Risk Analysis studies on banana fruit fly, *Bactrocera musae*, recolonising an area near Cairns, North Queensland after area-wide insecticidal treatments had ceased.

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Abstract The papaya fruit fly, (PFF), *Bactrocera papayae* was first detected in the Cairns district in October 1995, an eradication campaign started in the same month and area freedom claimed in August 1998. The lure used in male annihilation of PFF was methyl eugenol, but other species of fruit fly attracted to methyl eugenol were effectively eliminated from the treated area. When the treatments ceased, various species of fruit flies began recolonising from populations outside the zone. Banana fruit fly, (BFF) *Bactrocera musae* was used as the indicator species. As trapping continued, the establishment and subsequent population increases of BFF were monitored quantitatively. As part of the eradication campaign, a model to simulate localised extinction and reinvasion of local populations of PFF was developed using risk analysis software, @Risk® (Palisade Corp.). This model made assumptions about the criteria for both extinction and re-establishment of PFF, based on male trapping data. The suitability of these parameters and values in predicting the establishment of fruit fly populations was tested using BFF trapping data. The data monitored the development of BFF populations from January 1996 up to March 1999 in the PFF eradication area. @Risk® was used to run simulations using the observed catches from a trapping grid to estimate numbers of female flies present using the same parameters and values used in the earlier PFF model. The predicted probability of at least two potential mating pairs overestimated the establishment of BFF in 5 out of 8 sites. The extinction criterion used in the PFF model was also unsuitable in some situations and was modified to include seasonal factors and average trap catches from both the previous and next quarter.

1. INTRODUCTION

A campaign to eradicate an incursion of papaya fruit fly (PFF), *Bactrocera papayae*, near cairns, north Queensland started December 1995 (Clift and Meats 1997). The eradication procedures used protein hydrolysate plus maldison spot spraying of foliage and of male lure caneite blocks treated with methyl eugenol plus maldison (Steiner and Lee 1955). While only PFF numbers were recorded for male lure traps in urban, disturbed or horticultural areas, all species from the World Heritage Rainforests (WHRF) were determined, counted and recorded.

The last wild flies were found at Ellis beach in July 1997, area freedom claimed in 1998 and eradication declared in May 1999. Eradication treatments ceased in March 1998 and all blocks had been removed by May 1998. Monitoring continued until March 1999

Recording of numbers of other fruit fly species began in July 1997 to establish reference data for future declaration of area freedom. The indicator species chosen was banana fruit fly (BFF) *Bactrocera musae*, a native rainforest species that infests commercial and backyard bananas in Queensland. In 1996, BFF occurred in the WHRF and in 1997 isolated infestations were found in the Pest Quarantine Area (PQA). Once treatments ceased in 1998, BFF started to be trapped in increasing numbers throughout the PQA.

Trapping data for PFF during the eradication campaign was used to develop a model to simulate localised extinction and reinvasion of areas (Clift and Meats 1997). The aim of the model was to define criteria for localised extinction of PFF and to distinguish a local, developing infestation from dispersing flies from other areas. The assumptions related to the minimum criteria for establishing a sustainable population. This model was set up in a situation of declining populations and was based on a series of assumptions which could only be tested against an independent set of data.

Data from trapping BFF as they recolonise previously disinfested areas after eradication procedures had ceased provides such an

independent set, but under conditions of an increasing population. The results of testing the assumptions made for the original model, (Clift and Meats 1997), under different circumstances, is reported.

2 METHODS and MATERIALS

2.1 Data Used

BFF trapping data, January 1996 to March 1999 from a 50 km radius around Mossman, Lat. 16° 17' S, Lon. 145° 29' E, was used. This area features three monitored WHRF areas, several urban developments and horticultural production areas. It also includes Ellis Beach, Lat. 16° 44' S, Lon. 145° 39' E, which was intensively treated and trapped during 1997 as the last record of wild PFF.

BFF trapping counts from eight areas were chosen to analyze the development of local populations. These were three WHRF areas, Cape Kimberley Lat. 16° 17' S, Lon. 145° 29' E,, Mt. Lewis Lat. 16° 35' S, Lon. 145° 17' E, and Rex Range Lat. 16° 39' S, Lon. 145° 34' E,. Other areas were Oak Beach Lat. 16° 36' S, Lon. 145° 31' E, Ellis Beach, Mary Farms, Port Douglas Lat. 16° 29' S, Lon. 145° 28' E, and Mossman. The trapping data, including trap co-ordinates, were extracted from a MS97 ACCESS Database, exported to a Lotus Ver 5 spreadsheet and separated into the eight areas for 1996 to 1999: all traps within a 6 km radius of the median trap co-ordinates within each area were used. Catches were summarised as quarterly totals, then converted to catch per trap per week. Q1, January to March is the wet season in the area, when BFF numbers would be expected to be high: Q2, April to June is also a time of native fruit development when BFF would also be expected to be abundant. Q3, July to September is the dry season, least suitable for BFF. Q4, October to December is the build up to the wet season, when BFF numbers would be building up.

2.2 Simulating Population Establishment

The same model used for PFF (Clift and Meats 1997) was used, with the same parameters, values and criteria. Briefly, the spreadsheet model, set up in @Risk® and Lotus® 123 Ver 5, used 100 traps per week over four months. The mean catch density simulated ranged between 0.001 and 1 male BFF per trap per week. The total catch is calculated for each week and is used as input for a binomial function to estimate the number of females in the area. The sex ratio is usually 1:1 in fruit flies, probability 0.5, but a probability of 0.25 is used to allow for flies to locate each other. Based on (Meats 1998) this is a considerable overestimate, but it provides a basis for comparison. Nearly 80% of individuals of *Bactrocera* species fruit flies disperse before they reach sexual maturity (Meats 1996, 1998), so either a large initial number in one location, or at least two pairs of BFF, associated with different traps, is considered necessary for a population to establish (Clift and Meats 1997). The @Risk software was set to 1000 simulation runs, using the Latin Hypercube sampling procedure, providing the frequency distribution of the binomial estimate of numbers of female flies at various mean male catch rates. The criterion for establishment of a population was that the estimated probability of two male and two female BFF being in the same area was at least 0.2.

3. RESULTS

The BFF trapping data has monitored the development of fly populations over eight areas. There was an exponential increase in BFF at Oak Beach, ranging down to marginal populations at Mary Farms. The observed mean trap catch for each quarter for each location is provided as Table 1. The probability of there being at least two male and two female flies at the observed level of BFF males in each quarter at each location, as determined by the simulation model is provided.

Cape Kimberley is clearly a favourable site for BFF: as part of the WHRF, it was never sprayed or blocked. Throughout the time of the monitoring, there was a sustainable BFF population present, except for Q3 of 1997 (Table 1). In contrast. The other two WHRF areas, Mt. Lewis and Rex Range were less suitable, with low male trap catches in successive quarters and the trap catches indicating localised extinctions (Table 1).

Despite the ongoing eradication campaign during 1997, there was a permanent population of BFF at Oak Beach, a small semi-rural settlement. BFF numbers increased dramatically once treatments ceased by the end of Q2 of 1998 (Table 1). Ellis beach, was heavily treated during Q1 and Q2 of 1997, with no BFF trapped until later in Q3, 1997: it was supporting at best a marginal BFF population until the Q3 of 1998, six months after the eradication campaign ceased (Table 1).

Mary Farms, an isolated rural, production area had a marginal BFF population after Q1 1998, when eradication spot treatments ceased. It was only in Q1, 1999 that BFF numbers noticeably increased. At Port Douglas, the BFF populations were also marginal until Q1 1999. Throughout 1998, based on the criterion of a probability of 0.2 of at least

Table 1 Summary of Banana fruit fly trap catch data and simulation results indicating probability of two or more females in each area averaged every quarter (three months). Spray treatments ceased during Q1, 1998 and all blocks had been removed during Q2, 1998

Location, Mean Catch & Simulation results[1]		1996				1997				1998				1999
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
Cape Kimberley	Mean Catch	1.08	2.12	0.15	0.047	0.38	0.17	0.004	0.48	1.82	2.22	3.00	8.24	3.95
	Pr > 2 females[1]	>0.99	>0.99	0.88	0.34	0.98	0.91	<0.02	0.98	>0.99	>0.99	>0.99	>0.99	>0.99
Mt Lewis	Mean Catch	0.035	0.002	0.005	0.005	0.018	0.005	0	0.008	0	0.029	0	0.14	2.85
	Pr > 2 females	0.24	<0.01	<0.02	<0.02	<0.05	<0.02	<0.001	<0.05	<0.001	0.2	<0.001	0.83	>0.99
Rex Range	Mean Catch	0.58	0.067	0	0.058	0.13	0	0	0.041	0.23	0.057	0.034	0.73	3.22
	Pr > 2 females	0.98	0.45	<0.001	0.98	0.83	<0.001	<0.001	0.29	0.96	0.45	0.25	0.98	>0.99
Oak Beach	Mean Catch	-	-	-	-	-	-	0.25	0.87	1.32	0.53	0.41	3.27	7.04
	Pr > 2 females	-	-	-	-			0.96	0.98	>0.99	0.98	0.97	>0.99	>0.99
Ellis Beach	Mean Catch	-	-	-	-	0	0	0.0026	0.039	0.073	0.030	0.071	0.85	3.43
	Pr > 2 females	-	-	-	-	<0.001	<0.001	<0.01	0.25	0.53	0.2	0.53	0.99	>0.99
Mary Farms	Mean Catch	-	-	-	-	-	0	0	0.027	1.26	0.037	0.0033	0.047	0.62
	Pr > 2 females	-	-	-	-		<0.001	<0.001	0.2	>0.99	0.25	<0.05	0.34	0.99
Port Douglas	Mean Catch	-	-	-	-	-	-	0	0.022	0.079	0.035	0.016	0.65	2.16
	Pr > 2 females	-	-	-	-			<0.001	0.02	0.98	0.24	0.10	0.98	>0.99
Mossman	Mean Catch	-	-	-	-	0	0	0	0.032	0.10	0.13	0.17	3.15	4.92
	Pr > 2 females	-	-	-	-	<0.001	<0.001	<0.001	0.24	0.82	0.83	0.90	>0.99	>0.99

[1] Estimates from the output of the simulation model.

two females and two males present, the results of the simulation model indicated a sustainable population of BFF. This conclusion is not supported by the trap catches. Similarly, at Mossman, the simulation results indicated permanent BFF populations had established by Q4 1997. Eradication procedures were being used in the area during Q1 and Q2 of 1997 and neither BFF numbers nor the simulation results suggested the establishment of a permanent population. BFF trap catches did not increase until Q4 1998

4 DISCUSSION

Meats (1998) discussed the dynamics of a propagule of Queensland fruit fly, *B tryoni,* regarding the likelihood of establishment of a permanent population, suggesting a lower density limit of 6 males ha^{-1}. He cautioned that a lower limit may apply at the fringes of established infestations. BFF are endemic to the Cairns area and Cape Kimberley, a WHRF area, can clearly support high populations of BFF.

Therefore, although the PFF eradication procedures were effective in reducing numbers within the treated area to below levels for sustainable populations, flies continued to diffuse into the area from surrounding WHRF. The criteria for establishment of a sustainable population originally set by Clift and Meats (1997) for PFF does not distinguish between moderate numbers of BFF "diffusing" into the area and an established population.

Both Cape Kimberley and Oak Beach were suitable for BFF, the latter site supporting BFF in 1997 despite an eradication campaign in progress. In both situations, the model results indicate very high predicted probabilities, > 0.98 of both male and female flies being in the same area.

Other situations are not clearly defined, with the predicted probabilities being lower and variable. At Ellis Beach and Mossman, the probabilities of potential mates are low during the eradication campaign, which is not unexpected However, Ellis Beach, Mary Farms, Port Douglas and Mossman, were not supporting high numbers of BFF until early 1999.

Using the criterion of an estimated probability of 0.2 for two potential mating pairs, sustainable populations of BFF are predicted in these areas during 1998. The trap catches in Table 1 do not support this conclusion with trap catches for Port Douglas during most of 1998 being more consistent with BFF diffusing in from the WHRF.

Meats (1998), working with QFF cautioned his numerical values were species specific. He used a value of 0.1 as the probability of mating occurring if a male and female QFF were in the same tree and a value of n/400 for a fly to be in the tree, where n is the density in flies ha^{-1}.

Methyl eugenol flies are different to cue-lure flies (Drew and Hooper 1981, Steiner and Lee 1955), but the values used are clearly unsuitable for BFF when the population is increasing. The work of Meats (1998) suggests that the value used for the PFF model, 0.25, which allows both for the probability of both sexes being present and mating was far too high. The criterion for establishment of a sustainable population, 0.2 for two potential mating pairs is too low, further compounding the error.

The criterion for extinction, a succession of zero catches for 12 weeks, means that zero catches over three months, 13 weeks, indicates extinction. This interpretation is unlikely to be valid for Cape Kimberley, Q3 1997, but more probable for Mt. Lewis and Rex Range. The successions of zeros during Q1, Q2 and Q3 of 1997 for Ellis Beach, Mary Farms and Mossman also probably indicate absence of BFF populations.

Rather than a value of 0.2 for the probability of there being two potential mating pairs, a value of 0.9 would be more suitable for this set of data. There are further sets of data for different areas within the PFF eradication area that could be used to test parameter values fitted to the data set used for this study

The concept behind the PFF model used is an extension of the methods described in Meats (1998). He noted that fruit fly populations are often clumped and local density "hot spots" could provide higher density at a local level. The model used for PFF (Clift and Meats 1997) included a Poisson distribution to allow for observed variation in trap catches. The values derived from first principles for PFF were satisfactory in modelling an eradication situation, but are not suitable in the present situation with BFF.

5. CONCLUSIONS

The parameter values used in a model to simulate PFF reinvasion in an eradication context, with a declining population were not suitable for BFF reinvading from surrounding rainforest.

A minimum value of 0.9 for the probability of there being two potential mating pairs is more appropriate for the BFF data used in this study.

The criterion for extinction, no flies trapped over three months, is valid under most conditions, but the trap catches in the previous and next quarter can modify this condition.

Parameter values can be fitted to the data set used for this study and validated using data from different areas within the PFF eradication area.

6. REFERENCES

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