Modelling winter survival, mating and trapping of Queensland fruit fly in Auckland, New Zealand

J.M. Kean^{1,2}

¹AgResearch, Ruakura Research Centre, 10 Bisley Road,
Private Bag 3123, Hamilton 3240, New Zealand

²Better Border Biosecurity, b3nz.org

Corresponding author: john.kean@agresearch.co.nz

Abstract In February 2015, an established population of the Queensland fruit fly (Qfly, *Bactrocera tryoni*) was detected in Grey Lynn, Auckland. It was questionable whether Qfly might successfully overwinter in Auckland, and how trap efficacy and mating behaviour would be affected by winter conditions. During the official biosecurity response to eradicate Qfly these questions were addressed using published Qfly models that had been developed and parameterised from biological data from its native range. A model for cold acclimatisation suggested that Auckland winters would not be sufficiently cold to cause significant mortality of adult Qfly, but substantial cold mortality might occur in more southern locations. The temperature requirement for mating suggested mating would be relatively rare from June to October and two models for relative trap efficacy suggested that traps would be relatively ineffective until late spring (October–November). The Ministry for Primary Industry’s biosecurity response was successful, with no detection of Qfly after March 2015 and eradication formally declared in December 2015.

Keywords *Bactrocera tryoni*, Qfly, eradication, biosecurity, invasion, risk analysis.

INTRODUCTION

On 16 February 2015, a single male fruit fly was recovered from a cue lure-baited fruit fly surveillance trap in Grey Lynn, Auckland, New Zealand. The condition of the specimen suggested it had been caught within the previous 24 hours. It was formally identified by the following day as *Bactrocera tryoni* (Froggatt), the Queensland fruit fly (Qfly), which is a major pest of horticulture in Australia, New Caledonia and French Polynesia. The Ministry for Primary Industries (MPI) launched an investigation that found further adult, larval and pupal Qfly in a small number of Grey Lynn properties, which triggered an eradication response coordinated by MPI. Many of these

urban properties contained small gardens with fruit trees and other plants that could support Qfly. The last detection of Qfly from this incursion occurred on 13 March 2015 and the population was officially declared eradicated on 4 December 2015 (MPI 2015). Since the eradication programme spanned the winter months, it was important to consider the overwintering behaviour of Qfly, whether it might survive the cold months in Auckland, and how trap efficacy and mating behaviour would be affected by winter conditions.

In its native Australia, Qfly overwinters in temperate areas as quiescent adults, while other life stages are typically killed off by cold

temperatures (Fletcher 1979, Clarke et al 2011). During winter, adult flies feed (and hence respond to baited traps) and mate during the relatively warm hours, but these activities are less frequent than during the summer months. As temperature lowers further, insects may enter a state of torpor (chill coma), where they are unable to move and may be more susceptible to predation and other mortality factors. At sufficiently low temperatures insects are killed by physiological damage to cells (Roberts 1978, Bale & Hayward 2010). This study used three published models for torpor induction, cold survival, mating activity and trap efficacy to investigate the likely overwintering activities of Qfly in Auckland and selected New Zealand sites.

MATERIALS AND METHODS

Meteorological data

During the Qfly incursion response a meteorological station was installed at Chamberlain Park Golf Course, Auckland (-36.874°N, 174.723°E), 1 km from the epicentre of the incursion. This provided air temperatures at 10 min intervals from 28 February to 17 December 2015. NIWA's

CliFlo database (cliflo.niwa.co.nz) provided hourly meteorological data for Lincoln Road (-36.869°N, 174.629°E), the nearest permanent weather station, 9 km from the incursion site, from 1 January 2004 to 31 December 2015. For comparison, daily temperature data from New Zealand's main city airports (Table 1) were obtained from CliFlo for the same period.

Overwintering survival

Meats (1976a, b, c) investigated the torpor and cold survival thresholds of Qfly and showed that it was affected by previous exposure to cool temperatures. His acclimatisation model (Meats 1976c) was applied to the New Zealand temperature data described above. In each case, the number of days per year were counted on which the minimum daily temperature was predicted to induce torpor or 50% cold mortality.

Mating activity

Laboratory studies showed that Qfly does not mate below 16°C (Meats & Fay 2000), and observations from field cages showed that

Table 1 Number of days per year on which adult Queensland fruit flies are predicted to become torpid. Asterisks indicate when winter temperatures became low enough to cause >50% adult mortality on at least one occasion.

City (at airport)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Whangarei	0	0	0	1	1	0	1	0	0	1	1
Auckland	0	0	0	1	3	0	0	0	0	1	0
Tauranga	2	5	0	3	4	0	1	2	1	4	3
Hamilton	28	43	25	22	45	28	26	40	19	32	35
Gisborne	6	4	5	6	7	3	7	1	5	5	14
Napier	15	11	8	13	19	14	11	23	14	7	24
New Plymouth	2	4	9	7	11	5	5	4	3	6	9
Palmerston North	25	25	22	28	35	26	19	38	14	25	26
Wellington	0	0	1	1	1	1	0	1	0	2	0
Nelson	13	29	26	36	42	15	24	36	39	21	35
Christchurch	59*	72	62*	74	73	64*	64*	68*	54	83*	77*
Dunedin	92*	92*	89*	93*	88*	98*	82*	92*	80*	82*	94*
Queenstown	91*	103*	95*	113*	107*	105*	103*	100*	85*	98*	111*

mating occurs exclusively at dusk (Tychsen 1978). Therefore, the temperatures recorded at Chamberlain Park and interpolated from the hourly values at Lincoln Road at civil sunset time were compared to the 16°C threshold. In addition, a temperature-dependent model for male mating frequency (Meats & Fay 2000) was used to assess relative mating activity throughout the year, based on a “4-step” interpolation of daily trends (Kean 2013), based on the daily minimum and maximum temperatures recorded at the same sites.

Trap efficacy

Cage experiments suggest that Qfly males are most strongly attracted to cuelure in the morning, mostly before 9 am (Weldon et al. 2008), but field workers have also noted activity in the afternoon (D. Voice, MPI, personal communication). Assuming that males do not fly at less than 16°C (Reynolds et al. 2010), the hourly data from Lincoln Road were used to tally the proportion of times that were $\geq 16^\circ\text{C}$ for each day (i.e. 24 hr period), for each morning (midnight to noon) and before 9 am (from midnight) to accommodate uncertainty in the timing of attraction. Yonow et al. (2004) modelled trap capture data using an activity index which depends on both maximum daily temperature and daily rainfall. Their model was also applied to the Lincoln Road meteorological data.

RESULTS

Figure 1 shows predicted changes in the threshold for torpor from the model of Meats (1976c) in relation to daily minimum temperatures at Chamberlain Park in 2015. The model suggested that only four days of that winter were cool enough to induce torpor. Figure 2 shows that temperatures remained well above the -4 to -6°C reported to cause substantial mortality of torpid flies. Analysis of the temperatures that occurred from 2005 to 2015 at Lincoln Road suggests that torpor would be induced on 0, 7, 1, 7, 21, 10, 7, 4, 0, 3 and 6 days of each year respectively over this

Figure 1 Simulation of the torpor threshold, below which Queensland fruit fly adults are unable to move, from the model of Meats (1976c) (line) and daily minimum temperatures $<8^\circ\text{C}$ from Chamberlain Park, Auckland in 2015 (points).

Figure 2 Simulated thresholds for mortality of Queensland fruit fly adults from the model of Meats (1976c) (lines) and daily minimum temperatures $<2^\circ\text{C}$ from Chamberlain Park, Auckland in 2015 (points).

Figure 3 Temperatures recorded at Chamberlain Park, Auckland at civil sunset in 2015. The dotted line indicates the 16°C threshold required for flight and mating.

Figure 4 Proportion of evenings suitable for Queensland fruit fly mating (i.e. air temperature $\geq 16^{\circ}\text{C}$ at civil sunset) by day of the year at Lincoln Road, 2004-2015. The line shows a 10-day moving average.

11-year period, but it was never cool enough to cause substantial adult mortality during that time. The winter torpor and mortality results for other sites including Auckland airport are summarised in Table 1. The number of torpor days predicted for coastal Auckland airport were substantially fewer than Lincoln Road which is further inland, reflecting some of the microclimate variation within Auckland. Therefore, care should be taken in extrapolating results from one weather station to the wider region. Nevertheless, the results in Table 1 suggested a clear trend in the suitability of the climate from north to south to support Qfly survival. These results are in agreement with the CLIMEX model and the potential for Qfly to overwinter in at least two climatically different parts of Auckland.

The models predicted that Auckland winter temperatures would, however, affect adult mating activity and trap efficacy. Sunset temperatures suggested that mating would virtually cease at Chamberlain Park in late May 2015 and not recommence until mid-October 2015 (Figure 3). At Lincoln Road, the long term data suggested that fewer than 10% of the evenings were suitable for mating from mid-June to early September, but not until November would more than half of the evenings be suitable for mating (Figure 4). Very

Figure 5 Mean daily mating activity of Queensland fruit fly at Lincoln Road, 2005-2015, as predicted by the model of Meats & Fay (2000).

Figure 6 Proportion of time suitable for Queensland fruit fly trapping when the air temperature $\geq 16^{\circ}\text{C}$ at Lincoln Road, 2004-2015.

Figure 7 Mean relative trap efficacy at Lincoln Road, 2005-2015, predicted by the model of Yonow et al. (2004).

similar results were obtained using the mating model of Meats & Fay (2000) (Figure 5).

Figure 6 shows the proportion of hours (all day, midnight to noon, or midnight to 9 am) with maximum hourly air temperatures $\geq 16^{\circ}\text{C}$ at Lincoln Road, averaged by month. These results suggest that from June through October only about one morning per week on average would be suitable for trapping Qfly males, as compared to about six mornings per week in summer. The all-day results suggest relatively low male activity from June to September. The model of Yonow et al. (2004) also suggested relatively low trap efficacy from May to October (Figure 7).

DISCUSSION

The main factors restricting the Australian distribution of Queensland fruit fly are thought to be cool temperatures, low rainfall and fruit availability (Muthuthantri et al. 2010, Clarke et al. 2011). Given New Zealand's ample rainfall and the year-round availability of host fruits in many urban gardens, it is likely that the geographic distribution of Qfly here would be primarily driven by winter temperatures. Meats' (1976c) overwintering model suggested that Auckland winters are neither sufficiently cold to regularly induce torpor in Qfly adults, nor to cause cold mortality. This suggests that Auckland may be climatically suitable for Qfly establishment and persistence between seasons. In contrast, results for inland and South Island cities that are typically much colder than coastal Auckland suggested there would be a much greater incidence of adult torpor and, from Christchurch south, substantial cold mortality that make these areas less suitable for Qfly persistence (Table 1).

This agrees with predictions from a CLIMEX model for Qfly (Yonow & Sutherst 1998), which suggests that Northland, Auckland, the Bay of Plenty, East Cape and parts of coastal Hawke's Bay may be suitable for Qfly persistence (J.M. Kean, AgResearch Ltd, unpublished data). Conversely, the MaxEnt model for New Zealand by Aguilar et al. (2015) suggests that Auckland is much less suitable for Qfly than Gisborne and Hawke's Bay,

but similar to Nelson, Blenheim and Christchurch. That disagrees with the results of this study, which suggests that temperature would limit Qfly's ability to overwinter in the South Island cities, but not in Auckland. The MaxEnt model may misrepresent Qfly's potential range because the Australian presence data (from the Global Biodiversity Information Facility, GBIF.org) that were used to fit the model are not representative of the full native range of Qfly reported by Meats (1981), Yonow & Sutherst (1998) and Maelzer (2004). For example, the GBIF data currently contain no records for the Qfly populations that exist in south-eastern New South Wales and eastern Victoria. These areas are climatically similar to Auckland (Peacock & Worner 2006, Kriticos 2012).

Mating activity and trap efficacy in Auckland were both predicted to be substantially depressed through the winter and early spring (May/June to October/November). However, a male Qfly was trapped in Avondale, Auckland in May 2012, demonstrating at least some trap activity at that time of year. Figures 5 and 6 suggest that winter trap efficacy would increase again to May levels by October/November. New Zealand's routine fruit fly surveillance system currently operates from September to June in most areas (Acosta & White 2011), but the 2015 incursion response traps were operated throughout the winter. In Queensland and New South Wales, spring trap catches generally resume in August-September, although in some subtropical locations they may continue year-round (Yonow et al. 2004, Muthuthantri et al. 2010). A trial in Applethorpe-Stanthorpe (southeast Queensland) showed trap catches resuming in mid-September (Cowley et al. 1990). In Adelaide (South Australia) Qfly trap catches start in late October to early November (Maelzer 1990, Maelzer et al. 2004), but this may reflect the phenology of invading populations rather than spring increase in the ability to trap local fruit flies.

In conclusion, it seems unlikely that an Auckland winter would be sufficiently cold to prevent persistence of a Queensland fruit fly population. However, if a population had persisted in Grey Lynn, Auckland through the 2015 winter there would have been little incidence of mating and

relatively low trap efficacy until October–November. Nevertheless, if it had been present Qfly should have been detectable in traps over the spring leading up to declaration of eradication in December.

ACKNOWLEDGEMENTS

This work arose from stimulating discussions with Alan Flynn and Dave Voice of MPI. All meteorological data were collected and supplied by NIWA. Pip Gerard, Federico Tomasetto, Alan Flynn, Dave Voice, George Gill, Tom Batchelor and an anonymous reviewer gave useful feedback on the draft manuscript. The research was co-funded by MPI and by AgResearch's contribution to the Better Border Biosecurity (B3) collaboration (b3nz.org).

REFERENCES

- Acosta H, White P 2011. Atlas of Biosecurity Surveillance, 2011 May. Ministry of Agriculture and Forestry, Wellington, New Zealand.
- Aguilar G, Blanchon D, Foote H, Pollonais C, Mosee A 2015. Queensland fruit fly invasion of New Zealand: Predicting area suitability under future climate change scenarios. Unitec ePress Perspectives in Biosecurity Research Series 2. Retrieved from <http://www.unitec.ac.nz/epress/>.
- Bale JS, Hayward SAL 2010. Insect overwintering in a changing climate. *Journal of Experimental Biology* 213: 980–994.
- Clarke AR, Powell KS, Weldon CW, Taylor PW 2011. The ecology of *Bactrocera tryoni* (Diptera: Tephritidae): what do we know to assist pest management? *Annals of Applied Biology* 158: 26–54.
- Cowley JM, Page FD, Nimmo PR, Cowley DR 1990. Comparison of the effectiveness of two traps for *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) and implications for quarantine surveillance systems. *Australian Journal of Entomology* 29: 171–176.
- Fletcher BS 1979. The overwintering survival of adults of the Queensland fruit fly, *Dacus tryoni*, under natural conditions. *Australian Journal of Zoology* 27: 403.
- Kean JM 2013. How accurate are methods for predicting phenology in New Zealand? *New Zealand Plant Protection* 66: 124–131.
- Kriticos D 2012. Regional climate-matching to estimate current and future sources of biosecurity threats. *Biological Invasions* 14: 1533–1544.
- Maelzer DA 1990. Fruit-fly outbreaks in Adelaide, S.A., from 1948–49 to 1985–86. II. The phenology of both pestilent species. *Australian Journal of Zoology* 38: 555–572.
- Maelzer DA, Bailey PT, Perepelicia N 2004. Factors supporting the non-persistence of fruit fly populations in South Australia. *Australian Journal of Experimental Agriculture* 44: 109–126.
- Meats A 1976a. Seasonal trends in acclimatization to cold in the Queensland fruit fly (*Dacus tryoni*, Diptera) and their prediction by means of a physiological model fed with climatological data. *Oecologia* 26: 73–87.
- Meats A 1976b. Developmental and long-term acclimation to cold by the Queensland fruit-fly (*Dacus tryoni*) at constant and fluctuating temperatures. *Journal of Insect Physiology* 22: 1013–1019.
- Meats A 1976c. Thresholds for cold-torpor and cold-survival in the Queensland fruit fly, and predictability of rates of change in survival threshold. *Journal of Insect Physiology* 22: 1505–1509.
- Meats A 1981. The bioclimatic potential of the Queensland fruit fly, *Dacus tryoni*, in Australia. *Proceedings of the Ecological Society of Australia* 11: 151–161.
- Meats A, Fay HAC 2000. Distribution of mating frequency among males of the Queensland fruit fly, *Bactrocera tryoni* (Froggatt), in relation to temperature, acclimation and chance. *General and Applied Entomology* 29: 27–30.
- MPI 2015. Fruit fly eradicated from Auckland and restrictions lifted. Ministry for Primary Industries press release, 4 December 2015. <http://www.mpi.govt.nz/news-and-resources/media-releases/fruit-fly-eradicated-from-auckland/>

- eradicated-from-auckland-and-restrictions-lifted/
- Muthuthantri S, Maelzer DA, Zalucki MP, Clarke AR 2010. The seasonal phenology of *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae) in Queensland. Australian Journal of Entomology 49: 221–233.
- Peacock L, Worner SP 2006. Using analogous climates and global insect distribution data to identify potential sources of new invasive insect pests in New Zealand. New Zealand Journal of Zoology 33: 141–145.
- Reynolds OL, Dominiak BC, Orchard BA 2010. Pupal release of the Queensland fruit fly, *Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae), in the sterile insect technique: seasonal variation in eclosion and flight. Australian Journal of Entomology 49: 150–159.
- Roberts RM 1978. Seasonal strategies in insects. New Zealand Entomologist 6: 350–356.
- Tychsen PH 1978. Mating behaviour of the Queensland fruit fly, *Dacus tryoni* (Diptera: Tephritidae), in field cages. Australian Journal of Entomology 16: 459–465.
- Weldon CW, Perez-Staples D, Taylor PW 2008. Feeding on yeast hydrolysate enhances attraction to cue-lure in Queensland fruit flies, *Bactrocera tryoni*. Entomologia Experimentalis et Applicata 129: 200–209.
- Yonow T, Sutherst RW 1998. The geographical distribution of the Queensland fruit fly, *Bactrocera (Dacus) tryoni*, in relation to climate. Australian Journal of Agricultural Research 49: 935–954.
- Yonow T, Zalucki MP, Sutherst RW, Dominiak BC, Maywald GF, Maelzer DA, Kriticos DJ 2004. Modelling the population dynamics of the Queensland fruit fly, *Bactrocera (Dacus) tryoni*: a cohort-based approach incorporating the effects of weather. Ecological Modelling 173: 9–30.