Use Of A Bayesian Belief Network To Identify Situations That Favour Fruit Fly Incursions In Inland SE Australia

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EXTENDED ABSTRACT

In previous work, Clift and Meats successfully modelled the introduction of the Queensland Fruit Fly (Qfly), *Bactrocera tryoni* into the Fruit Fly Exclusion Zone (FFEZ). Incursions occur despite quarantine and were detected by male lure survey traps.

However, it was not possible to predict which incursions became declared outbreaks as factors determining the establishment of a founder Qfly population are complex.

Microsatellite based studies had suggested the origin of fruit fly incursions is most likely from endemic populations near to the FFEZ, implying that in climatically unfavourable years, there are no incursions. With respect to Qfly incursions, the main problem is humans transporting fruit, an unknown proportion of which is infested by fruit flies, into the FFEZ. What is known is the date and location of each male lure trap and similar data for fruit fly larval infestations. .

In this paper, Bayesian Belief Networks are used to integrate both detailed and qualitative information into a Qfly incursion model for determining those factors, or combination of factors, that are important in the establishment of a founder Qfly populations.

The starting point for the Belief Network (Figure 1), is the emergence of adult flies (**Adults**), and the location in relation to the nearest endemic population (**Loc_efct**). The number of adult flies is implied from the numbers of flies trapped in the first two weeks (**Trapped1**) and is believed to be influenced by nearby roads (**Roads**) and the size of nearby towns or presence of orchards (**TownSz**) The establishment of an incursion (**Establish**) is based on finding larvae and/or trapping flies subsequent to the first two weeks (**Trapped2**).

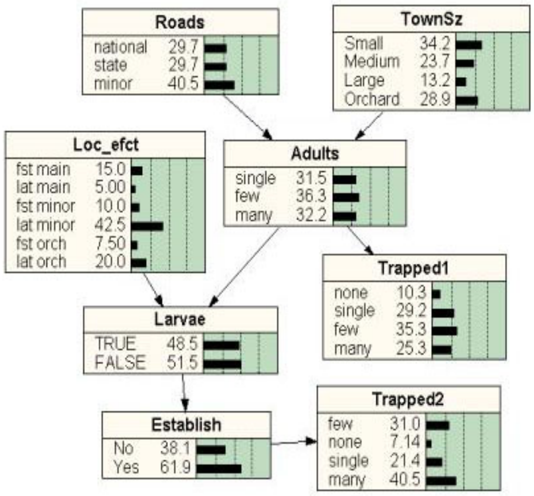

Figure 1. Netica Fruitfly incursion model.

Information on fruit fly trappings and outbreaks in NSW from 1990 to 1996 provided the case data needed to populate the Qfly model. The Sensitivity module of Netica® was used to determine which of the factors included in the model most influenced the nodes **Establish and Adults**.

Surprisingly, the nodes for **Roads, TownSz** and **Loc_efct** had very little influence on **Establish**. The main influences were **Trapped2, Larvae, Trapped1 and Adults.**

The influences on **Establish** are continuing to trap adults and the presence of larvae. The size of the initial inoculum (**Adults**) was significant, but location within the FFEZ was not. The implication is that people take fruit into the FFEZ while visiting friends/relatives in towns and orchards.

1. INTRODUCTION

The Queensland fruit fly (Qfly) *Bactrocera tryoni* (Froggatt) is endemic in the eastern coast of Australia (Meats *et al* 2003) There is an irrigated, fruit-producing inland area in SE Australia quarantined against Qfly (Fig 1), termed the fruit fly exclusion zone (FFEZ). The FFEZ straddles the borders of South Australia (SA) Victoria (Vic) and New South Wales (NSW) (Anon 1997).

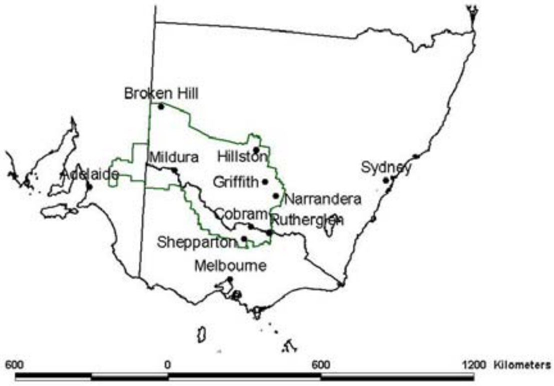

Figure 1. The FFEZ (Capital cities and Qfly incursion sites shown).

Incursions occur despite quarantine and are detected by surveillance traps and as infested fruit. Records of these incidents maintained by the relevant state departments of Agriculture allow us to study factors influencing incursions. In previous work, Clift and Meats (2001) were able to successfully model the introduction of Qfly into the FFEZ. However, they were not able to model which incursions became declared outbreaks.

It is important to understand the factors that operate to enable an introduction to establish as a breeding population. Some of these are discussed by Meats *et al* (2003). A Bayesian Belief Network (BBN) was selected as the program to develop an incursion model as a BBN allows both detailed data (Qfly incidence) and broader, qualitative data to be combined (Wooldridge and Done 2003).

This paper describes a preliminary BBN developed to determine the non-climatic factors important in converting an incursion of Qfly into a breeding population. The results of using the model are discussed in relation to Qfly management.

2. QFLY ESTABLISHMENT

The sequence of events being modelled are outlined in Meats *et al* (2003). Briefly, infested fruit is taken into the FFEZ and once the infestation is discovered, the fruit disposed of in a variety of ways. Sometimes, Qfly , larvae can complete development and emerge as adults. In a proportion of these occasions, a variable number of these flies are trapped in a surveillance grid, or mate and infest fruit. Once a larval population is present, at least some of the resulting adults are trapped over the following weeks and if the numbers involved exceed a trigger point specified in Qfly management protocol (Anon 1997) an outbreak is declared and control procedures started.

3. QFLY INCURSION DATA

The density of the trapping grid, dates of trap clearances, the number of Qfly caught in each and their geographical location (postal address or GPS coordinates) were obtained from records maintained by the NSW and Vic departments of Agriculture. Postal address and date of larval finds were also noted. Further information on town size, urban or orchard situation and the nearest road was also noted. Although there were many records from Adelaide, these were not used because the location information was not compatible with the NSW and Vic data. Records from 1990 up until June 1996 were used because after that interval, a major outbreak occurred that could distort the data.

The main locations involved were: Griffith area (urban and orchards), Narrandera (urban), Broken Hill (urban), Hillston area (urban and orchards) in NSW: Mildura area (urban and orchards), Rutherglen (urban), Shepparton (urban) and Cobram (urban). These sites are shown in Figure 1.

Climatic data was not specifically included. DNA fingerprinting indicated that incursion flies had originted from towns adjacent to the FFEZ (Sved *et al* 2003, Gilchrist 2004), implying that when the climate was unfavourable, there would be far fewer, if any, incursions. We therefore considered that climatic factors were already factored into the incursion data.

Information for all incursions in NSW and Vic between 1990 and June 1996 were used to create a case to populate the Qfly incursion BBN.

4. BBN MODEL

Netica® (Norsys 1997) was used to construct the Qfly incursion BBN (Figure 2). The model contains eight variable defined by the following nodes:

Adults: Defines the starting inoculum, which been inferred from number of flies trapped in the first two weeks, since it is not directly measured. The states for **Adults** are single, few and many. Single was used when there was a single catch, with no further catches or larval finds. Few was the most common, used when there were less than 5 flies caught initially, , sometimes also with larval finds. Many was used when over 5 flies were trapped in the first two weeks, combined with larval finds.

Roads: Defines the classification of the nearest road to the location of the incursion. The states are national, state and minor. National refers to a National highway, State to a State highway and minor for other roads. This node was included to indicate which road system carried most of the infested fruit. The node was considered to directly influence the frequency and size of Qfly inoculum.

TownSz: Defines the size of the township or if it is an orchard. The states are Small (<1000 inhabitants), Medium (1000 to 6000 inhabitants), Large (> 6000 inhabitants) and Orchard (any size commercial production unit). This was also considered to directly influence Qfly inoculum on the basis that travelling public could be expected to stop more often in larger townships, with better tourist facilities.

Loc_efct: This node combines town/orchard with the physical location in relation to the nearest endemic Qfly population. States are fst main (first medium or large town encountered after entering the FFEZ), lat_main (subsequent medium or large towns encountered after entering the FFEZ);
fst minor (first small town encountered after entering the FFEZ), lat minor (subsequent small towns encountered after entering the FFEZ), fst orchard (first orchard encountered after entering the FFEZ) and lat orchard (subsequent orchards encountered after entering the FFEZ). This node was originally thought to have a major influence on the establishment of a larval population.

Larvae: This is a binary node with the states true (larvae found) or false (larvae not found). The presence of larvae is one of the major triggers for declaring an outbreak. It clearly requires adults, but is also influenced by location effects.

Trapped1: This node contains information on Qfly trapping in the first two weeks, but is usually a trigger to set more traps and look for larvae, rather than outbreak declaration. States are none (no Qfly trapped), single (one fly only trapped), few (less than five flies trapped) and many (five or more flies trapped).

Establish: This is also a binary node with the states yes (population is established) and no (population is not established). Establishment directly determines outbreak declaration and hence is the main output of the model.

Trapped2: This node contains information on Qfly trapping after the first two weeks, which combined with **Larvae,** are the main triggers to declaring a Qfly incursion an outbreak.

A range of model configurations were tested, varying the point of influence of **Roads**, **TownSz** and **Loc_efct**. The configuration accounting for the highest proportion of observed Variance in the **Establish** node was selected as the BBN to use. A schematic representation of this BBN is shown below as Figure 2.

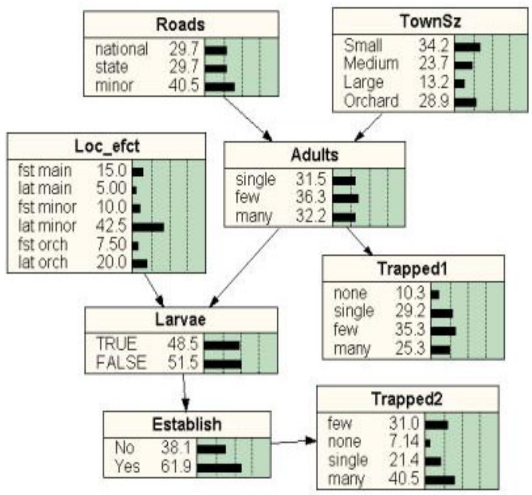

Figure 2. Schematic representation of the Incursion BBN, showing the values for each state in each node.

5. BBN SENSITIVITY RESULTS

The results of sensitivity analyses are shown in Tables 1 and 2. These tables were derived using Netica's 'Sensitivity to Findings' function and lists all nodes in the Qfly incursion BBN in order from most to least influential on either the **Establishment** or **Larvae** nodes.

Table 1. Sensitivity analysis results for the Establish node in the Qfly incursion BBN.

Node	Entropy Information	Variance of Beliefs
Trapped2	0.34641	0.0994464
Larvae	0.33878	0.0976898
Adults	0.08996	0.0286107
Trapped1	0.02843	0.0092740
TownSz	0.00006	0.0000207
Roads	0.00003	0.0000105
Loc_efct	0.00000	0.0000000

It was surprising that none of the Nodes originally expected to influence **Establish** were significant regarding either entropy or variance. Variation within the nodes **Trapped2, Larvae** and **Adults** together accounted for over 95 per cent of the variation in the **Establish** node.

This suggests that development of a larval population, further trapping adult Qfly, as well as the size of the initial incursion are important factors.

The same reasoning would suggest that **Roads**, **TownSz** and **Loc_efct** have negligible impact on establishment.

Table 2. Sensitivity analysis results for the **Larvae** node in the Qfly incursion BBN.

Node	Entropy Information	Variance of Beliefs
Establish	0.3388	0.1035
Adults	0.23325	0.07315
Trapped2	0.1352	0.04364
Trapped1	0.07076	0.02371
TownSz	0.0001526	0.0000105
Roads	0.00000	0.0000000

The large influence of the **Establish** node on **Larvae** is at least partially due to the model structure. The remainder of the nodes listed as having an influence on **Larvae** can be explained biologically. The importance of the initial incursion was certainly expected: it is also logical that the continuing trapping of adults (**Trapped2**) has a larger influence on Larvae than earlier trappings. Although not presented, the node **Trapped1** had the largest influence on **Adults**, whereas **Roads** or **TownSz** had little influence.

6. DISCUSSION

The model results suggest that the initial size of the inoculum (Adults) is more important than where it is introduced (Loc_efct). This is only partially true as the surveillance traps are only placed in either urban environments or irrigated orchards. Therefore, as only the areas favourable for Qfly are monitored, there is a bias in the records that would be expected to minimise geographic relationships.

The implication is that if an incursion occurs in an urban or irrigated location within the FFEZ, exactly where is not relevant. Climatic effects operate mainly on the frequency of introduction of infested fruit rather than establishment after emergence.

Meats *et al* (2003) discussed the importance of the Allee effect (Allee et al 1949, Moller and Legendre 2001) in relation to establishment of Qfly in low density incursions. The trapping of Qfly adults does not necessarily equate to an established population. That Clift and Meats (2001) could model introductions of Qfly, but not establishment of a population is consistent with the Allee effect incorporating a significant random factor that could not be modelled.

The absence of a clear geographical component in the location of trapped flies suggests that at least some of introductions are from relatives/friends of local inhabitants of the FFEZ, rather than passing travellers. If passing travellers were the major contributors, there would be a tendency for the Qfly to be trapped mainly at the first points of contact within the FFEZ: hence **Loc_efct** would have had a significant influence on **Larvae** and **Establish**, but in the model this was not observed.

The frequencies for the states in the node **Loc-efct** were obtained from the dataset of fruit fly trappings indicating the most common location for a finding a fruit fly in a trap was lat_minor – that is a small town within the FFEZ (Figure 1). There is no evidence that the edge of the FFEZ is more likely than the inner areas to be infested. The role of itinerant fruit pickers is less easy to define. It is likely that a proportion of the Qfly trapped in orchards, especially the larger orchards with on-site accommodation, has come in via the pickers.

Although there is a large random factor in the establishment of a breeding population from the initial introduction, the BBN did indicate that the larger introductions established more frequently than those with fewer adults. The nodes written into the BBN did not define the other factors that influence an incursion turning into an outbreak.

The nodes did confirm that continued trapping of Qfly (**Trapped2)** and presence of larvae (**Larvae**) were important in detecting when an incursion had become an outbreak. The same definitions for declaration of an outbreak in the Code of Practice (Anon 1997) were used for the states within the nodes concerned with Qfly trapping.

Sved *et al* (2003) and Gilchrist (2004) have concluded that the origin of Qfly incursions is in the townships to the east and north of the FFEZ, often within 100 km of the FFEZ. Fruit grown or bought in these towns, then transported into the FFEZ represents the main risk. The results obtained from the BBN can be interpreted to indicate the importance of local involvement of both friends/relatives of the inhabitants within the FFEZ and itinerant fruit pickers.

Awareness programs to minimise Qfly introductions need to be targeted to local inhabitants, as well as visitors.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

Allee, WC, Merson AE, Park O, Park T, Schmidt KP (1949) "Principles of animal ecology.' (WB Saunders: Philadelphia, PA)

Anon. (1997) "Code of Practice for management of Queensland fruitfly.' Standing Committee on Agriculture and Resource Management, Department of Primary Industries, Canberra.

Clift, A, Meats, A (2001) Why model tephritid fruit fly incursions in Agricultural production areas? *MODSIM200l*, 1835-1840

Gilchrist, AS (2004) Final Report Project AH01013 'Use of microsatellites to determine the source of Queensland fruit fly outbreaks in the Fruit Fly Exclusion Zone" Fruit Fly Research Centre, University of Sydney, 40 pp.

Meats, A, Clift, A and Robson, MK (2003) Incipient founder populations of Mediterranean and Queensland fruit flies in Australia: the relation of trap catch to infestation radius and models for quarantine radius. *Australian Journal of Experimental Agriculture* **43**, 397-406

Moller, AP, Legendre, S (2001) Allee effect, sexual selection and demographic stochasity. *Oikos* **92,** 27-34.

Norsys Software Corp. (1997) Netica Application Users Guide. Norsys Software Corp, Vancouver, Canada. www.norsys.com

Sved, J, Yu, H, Gilchrist, As, Dominiak, BC (2003) Inferring modes of colonization for pest species using heterozygosity comparisons and a shared allele test. *Genetics* **163**, 429-466.

Wooldridge, S and Done, T (2003) The use of Bayesian Belief networks to aid in the understanding and management of large-scale coral bleaching. *MODSIM2003*, 614-619.