact of the bait bins will only become evident after some time. In this case, the impact is defined by two parameters; ω a measure of the magnitude of the impact, and δ a measure of the "closeness" of the data to ω. If δ is close to zero, then the time series will be close to its final permanent level, while if δ is close to one then it indicates that the result of the impact will only be evident after many more observations.

Prior to the interrupted time series analysis the time series must be modelled using ARIMA (autoregressive integrated moving average) techniques (Box and Jenkins, 1976). ARIMA methods allow a time series to be decomposed into autoregressive and moving average parameters from

which closer examination of and prediction (forecasting) from a time series can be made. Details of fitting an ARIMA process can be found in Diggle (1990).

Results

Population Fluctuations and Seasonality

The ACF of the *L. cuprina* time series indicates that at Fowler's Gap this species exhibits phase-forgetting quasi-cycles (i.e. decaying oscillations in the correlogram as the lag becomes larger). The correlograms of the original (Figure 2a) and differenced (Figure 2b) time series and the partial correlograms of the original (Figure 3a) and differenced (Figure 3b) time series indicate that *L. cuprina* population abundance is influenced by serial dependence at a lag of about one month and also a much stronger seasonal dependence that cycles at a 12 month time interval.

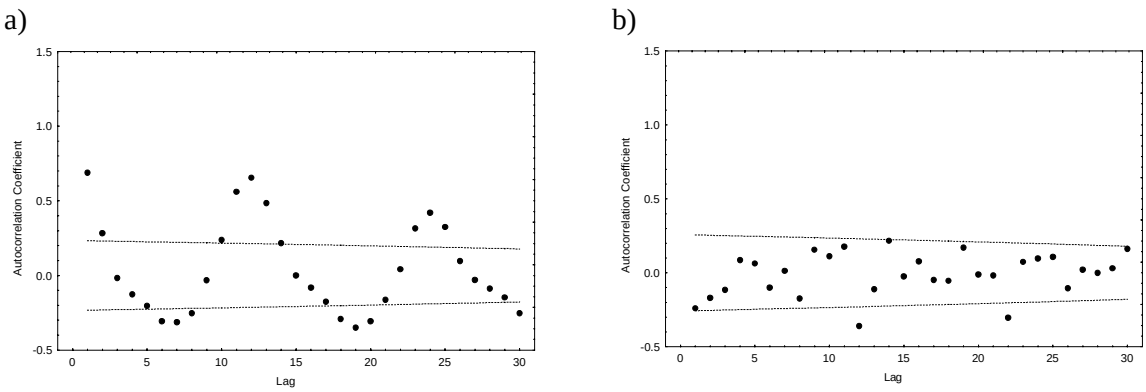

Figure 2. Correlogram of the $\log_e$ transformed mean standardised trap catch +1 for *Lucilia cuprina* time series. The dashed lines represent two standard errors around each lag. a) Original correlogram. b) Correlogram differenced by 1 month to remove trend and serial correlation and again differenced by 12 months to remove seasonal correlation.

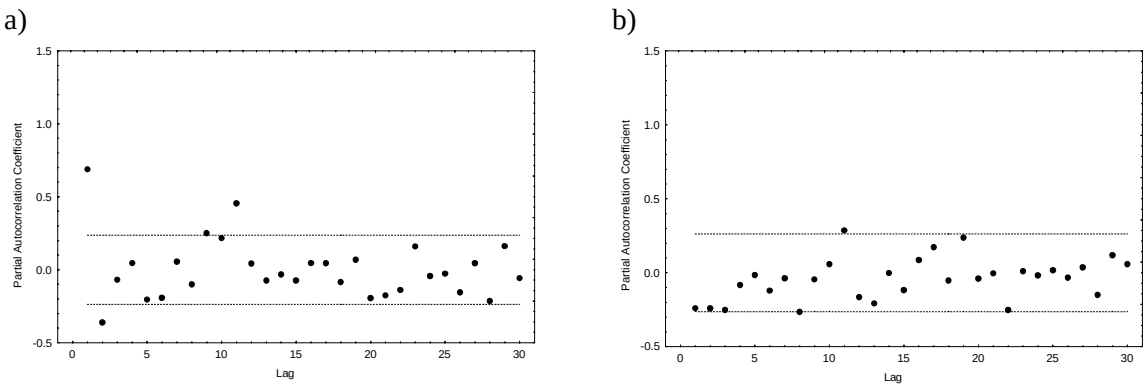

Figure 3. Partial correlogram of the $\log_e$ transformed mean standardised trap catch +1 of *Lucilia cuprina* time series. The dashed lines represent two standard errors around each lag. a) original partial correlogram. b) Partial correlogram differenced by 1 month to remove trend and serial correlation and again differenced by 12 months to remove seasonal correlation.

Spectral Analysis

The results of the spectral analysis indicate that *L. cuprina* has a major peak around 12 months (frequency 0.080 - 0.085) (Figure 4) with a secondary spike at about 6 months (frequency 0.17).

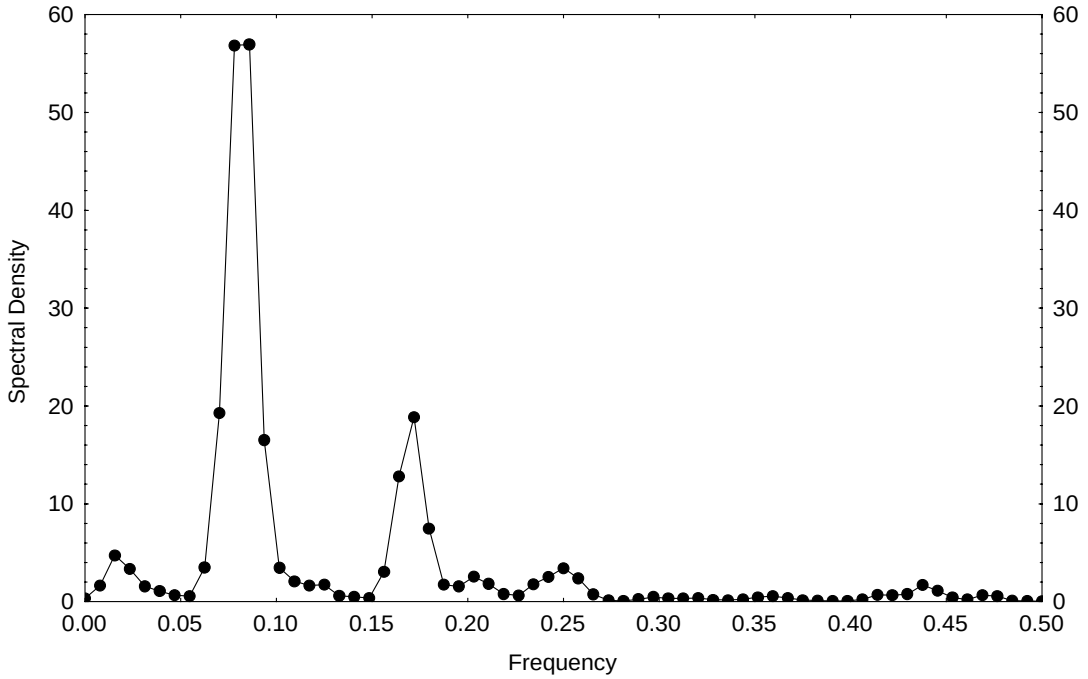

Figure 4. Spectral density estimate for *L. cuprina* from the time series September 1986 to September 1992.

Cross-Correlation

No correlations were found between monthly rainfall and *L. cuprina* population numbers. Monthly sheep strike was positively correlated with the previous month's rainfall and also slightly negatively correlated with the previous 7 month's rainfall (Figure 5a). Monthly sheep strike was also positively correlated with the previous month's population numbers of *L. cuprina* and negatively correlated with population numbers of 2 months previous. Because of the strong seasonality of *L. cuprina* and strike, this correlation also occurred at a plus and minus lag of approximately 11 - 12 months (Figure 5b).

a) b)

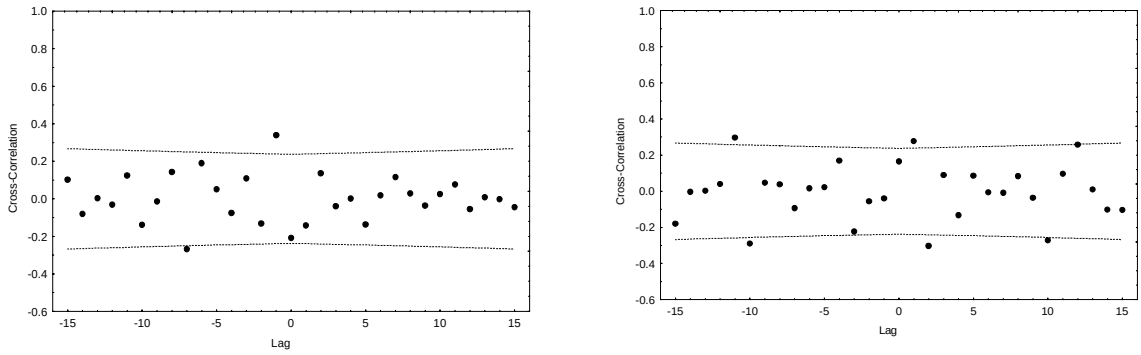

Figure 5. a) The cross-correlogram of the monthly sheep strike and lagged monthly rainfall time series. The dashed lines represent two standard errors. b) The cross-correlogram of the L. cuprina and lagged monthly sheep strike time series. The dashed lines represent two standard errors.

Interrupted Time Series Analysis

For the *L. cuprina* and observed sheep strike time series', one moving average (seasonal) and one autoregressive process were fitted. The *L. cuprina* and sheep strike series were differenced once with a lag of 12 (months) to remove the strong seasonal dependency in both series. The estimated parameters are given in Table 1, along with their standard errors. All parameters were highly significant.

After fitting the ARIMA models to each time series, they were checked by examination of the residuals. All time plots of the residuals satisfied the condition of resembling a white noise sequence. The autocorrelograms and partial autocorrelograms of the residuals did not indicate any significant serial correlation.

Table 1. Estimated parameters of ARIMA models fitted to each of the time series indicated. All parameters were highly significant. Standard errors are given in brackets. NA = not applicable.

Time Series	Constant	*p*	*q*	*Ps*	*Qs*	Initial SS	Residual SS	Variance Explained (%)
L. cuprina	NA	0.721 (0.073)	NA	NA	0.708 (0.156)	286.5	115.1	59.8
Sheep Strike	NA	0.292 (0.107)	NA	NA	0.780 (0.184)	197.7	149.2	24.5

Results of the interrupted time series analysis indicated that both *L. cuprina* population numbers and sheep strike showed no significant changes after the bait bins were opened (Table 2). The ω value for sheep strike was negative indicating the mean number of sheep struck had decreased over the period of the time series but this decrease was not significant.

Table 2. Results of the interrupted time series analysis. ω = magnitude of impact (change in mean), δ = 'closeness' of data to ω. NA = not applicable. * = statistically significant.

Time Series	Interruption Type	Omega (ω)	Delta (δ)
L. cuprina	Permanent abrupt	0.259 (0.686)	NA
	Permanent gradual	0.223 (0.565)	0.409 (1.064)
Sheep strike	Permanent abrupt	-0.259 (0.342)	NA
	Permanent gradual	-0.372 (0.517)	-0.368 (0.981)

Discussion

Results from the autocorrelation functions and spectral analysis suggest that *L. cuprina* is strongly seasonal in its pattern abundance. A strong seasonal pattern could indicate that this species is synchronising its lifecycle with favourable conditions, whether it be seasonal conditions, food availability or absence of competitors or predators. The avoidance of cold conditions and overwintering behaviour is investigated in another paper in these proceedings so will not be discussed here. Rainfall at Fowler's Gap does not significantly affect *L. cuprina* population numbers.

A positive correlation was found between sheep strike and the previous month's *L. cuprina* numbers. *Lucilia cuprina* is an obligate parasite on sheep (Waterhouse, 1947; Wardhaugh and Dallwitz, 1984; Anderson *et al.*, 1988), so sheep strike could be an indicator of food source availability (susceptible sheep present). Autocorrelation results indicated that sheep strike was also strongly seasonal at Fowler's Gap. Whether strike is seasonal due to *L. cuprina* influence or seasonality of *L. cuprina* is due to strike's seasonality could not be resolved from the data collected during this study. Strike data and fly population numbers would need to be surveyed at a more frequent interval than the monthly collection in this study.

The incidence of flystrike increasing with increasing density and activity of gravid *L. cuprina* females have been reported from previous studies (Wardhaugh and Morton, 1990; Anderson, 1991; Bishopp *et al*. 1991). In this study, strike at Fowler's Gap was positively correlated with the previous month's population numbers of *L. cuprina*. The monthly sheep strike figures were obtained from observed strike in the field. Sheep flock management at Fowler's Gap does not include intensive monitoring of all sheep flocks at all times. Overt strikes would have been more readily detected by this method than the more prevalent covert strike (Wardhaugh and Dallwitz, 1984; Anderson *et al.*, 1988), so strikes would have been well in progress before detection, which could lead to a delay in

their recording. With this delay in observing and treating strikes, some deaths may already have occurred before treatment was possible.

A negative correlation between strike and the population numbers of *L. cuprina* from two month's previous was also detected in the cross-correlation analysis. If there was a month of high strike, the majority of struck sheep would be observed and treated, leading to a low incidence in the following month. As a precaution, susceptible sheep also would have been treated.

The association between rainfall and strike, particularly body strike, has long been recognised (Seddon, 1931; Hayman, 1953; Wardhaugh and Morton, 1990). Sheep strike at Fowler's Gap was no different, and was found to be correlated with the previous month's rainfall, although distinctions between the types of strike (e.g. body, breech) was not available to allow for more detailed analysis.

Intensive fly trapping has been shown to reduce strike incidence; traps placed at density of 1/10 ha reduced strike by up to 50% (Mackerras *et al.*, 1936). A similar study to test the efficacy of trapping to reduce fly numbers was conducted in New Zealand (Dymock & Forgie, 1995) over a three year period. This study claimed a 95% decline in *L. cuprina* population numbers over this time, however strike incidence was low throughout the study so no effect of baiting could be determined. Bait bins were first used at Fowler's Gap in July 1987 and were used continuously for the last five years of this study to test the effectiveness and economical viability of trapping as a management tool against flystrike. Anderson *et al.* (1990) and Anderson *et al.* (1992) concluded that the introduction of these bait bins at Fowler's Gap appeared to reduce blowfly population numbers and the incidence of flystrike. However, the results from the interrupted time series analysis indicate that there were no significant effects of bait bins on *L. cuprina* population numbers, or on the incidence of sheep strike.

This result highlights the problem of using short term biological data, and not having a control site for comparison. Without the data from an area that was not baited, and/or additional fly population data from years when baiting was not conducted, it can not be ruled out that the reduction in *L. cuprina* population numbers was due to some other long term influence.

Conclusion

An understanding of the ecology and population dynamics of myiasis producing blowflies is important for developing a successful management strategy against sheep strike. This study investigated the seasonality of *Lucilia cuprina* in western NSW. The strong seasonal pattern of this species could indicate that this species is synchronising its lifecycle with favourable conditions, whether it be seasonal conditions, food availability or absence of competitors or predators. There was a positive correlation between sheep strike and the previous month's *L. cuprina* numbers, and a negative correlation between strike and the population numbers of *L. cuprina* from two month's previous. Sheep strike was correlated with the previous month's rainfall. As part of an integrated management plan for blowfly strike the need to decrease the sheep's susceptibility to strike is combined with direct action on the blowfly's behaviour and population numbers. One of the suggested methods to attack blowfly population numbers directly is that of trapping. The results from the interrupted time series analysis indicated that there were no significant effects of bait bins on *L. cuprina* population numbers, or on the incidence of sheep strike in the five years they were used at the study site.

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