Why Model Tephritid Fruit Fly Incursions In Agricultural Production Areas?

A Clift and A Meats

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Abstract: The Mediterranean Fruit Fly, *Ceratitis capitata* and the Queensland Fruit Fly, *Bactrocera tryoni* are regularly found as small incursions in South Australia (normally free of these flies) and the latter species also makes incursions into the New South Wales and Victorian sectors of the Fruit Fly Exclusion Zone. These populations are eradicated soon after detection to restore area freedom for trade purposes. Information is available from roadblocks run by State Departments of Agriculture on the amount of fruit carried by travellers and the level of infestation, but the relationship with the number of outbreaks is inconsistent. The proportion of infested fruit carried is low and previous analyses have therefore concentrated on factors influencing travellers to carry fruit, rather than the level of infestation in the fruit. It was decided to use simulation modelling as an aid to interpreting the available data. The initial simulation model, based on published data, was developed to provide estimates of the expected amount of infested fruit entering fruit fly free areas and the relative importance of various factors influencing both infestation levels and subsequent establishment of either species in South Australia. The model used was based on a spreadsheet within the risk management program @Risk®. The estimated range in frequency of vehicles with infested fruit was similar to that observed and the frequency of home grown fruit that is carried by travellers (which is more likely to be infested) was an important factor in determining the number of potential incursions. Climatic factors were important in determining both the proportion of infested fruit and the likelihood of an incursion establishing. Information on fruit fly trappings from all three states, plus further information from the roadblock reports, will be required to develop the model further.

Keywords: Tephritid fruit fly; Incursions; Movement of fruit; Modelling

1. INTRODUCTION

Queensland Fruit Fly, *Bactrocera tryoni* (Qfly) and Mediterranean Fruit Fly, *Ceratitis capitata* (Medfly) are regularly found as small incursions in parts of southern Australia that are normally free of these flies [Maelzer 1990a and b; Madge et al., 1997]. These populations are eradicated as soon as possible after detection to maintain area freedom for trade purposes, [Dominiak et al.; 2000a and b]. Australia has national and international treaties that allow fruit to be exported from areas free from Qfly and Medfly [Campbell, 2000]. The main mode of entry of either species into formerly free areas is by movement of infested fruit [Bailey and Perepelicia, 1998; Campbell, 2000].

The value of roadblocks to protect horticultural production areas has always been contentious [Dominiak et al., 1998], although South Australia, (SA), Victoria (Vic) and New South Wales (NSW) Departments of Agriculture maintain roadblocks of various levels of intensity [Maelzer 1990a and b, Dominiak et al., 2000a; Campbell, 2000]. The proportion of infested fruit is small and variable, with fruit from home gardens, roadside stalls and fruit shops more likely to be infested than fruit from supermarkets [Campbell, 2000].

Numbers of outbreaks and levels of infested fruit varied between years, with the presence of roadblocks having inconsistent effects [Maelzer 1990a; Bailey and Perepelicia 1998; Dominiak et al., 2000b; Campbell, 2000]. The relationships between levels of infested fruit and the incidence of infestations for either species were inconsistent, climatic factors also having a major role [Maelzer 1990b, Dominiak et al., 2000b].

Simulation modelling could assist in better understanding what is clearly a complex situation. Initially, a model was developed to estimate the relative importance of infestation levels and climatic factors on the potential introduction and establishment of either species in SA. The model parameters and roadblock reports used to estimate the values are described in this paper. Outbreak information and independent roadblock data from SA were compared to the model output.

2. DATA USED IN MODEL

2.1 Roadblock and Infestation Reports

The effectiveness of roadblocks to minimise Qfly introductions into southern Australia has been reviewed [Dominiak et al., 2000a], it being reported that retirees and families on holiday carried more fruit fly host produce and that roadblocks were an important part of public awareness campaigns. Campbell [2000] reported the results of a detailed roadblock project, concluding that some drivers were "habitual offenders". Both reports suggested fines as a possible deterrent and public awareness campaigns to be directed at backyard growers in major cities. The locations of the roadblocks referred to are shown as Figure 1.

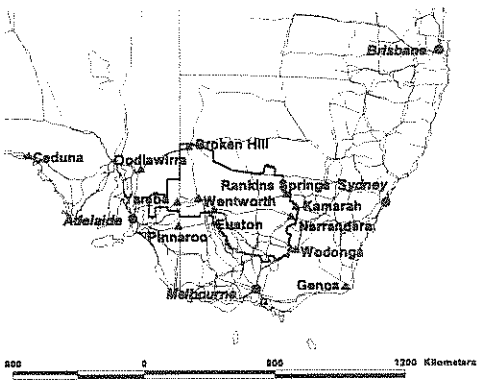

Figure 1. Main roads and roadblock sites in SE Australia.

Table 1 Percent vehicles with fruit and level of infestation carried into fly free areas.

Site & seasons	with fruit	infested fruit
Euston[1] 1976/83	8.9%	0.5%
Wentworth[1] 1976/83	4.6%	0.08%
Wodonga[1] 1976/83	2.0%	0.01%
Genoa[1] 1976/83	23.0%	0.03%
Narrandera[2] 1994/95	15.8%	0.17%
Kamarah[3] 1996/98	9.0%	0.0%
Rankin Spring[3] 1997/98	18.0%	0.0%
Euston 1997/00[4]	11.0%	0.05%
Broken Hill 1997/00[4]	15.7%	0.05%

[1] Dominiak *et al* [2000b], [2] NSW Agriculture [1997], [3] Dominiak *et al* [2000a], [4] Campbell [2000]

The reports cited reported traffic flows, number carrying fruit and the proportion of infested fruit. NSW Agriculture [1997], Campbell [2000] and Dominiak *et al* [2000b] reported details of infested fruit per day and source of fruit. The infestation data is summarised as Table 1.

2.2 Derived Infestation Data

Where sufficient detail was available, the infestation data was converted to vehicles with infested fruit per day of roadblock operation. This was done by dividing the number of vehicles with infested fruit by the number of days that the roadblock was in operation for that season. The results are summarised as Table 2.

Table 2. Number of vehicles/day with infested fruit.

Site & seasons	infested	range
Euston 1976/83	0.182	0.09-0.355
Narrandera 1994/98	0.049	0.0-0.148
Euston 1997/00	0.016	0.0-0.05
Broken Hill 1997/00	0.03	0.02-0.05

Data after 1994 indicated the source of infested fruit and the numbers of pieces of fruit. Out of 18 vehicles with infested fruit, 11 were carrying backyard fruit, 3 purchased fruit from a roadside stall, 2 from a fruit shop and two from a supermarket. Of the 18 vehicles, 9 were carrying sufficient infested fruit to be considered a reasonable probability of resulting in detectable numbers of adult Qfly, defined as at or over 5 pome fruit, 3 stonefruit, 3 grapefruit or 1 mango.

2.3 Suitability of Climatic Conditions

The suitability of a season for fruit fly populations to develop can be inferred from the numbers of fruit fly interceptions at roadblocks. The data on fruit infestation reported on an annual basis in Dominiak et al. [2000a and b], NSW Agriculture [1997], and Campbell [2000] provided observations over 10 years. Out of the 10 years, 2 showed high levels of interceptions, 3 showed low levels and the other 5 were intermediate. This was rounded to 0.25, 0.5 and 0.25 for good, average and poor seasons.

Given the geographic distances involved in south-eastern Australia between the roadblock sites in NSW, Vic and SA (Figure 1), it was considered unlikely that similar climatic conditions would apply in all seasons. The Climate Matching module of Climex® [Yonow and Sutherst, 1998] was used to determine from past climatic records the expected correlation in climate between the sites in Adelaide, inland and coastal NSW.

2.4 South Australian Fruit Fly Reports

Fruit fly infestation and roadblock data, collected between 1 July to 30 June within each season, were reported by Maelzer [1990a and b], Madge et al. [1997] and Bailey and Perepelicia [1998]. The roadblock sites are shown in Figure 1. Roadblock data comprised totals over three separate roadblocks (and hence highways) for Qfly during the period 1965 to 1987 and for a single roadblock for Medfly from 1967 to 1987. The total number of vehicles with infested fruit varied considerably between seasons, ranging from 2 up to 74 for Qfly and 3 to 37 for Medfly.

Numbers of declared outbreaks over 50 seasons, from 1946/47 to 1996/97 for each species were similarly variable, ranging from nil to 6 for Qfly and up to 9 for Medfly. There were no outbreaks in 10 of the 50 seasons, outbreaks of Qfly being reported in 34 seasons and for Medfly in 25 seasons. There was no apparent relationship between the incidence of the two species, each outbreak being considered to represent a separate introduction [Bailey and Perepelicia 1998]. Outbreaks were predominantly in greater Adelaide, but did occur in rural towns [Madge et al., 1997].

3. THE MODEL

3.1 Model Parameters

The number of vehicles carrying infested fruit per day, V_i, was selected as the variable to model. To include climatic suitability at the fruit origin and at the destination, CS_o and CS_e respectively, the @Risk function RiskDiscrete, [Palisade, 2000] with values 0.95, 0.5, and 0.2 for good, average and poor seasons at frequencies of 0.25, 0.5 and 0.25 respectively, was used to allocate a value by random sampling from the specified frequencies. This value was then used as input for another RiskDiscrete function to allocate 0 or 1 to either C_o, climatic suitability at the fruit origin, or to C_e, at the destination (cells F2:H3). These values were set at the start of each iteration.

Two models were developed. Model I used V_i, as λ for the Poisson distribution to simulate the number of vehicles each day with infested fruit, V_{di}. Model II used the @Risk function RiskDiscrete, with two values 1 and 0, with probabilities of V_i and 1 - V_i to simulate V_{di}. In both models, V_{di} could then be totalled over 365 days to provide seasonal totals, V_{si}.

Most infested fruit intercepted in Vic or NSW were in late November through to April, with the greater proportion being from backyards [NSW Agriculture, 1997; Campbell, 2000]. Two levels of vehicles per day carrying infested fruit were set, based on the data summarised in Table 2. The @Risk function RiskTrigen was used: this enabled a distribution to be described with specified proportions of the range of values to be above or below selected values. Syntax for this function is lower value, most likely, upper value, lower percentile and upper percentile. The values, selected to produce similar distributions to Table 2 are:

Average rate, V_{iAv}	0.0, 0.01, 0.025, 30, 70
Backyard rate, V_{ib}	0.02, 0.15, 0.25, 20, 80

V_{ib} was used from December to April, when the reported data indicated that mostly backyard fruit, with higher infestation levels would be carried. V_{iAv} was used for the rest of the year. The values for the functions are such that low, or nil infested produce can be carried at any time, but higher rates can occur between December and April.

An IF function was used to prevent negative values being input into either function (cells E4:H5). CS_o and, CS_e were correlated at 0.6, both CS_o and CS_e were correlated with V_i at 0.7.

If more than a set number of fruit flies are trapped in an otherwise free zone, an outbreak is declared. As half the vehicles carrying infested fruit (9 out of 18) were carrying enough infested pieces as to be reasonably likely to result in detectable numbers of adult Qfly, the probability Od of a potential outbreak being declared was set at 0.5. Medfly do not disperse as readily as Qfly, so paradoxically they can establish more readily [Bailey and Perepelicia 1998], so that fewer infested fruit may be needed to establish a population. The probability of a potential outbreak for Medfly was set at 0.2. The variable Od_i was evaluated using the @Risk function RiskDiscrete, with two values, 1 and 0, and probability Od. In this way each instance of infested fruit was allocated to either result in a declared outbreak, value 1, or no outbreak, value 0 (cells H1:J1). Od_i

was then totalled over 365 days to provide seasonal totals, Od_{si}.

3.2 Structure of the Model

Two versions of the model were set up in @Risk Ver 4 [Palisade, 2000] as an add-in for Excel 2000. In both models there were 5 columns, the first containing the date, starting 1 August, through to 31 July of the following year.

The second column, labelled "Maximum Origin Infestation", contains the output from one of two functions: in Model I, the function was RiskPoisson, using the appropriate value of V_i, depending on the time of year; in Model II, the function was RiskDiscrete, using V_i, and 1- V_i, as the probabilities for 1 and 0 respectively. In Model I, the Poisson distribution returned values of 0, 1, 2, etc, but in Model II the possible values were 0 or 1. These values, V_{di}., were totalled over 365 days to give a simulated maximum total possible fruit fly introductions, V_{si}.. This value is the first estimate of roadblock interceptions, so can be compared to and validated against independent roadblock data from South Australia.

The remaining columns were the same in both models. Column 3 was labelled "Simulated Fruit Fly Introductions", which was the value in Column 2, V_{di}, multiplied by C_o, to allow for suitability of climate at the origin of the fruit obtained, CV_{di}.. Each instance of infested fruit was allocated to either result in a potential introduction, value 1, or no introduction, value 0. This is the simulated number of vehicles carrying infested fruit. These values were totalled over 365 days to give a simulated total possible fruit fly introductions, CV_{si}... This value provides the second estimate of roadblock interceptions, so can be compared to and validated against independent roadblock data from South Australia.

Column 4 contains the value in Column 3 multiplied by C_e , to allow for suitability of climate at the destination of the infested fruit. Each instance of infested fruit was allocated to either result in successful emergence of adult flies, value 1, or no emergence, value 0. This value simulates the number of times infested fruit are introduced into an area and adult fruit flies emerge. These values were totalled over 365 days to give a simulated total of possible occurrences of fruit fly emergence. There is no independent estimate of this value.

Column 5 was the value in Column 4 multiplied by Od_i to simulate the number of declared fruit fly outbreaks, SDO. Each instance of successful emergence of fruit flies was allocated to either result in a declared outbreak, value 1, or no outbreak, value 0. These values were totalled over 365 days to give a simulated total of possible fruit fly outbreaks, Od_{si}. This can be compared to and validated against independent outbreak data from South Australia.

3.3 Model Output

One iteration of the model represents one year. One thousand iterations of both models were run and sensitivity analyses done to determine the relative importance of the various input factors.

Outputs from the two models and observed data from South Australia are presented as Table 3.

Table 3. Model output compared to actual observations from South Australia.

Variable	Model I	Model II	South Aust[2]
V_{si}., freq[1]. 0	0.05	0.10	
V_{si}., min[1]	0	0	
V_{si}., max[a]	76	84	
V_{si}., max[b]	84	82	
V_{si}., avg[a]	24.6	25.6	
V_{si}., avg[b]	24.8	25.6	
CV_{si}. freq. 0	0.30	0.50	0.0
CV_{si} min	0.0	0.0	2.0
CV_{si}, max	75	84	74.0
CV_{si}, avg	18.4	14.0	19.2
Od_{si}, freq. 0	0.55	0.7	0.3
Od_{si}, min	0.0	0.0	0.0
Od_{si}, max[a]	42	42	6
Od_{si}, max[b]	71	60	9
Od_{si}, avg[a]	5.8	4.3	1.8
Od_{si}, avg[b]	9.7	6.3	1.4

[1] frequency and minimum similar for both species
[2] Maelzer [1990a] [a] Qfly, [b] Medfly

The two models produced similar mean values for V_{si}, but the distribution of the values were different. Model I, using the Poisson function, produced a lower frequency of zero values, 5% compared to 10% for Model II. This difference became larger, 30% compared to 50% for CV_{di} and 55% compared to 70% for Od_{si}

V_{si} from Model I was a better fit to the observed incidence of vehicles with infested fruit in SA than from Model II and also CV_{di} from either model. Od_{si} did not fit to the observed number of declared outbreaks in SA, neither in mean nor range.

The results of the sensitivity tests were similar for the two models. @Risk uses a regression technique to determine the influence on each output that can be ascribed to each input. The Backyard effect, V_{ib} is the main factor influencing V_{si}, at 0.58, followed by the Average rate, V_{iAv}. CV_{di} was predominantly influenced by climatic effects at the Origin of the fruit, CS_o, 0.75, followed by V_{ib} and V_{iAv}, at 0.3 and 0.2 respectively. The number of outbreaks was influenced by climatic effects at the Destination, CS_e, 0.59, followed by the same three factors as above. Both models suggest that climate has a greater influence on CV_{si} than the infestation levels, but that V_{ib} is the main influence on the infestation levels.

4. DISCUSSION

V_{si} output, the simulated maximum number of vehicles carrying infested fruit, from Model I (Table 3) provides a reasonable fit to the observed data. The observed independent data was the reported combined number of roadblock interceptions from three highways entering SA from the East [Maelzer, 1990a and b].

The Poisson function used in Model I was more suitable in estimating the number of vehicles per day carrying infested fruit than using the Discrete function to return 1 or 0 at the same frequency as λ (Table 3). The Poisson function appeared to be more robust, especially regarding the frequency for zero, which then had a flow on effect onto other model outputs.

The observed data on roadblock interceptions and incidence of outbreaks [Maelzer, 1990a and b; Madge et al, 1997; Bailey and Perepelicia, 1998; Dominiak et al. 2000b] all indicate major variation between sites and seasons, due in part to several factors, including climatic variation and origin of the fruit carried. The model parameters were based on values from three sites over several years, which provided the range of possible values. Model I was successful in predicting introductions, compared to an independent set of data.

The adjustment in Model I for climatic suitability greatly increased the frequency of zero interceptions, suggesting an over-correction. The parameters used to estimate V_{si} were obtained from three roadblock sites in NSW and Vic over several years (Table 2) and the climatic suitability varied considerably over those years. Deriving an estimate of climatic suitability from this data may have over-corrected for climate as the range of reported infestation rates used in the models already included a component for climatic effects. It may be more effective to use infestation levels from suitable years, then include the climatic suitability factor.

The output from Model I indicates that the level of infestation over the summer months, V_{ib}, is the major factor determining the number of potential introductions. Model I as presently constructed cannot separate climatic effects from infestation levels and V_{ib} includes components of each.

The parameters selected in Model I were not able to predict number of outbreaks from number and size of introductions. Model I was both overestimating the numbers of outbreaks, yet also was culling out many others, as indicated by the high rate of zero outbreaks. This suggests the factors affecting establishment of fruit flies in new areas is poorly understood.

There were major over-estimation of Od_{si}, in mean, range and frequency of zero outbreak years compared to the observed level of outbreaks [Madge et al, 1997]. It is not possible to directly experiment on introducing either fruit fly into an area free of the species [Maelzer, 1990b]. Hence, there is no data to directly evaluate the relative importance of factors known to influence fruit fly numbers in determining the establishment of a fruit fly population from a small inoculum.

5. CONCLUSIONS

Modelling was able to simulate the mean number of potential introductions, but not the number of years in which there were no introductions. It is not straightforward to convert the number of introductions to number of outbreaks. The factors and the way they were used in this model probably have distorted the output. Further work on factors influencing the establishment of a fruit fly population is required. A new model can be developed, with the parameters fitted to the data collated for this project and then this new model validated against independent data from Vic, and NSW and SA after 1990.

6. ACKNOWLEDGMENTS

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