Using the Negative Binomial Distribution and Risk Analysis Software to Simulate *Bactrocera papayae* Drew and Hancock (Diptera:Tephritidae) Metapopulations in an Eradication Context

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Abstract The papaya fruit fly, *Bactrocera papayae* Drew and Hancock was first detected in the Cairns district in October 1995 and an eradication campaign started in December. During 1996/97 the area infested has been reduced by over 90%, with the remainder in a series of metapopulations occurring among human settlements between Cairns, Mareeba and Cooktown. Catches of fruit flies in male lure traps are highly variable, following the negative binomial distribution; within any one trapping grid the k values are very low, <0.5, but sufficiently variable that it is not valid to fit a common k. Risk analysis software, @Risk (Palisade Corp), was used to run Monte Carlo simulations using the observed catches from a trapping grid, allowing confidence limits to be estimated. The probability of catching no flies with the observed distribution of catches was calculated; from this the number of weeks without catching any flies at two densities of trap catches was estimated at six weeks for a trap density of 0.01 males per trap and >16 weeks at a density of 0.003 males per trap, $p = 0.05$. Migration rates were estimated from traps in rainforest areas, where fruit collection had demonstrated the flies were not breeding. The probability of both extinction and reinvasion within local metapopulations was estimated for two different trap catch densities.

1. INTRODUCTION

The papaya fruit fly, *Bactrocera papayae* Drew and Hancock (PFF) was first detected in the Cairns district in October 1995 and an eradication campaign started by December 1995. A massive trapping grid, comprising local grids within settlements, traps along highways, transects along roads within World Heritage Rainforest areas and traps within the rainforest has been established. In 1997 there are over 2000 traps between Innisfail, west to Chillagoe and north to Cooktown. These traps use methyl eugenol to attract male PFF. Female traps are not as efficient as male traps. There are also weekly collections of fruit to determine if breeding populations of PFF are present. Control has been achieved by a combination of male annihilation (Steiner *et al* 1965) and bait spraying (Bateman 1991). During 1996/97 the area infested has been reduced by over 90%, with the remainder in a series of metapopulations occurring among human settlements between Cairns, Mareeba and Cooktown.

Local extinction of PFF within individual settlements and re-establishment would be expected to occur, with the frequency of re-establishment decreasing as the eradication program proceeds. In such a context, there is always the question of how long is the interval after catching the previous positive that there are no fruit flies left in the area. Catches of fruit flies in male lure traps are variable temporally as well as spatially (Cowley *et al* 1990). In any situation where the adult density is low, zeros frequently occur, as well as clusters of positive catches (O'Loughlin *et al* 1983, Cowley *et al* 1990). The negative binomial distribution is often fitted to such data (Bliss and Fisher 1953).

When trap counts are fitted to the negative binomial distribution, the k values found are low, ranging from >1 to below 0.1, indicating highly clustered populations (Bliss and Fisher 1953, Southwood 1953). These values are difficult to interpret using conventional techniques, with the proportion of positive traps, rather than actual counts are often used (Cowley *et al* 1990). Mite numbers on apple leaves also follow the negative binomial and Pielou (1960) successfully related proportion infested leaves to average count for a range of k values.

Risk analysis software, @RISK (Palisade Corp) allows Monte Carlo simulations of observed catches of male PFF from a trapping grid, without making any assumptions about the distribution of the data. The probability of catching no flies from an observed distribution of catches from a grid over a series of trapping intervals can be calculated. Using binomial probability, the range in numbers of females in the same area can be determined and the probability of re-establishment of PFF in an area estimated. We describe the observed PFF trapping data, report the results of simulations to determine the probability of localised extinction and subsequent re-establishment of PFF and compare the results to the observations.

2. METHODS AND MATERIALS

2.1 Data Used

Fortnightly totals for the entire PFF Cape York trapping grid from October 1995 to May 1997, representing up to 42 values per trap, were separated into the individual grids using a Lotus Ver 5 spreadsheet. The observed frequency distribution of catches for the following four grids: Cairns City, Northern Beaches, Goldsborough Valley - Gordonvale and combined Rainforests, were determined for each fortnight, each mean calculated and the proportion positive traps determined. Individual trap catches per fortnight ranged from 0 to 283, with considerable variation in the maximum value between fortnights.

2.2 Studies based on the negative Binomial Distribution

Using the negative binomial distribution, the probability of catching one or more PFF is given by (1):

$$(1) \qquad \Pr \text{ of} > 0 = 1 - \left(1 + \frac{\bar{x}}{k}\right)^{-k}$$

This equation was used to determine the expected proportion of positive traps for a range of k values, 0.05, 0.1, 0.2 or 0.5 and a wide range of mean PFF males per trap per fortnight, $\bar{x}$, from 0.001 up to 1000. All calculations were done using FigP® Ver 6.0c. The calculated probabilities of >0, the proportion of positive traps were compared to observed values from a subset of the trapping data. The graphs were done using FigP® ver 6.0c.

2.3 Simulating Trap Catches

The spreadsheet model, set up in Lotus 123 ver 5 for Windows, uses 100 traps per fortnight over 8 fortnights. The mean catch density varied between 0.003 and 0.3 male PFF per trap per fortnight, with the individual counts following an appropriate distribution: the total catch is calculated for each fortnight and is used as the input for a binomial function to determine the number of females in the area. Although the sex ratio is usually 1:1 in fruit flies, a probability of 0.25 is used to allow for the flies having to find each other. This is probably an overestimate, but provides a basis for comparisons. Fruit flies disperse before they reach sexual maturity (Meats 1996), so at least two pairs of PFF, associated with different traps, is considered necessary for an infestation to establish. The fortnightly totals are also totalled after one, two, up to eight, to determine the number and probability of successive zero catches that occur at each of a range of mean trap catch densities. The @Risk software was set to 1000 Monte Carlo simulation runs of this model for each value of the mean catch density, providing frequency distributions for each trap total and the binomial estimate of female numbers. The @Risk software provided the data used to produce the graphical output from the simulation runs.

3. RESULTS

The plots of (1), using a log/log scale, for *k* values of 0.5, 0.2 and 0.05, is presented as Fig 1. Observed points from the Cairns grid and Northern Beaches grid are also plotted, indicating that the very low *k* values used are representative of the data.

A summary of the trapping data for the four grids is summarised in Table 1. At low trap densities, below 0.5 flies per trap, the *k* value in the negative binomial distribution can be almost any value (Fig 1) and a Poisson distribution will also adequately describe the data. Therefore, in the simulation of the trap catches, a Poisson distribution was used, with a mean value ranging from 0.003 up to 0.3: typical simulation results are included for comparison in Table 1. In none of the simulation runs did any of the output variables show convergence, that is the between simulations variance of each ouput variable did not stabilise, even after 1000 simulations. This is an indication of the variability of fruit fly trap catches.

Table 1 Summary of Papaya Fruit Fly trapping data and simulation results

Trapping Interval	Variable	Cairns	Nth Beaches	Gordonvale	Rainforest	Simulation
Oct 95-Jan 96	Mean catch	28.4	1.43	0.42	0.16	0.05
	Longest run zeros	nil	nil	nil	1 fortnight	1 fortnight
	Extinct/Re-establish[1]	no/NA	no/NA	no/NA	no/NA	no/NA
Feb 96-May 96	Mean catch	0.28	0.09	0.19	0.065	0.03
	Longest run zeros	2 fortnights	1 fortnight	1 fortnight	nil	3 fortnights
	Extinct/Re-establish[1]	no/NA	no/NA	no/NA	no/NA	no/NA
Jun 96-Sept 96	Mean catch	0.027	0.006	0.000	0.01	0.01
	Longest run zeros	2 fortnights	4 fortnights	8 fortnights	1 fortnight	8 fortnights
	Extinct/Re-establish[1]	no/NA	no/NA	yes/no	no/NA	yes/yes
Oct 96-Jan 97	Mean catch	0.013	0.02	0.01	0.005	0.01
	Longest run zeros	7 fortnights	3 fortnights	7 fortnights	3 fortnights	8 fortnights
	Extinct/Re-establish[1]	yes/yes	no/NA	yes/yes	no/NA	yes/yes
Feb 97-May 97	Mean catch	0.056	0.04	0.006	0.000	0.003
	Longest run zeros	4 fortnights	2 fortnights	6 fortnights	9 fortnights	8 fortnights
	Extinct/Re-establish[1]	no/NA	no/NA	yes/no	yes/no	yes/no

[1] Decisions concerning extinction or re-establishment in each of the grids was supported by the results from rearing fruitflies out of collected fruit from each area.

The simulations provided an estimate of the probability of a succession of zero catches in all 100 traps for 1, 2, up to 8 fortnights: the estimates for 1 up to 8 fortnights for two trap densities is presented as Fig 2. In the simulation system, local extinction was assumed to have occurred when the probability of not finding a succession of zeros for the average trap catch densityexceeded 0.99. Reestablishment was assumed whenever the binomial probability indicated at least two pairs of PFF within the trapping grid. At a trap catch density of 0.01 PFF males per trap per fortnight, the probability of re-establishment of PFF was about 0.03.

4. DISCUSSION

Generally the distribution of fruit flies within an area is in discrete patches. This is reflected in the variable catches from male lure traps (Cowley *et al* 1990, Bateman 1991) and the low k values. The PFF trap catches are following the same pattern, as indicated in Fig 1. This extreme clustering can result in one trap with 9 PFF and the other 37 not catching anything, as occcurred in the Northern Beaches Grid.

Despite the range and inherent variability, the situation can be successfuly simulated using values of parameters derived independently from first principles (Fig 1, Table 1). The predicted scenarios are consistent with the observed trap catches when each grid is considered separately and the predicted number of consecutive zero catches at various trap densities is within the observed range (Table 1). The predicted re-establishment of PFF is also consistent with the inferred occurrences, but caution is required as extinction, followed by re-establishment is not a frequent event at low trap catch densities.

5. CONCLUSIONS

1) PFF trap catches are adequately described by the negative binomial distribution, but with very low, variable *k* values
2) At very low trap catch densities, <0.01 PFF per trap per fortnight, almost any contagious distribution will fit the data
3) It is possible to model the PFF trapping grids after making limited numbers of conservative assumptions.
4) At low trapping densities it is possible to estimate the number of consecutive trap catches to conclude , at ny desired level of confidence, that the PFF infestation has been eradicated. However, this is still only an estimate, hence it has an error component.
5) At a trap catch density of 0.01 PFF males per trap per fortnight, the probability of observing five consecutive zero catches from 100 traps is 0.01.
6) Further trapping data, from August to December 1997 will be used to validate these conclusions.

6. REFERENCES

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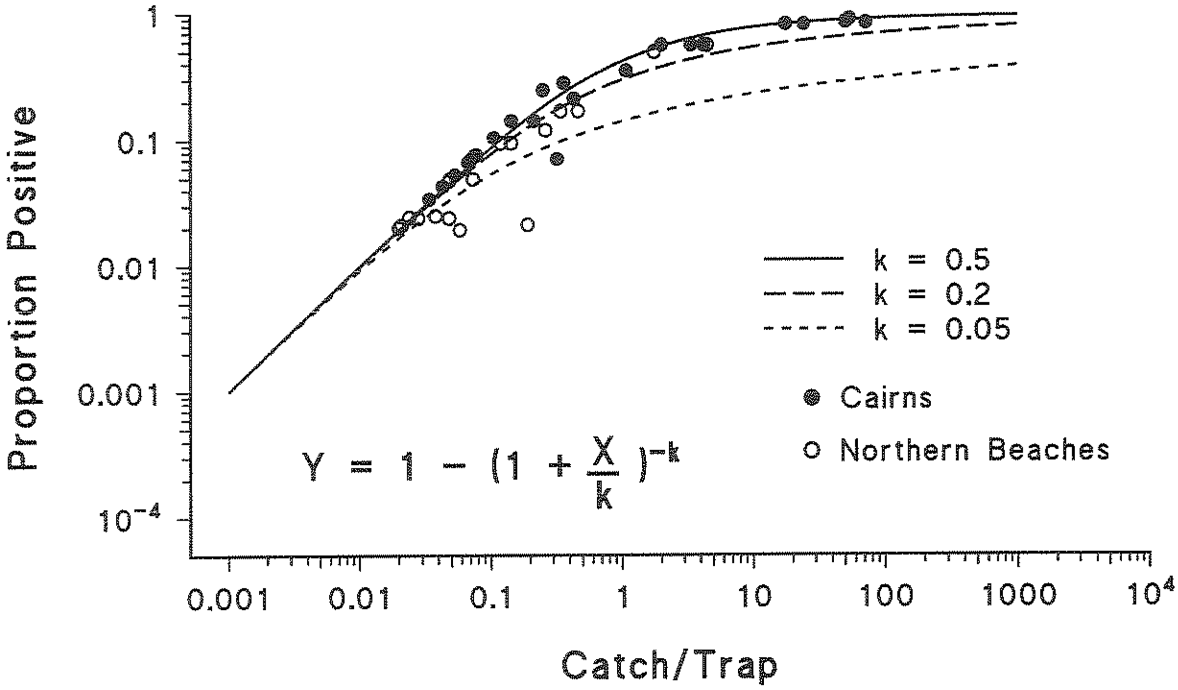

Fig 1 Observed and expected proportion positives from PFF trapping grids

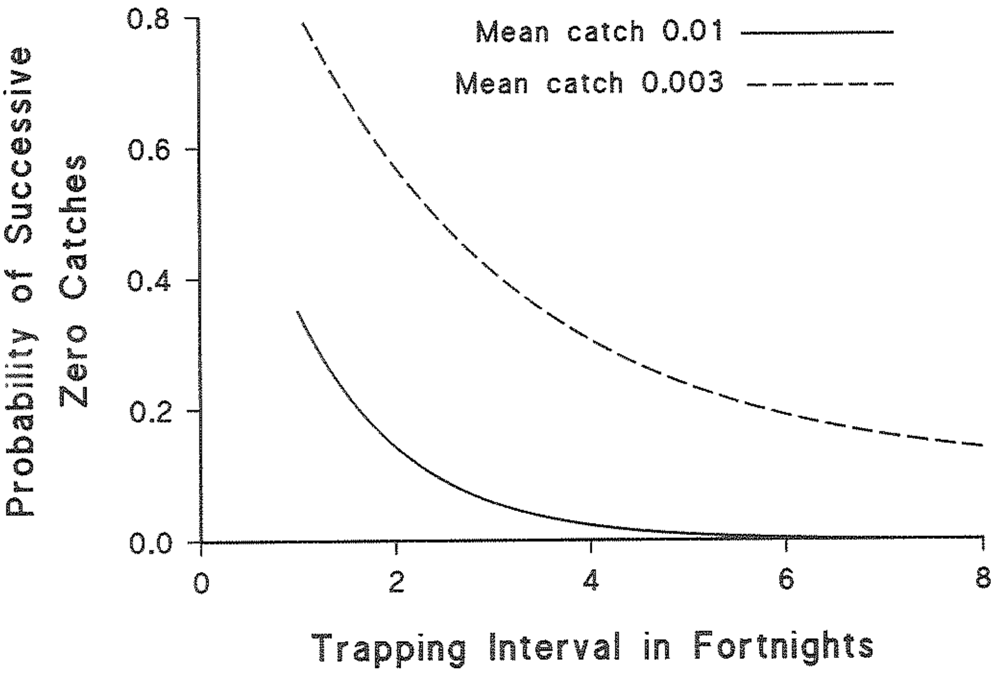

Fig 2 Probabilty of successive zero trap catches at two trapping densities