Climate and Mediterranean Fruit Fly Invasion Persistence: Insights from Agent-Based Simulations

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Outline

Outline

Recurrent “Finds” of Medfly in Free Areas

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Research

From trickle to flood: the large-scale, cryptic invasion of California by tropical fruit flies

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Tephritidae, invasion biology, subdetectable populations, eradication

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Since 1954, when the first tropical tephritid fruit fly was detected in California, a total of 17 species in four genera and 11 386 individuals (adults/larvae) have been detected in the state at more than 3348 locations in 330 cities. We conclude from spatial mapping analyses of historical capture patterns and modelling that, despite the 250+ emergency eradication projects that have been directed against these pests by state and federal agencies, a minimum of five and as many as nine or more tephritid species are established and widespread, including the Mediterranean, Mexican and oriental fruit flies, and possibly the peach, guava and melon fruit flies. We outline and discuss the evidence for our conclusions, with particular attention to the incremental, chronic and insidious nature of the invasion, which involves ultra-small, barely detectable populations. We finish by considering the implications of our results for invasion biology and for science-based invasion policy.

1. Introduction

Tropical fruit flies (Tephritidae), such as the Mediterranean fruit fly (*Ceratitis capitata*) from Africa, the oriental fruit fly (*Bactrocera dorsalis*) from Asia and the Mexican fruit fly (*Anastrepha ludens*) from the Americas, are recognized by entomologists as among the most destructive agricultural insect pests in the world [1,2]. Because of tephritids’ economic importance, US states such as California—considered by both the US Department of Agriculture (USDA) and the California Department of Food and Agriculture (CDFA) to be free of these pests, but with climates favourable to their establishment—invest heavily in measures to keep tephritids from becoming established. These steps include restricting importation of commodities that originate in regions with ongoing tephritid outbreaks, requiring post-harvest treatments for imported fruits and vegetables grown in areas where the pests are endemic or established, maintaining large-scale monitoring programmes for early detection, supporting preventive release programmes of sterile flies to pre-empt establishment, and launching eradication campaigns to eliminate pest populations once discovered.

Recurrent “Finds” of Medfly in Free Areas

Question: How long to maintain Quarantine?

NYT Retro Report

Specific Possibilities

PC Magazine Feb/Mar 1982

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Specific Possibilities

Why?

- Fly biology varies
- Outbreaks vary
- Response varies
- Time/location $\implies$ variation in climate/weather

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We will use our model of invasive Medfly outbreaks to play out millions of "what ifs"

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Thermal Unit Accumulation Model

QL: 3 generations of Degree-day (^oD) development

- Min and max temperature for development to occur (T_{min}, T_{max})
- 1^oD = 24 h with the temperature 1 ^{o} above T_{min}
- Each stage will have a required amount of ^oD for transition to the next stage

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^oD threshold from laboratory studies:

$$\frac{1}{d} = a + bT$$

d = developmental time in days
T = constant temperature
a = developmental rate at 0 ^oC
b = slope
$T_{min} = -a/b$
$K = 1/b$ = Length of time for stage transition

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A Bottom-Up Simulation

A computer simulation of a complex system

- Representations of unique, autonomous individuals (“Agents”)
- Closed-form solutions for all behaviors/relations are not necessary
- Observe emergent behavior of a collection of agents

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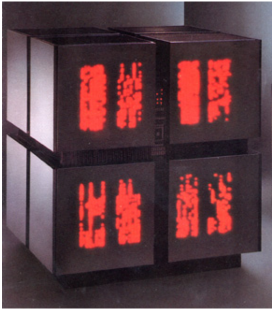

Connection Machine ∼1987, Thinking Machines Corp

Key Differences Between ABS and Degree-Day

Degree Day

- Requires few parameters
- Calculation is quick
- Three generation approach seems to work

ABS

- Demographically explicit
- More realistic (e.g. mortality)/ specific
- Stochastic
- Extreme flexibility, extensible

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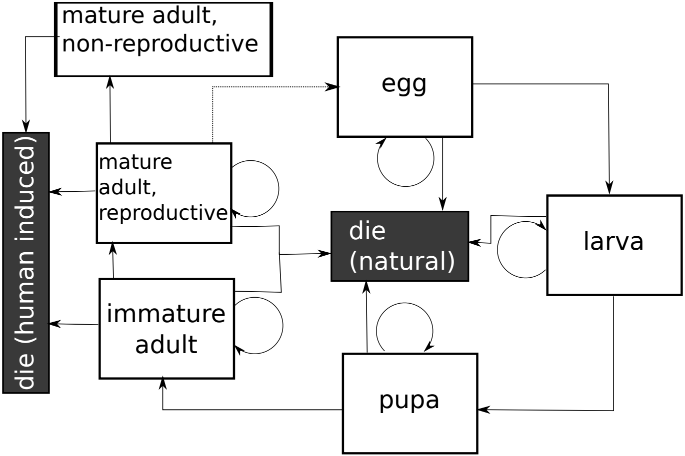
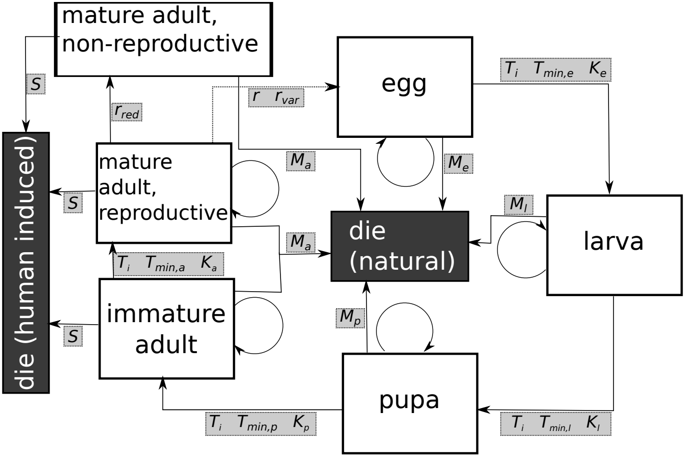
Medfly Agent Life Cycle



Medfly Agent Life Cycle



Principal Simulation Parameters: the Inputs

Key Input: Hourly temperature data (T)

Input parameter	Symbol	Input parameter	Symbol
Initial population size	N_0	Reproductive output	r
Daily mortality	M_x	Reproductive variance	r_{var}
Base temperature	$T_{min,x}$	Sterilization rate	r_{red}
Thermal constant	K_x	Human induced mortality	S
Developmental model	Dm	Time to countermeasures	t_S
Variation in development rate	γ	Initial age distribution	NA

Initialization

Simulation is *demographically explicit*; it needs numbers of individuals

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Development

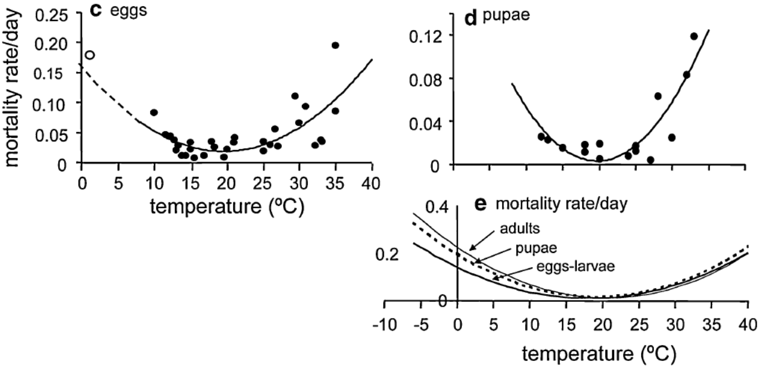
for all $T_i < T_{max}$, When

$$C + \gamma < \sum_{t=0}^{i} T_i - T_{min}$$

stage transition occurs.

i = current time
C = stage-specific thermal units needed for transition to next stage
γ = individual variation in development time

Mortality



From Gutierrez & Ponti (2011)

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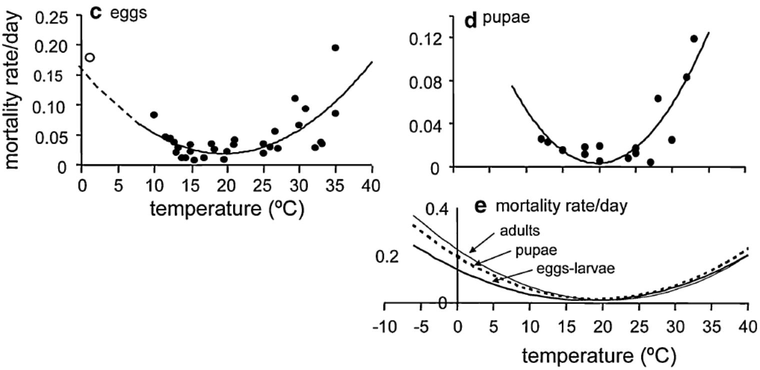

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$$\mu_{e,l} = 0.00040T^2 - 0.0145T + 0.1314$$
$$\mu_p = 0.00050T^2 - 0.0207T + 0.2142$$
$$\mu_a = 0.00049T^2 - 0.0187T + 0.1846$$

Reproduction

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r	Mean number of eggs
r_{var}	Variance in the number of eggs
r_{red}	Reduction in reproductive flies per unit time

Parameter Value Ranges

Input parameter	Range (min-max)	References

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$T_{min,p}$	9.1–13.8	5–7
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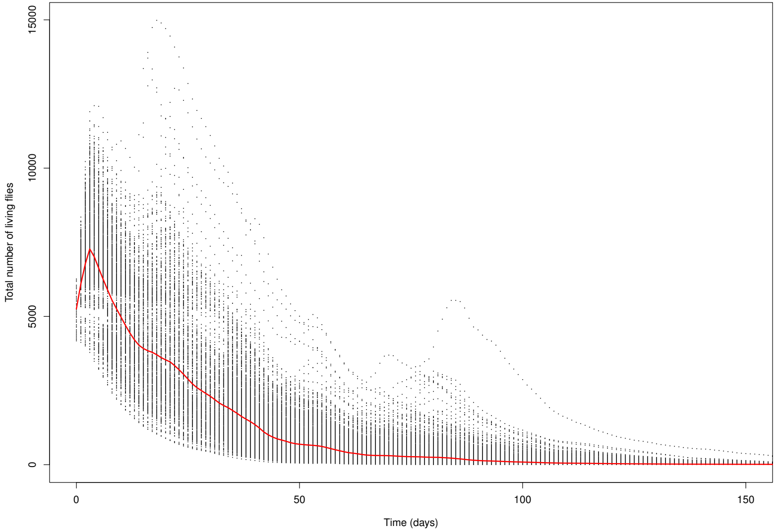
r	5.0–35.0	1,2,7,13,14–18
r_{red}	0.5–1.0	22,23

Outline

Santa Monica Outbreak

1000 simulations of 2009 outbreak, daily numbers with mean



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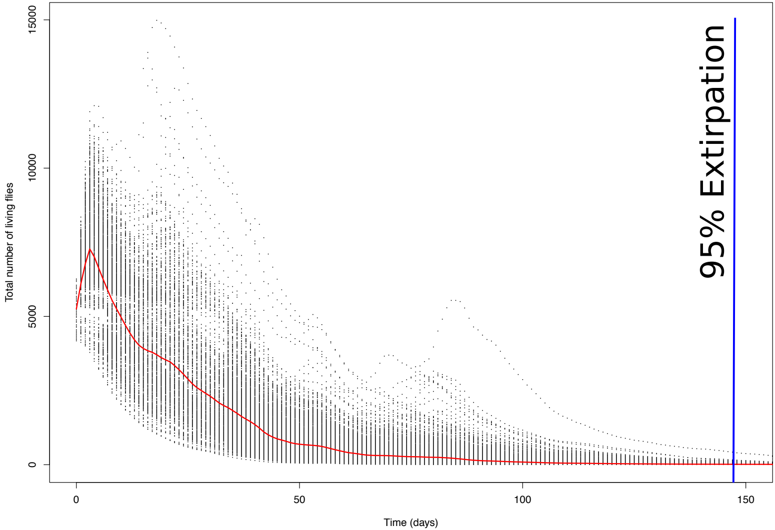

Seven Outbreaks in CA

10,000 simulations per outbreak

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Outbreak	N adults	QL (d)	$t_{0.95}$ (d)	$t_{0.95}-\text{QL}$
Santa Monica	3	297	231	-66
Fallbrook	4	273	206	-67
Spring Valley	2	204	200	-4
Imperial beach	1	145	172	+27
Mira mesa	6	166	181	+15
Escondido	7	337	167	-170
Cajon	21	245	227	-18
Total		1667	1384	-283

General Agreement

Interesting Differences in Details

- ABS within 20 d of DD in 3 of 7 outbreaks
- In one case (Imperial Beach) ABS suggests significantly longer quarantine
- ABS suggests significantly shorter quarantine in 3 of 7 cases
- In Escondido (09/2009) case, much shorter quarantine is suggested by ABS (170 d shorter!) Reason:

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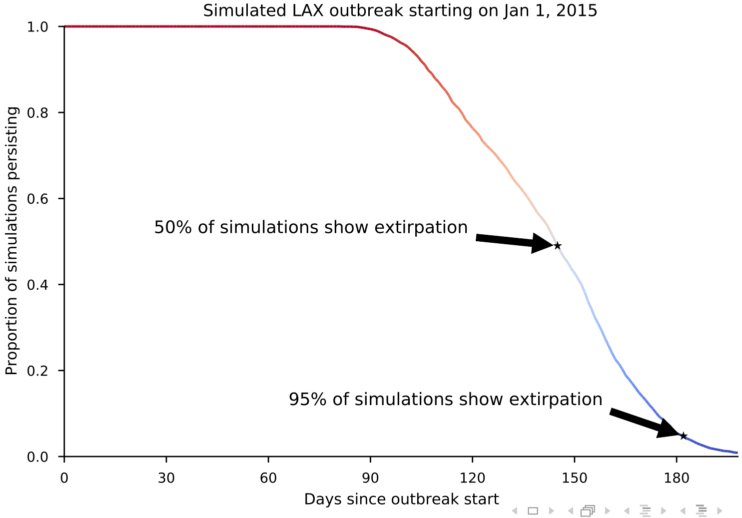
Date	Time	$T(^oC)$
11/16/09	2400	3.7
11/17/09	0100	2.4
11/17/09	0200	0.9
11/17/09	0300	0.4
11/17/09	0400	-0.3
11/17/09	0500	-0.4
11/17/09	0600	-1.1
11/17/09	0700	-0.8

Outline

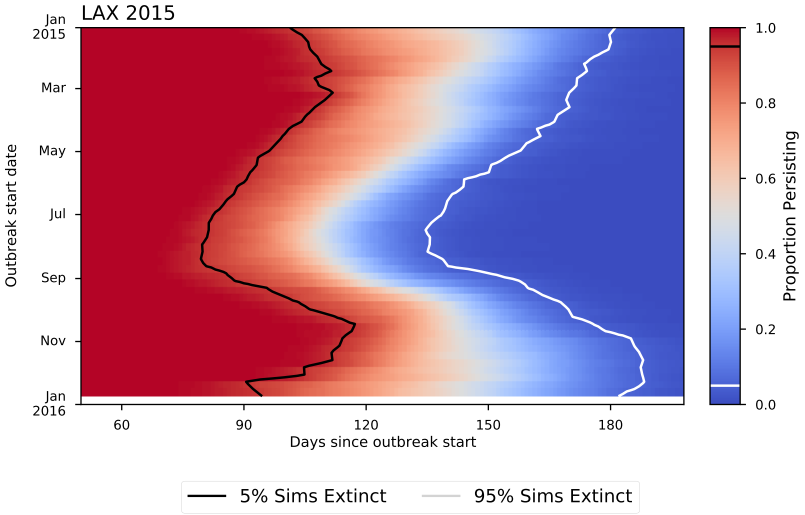
Hypothetical Single Outbreak

Visualizing 2,500 simulations with varying parameters



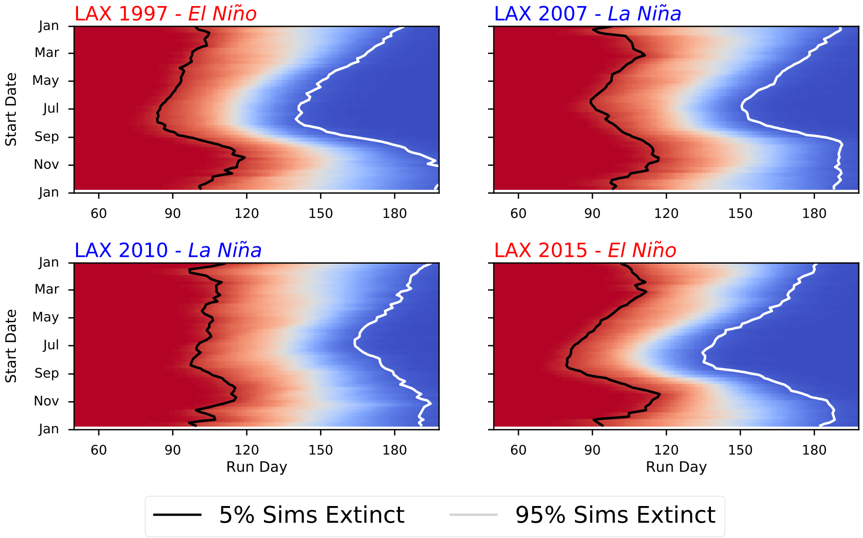
Hypothetical Outbreaks at Different Times

2,500 outbreaks starting at each week of the year



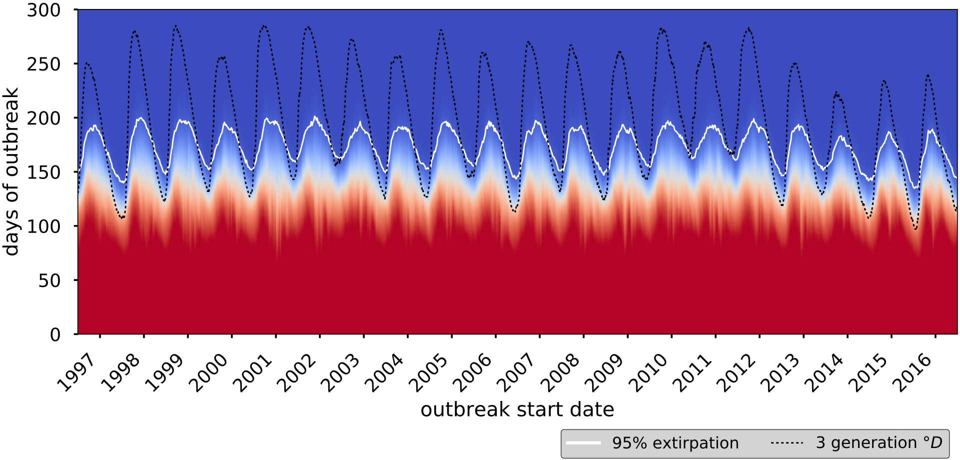
Climate Variablity

Inter-year variation



$5.2x10^6$ Simulations at Hourly Resolution

LAX - Outbreak Persistance



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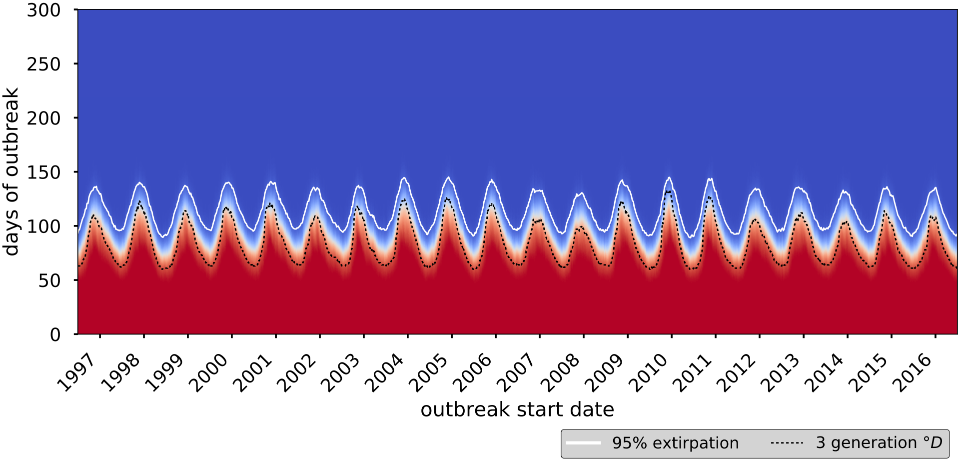

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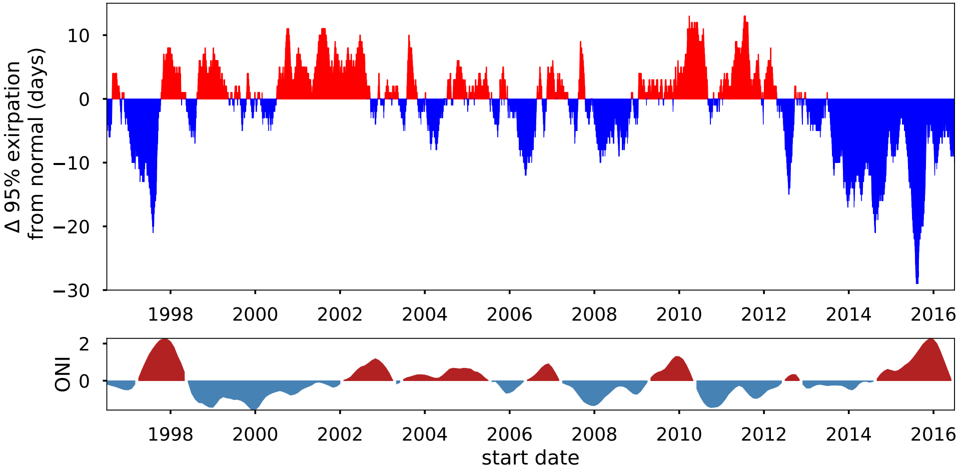
LAX - Normals and ONI



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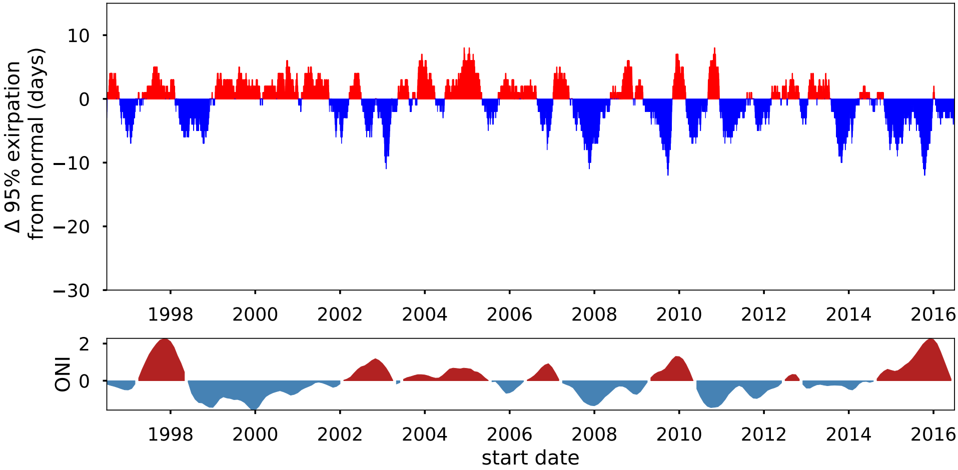

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Take-Home Message

Two outcomes to remember

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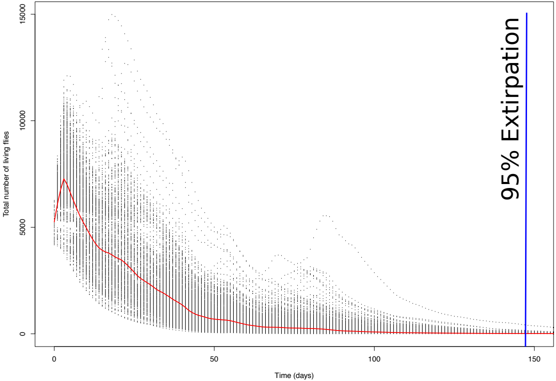
1. We simulate range of outcomes for a specific outbreak of *C. capitata*; Useful for quarantine length
2. We can ask "What if" questions across time and space to help planning



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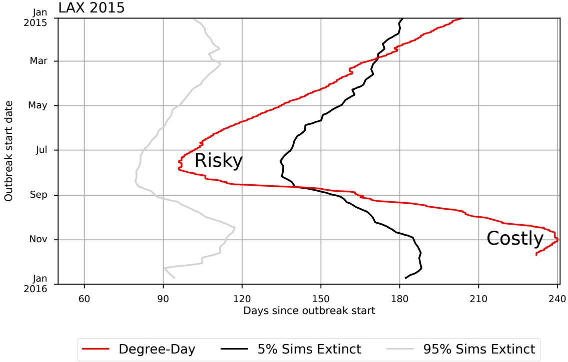

Thanks

FAO-IAEA for invitation to speak
Session Chairs: Changying Niu, Ihsan Haq

Data, program insight: Kevin Hoffman, CDFA;
Programing/Trap Model: Brian Hall

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