Estimating probabilities of extinction in environments with varying climate

John Hargrove

Using work done in collaboration with:

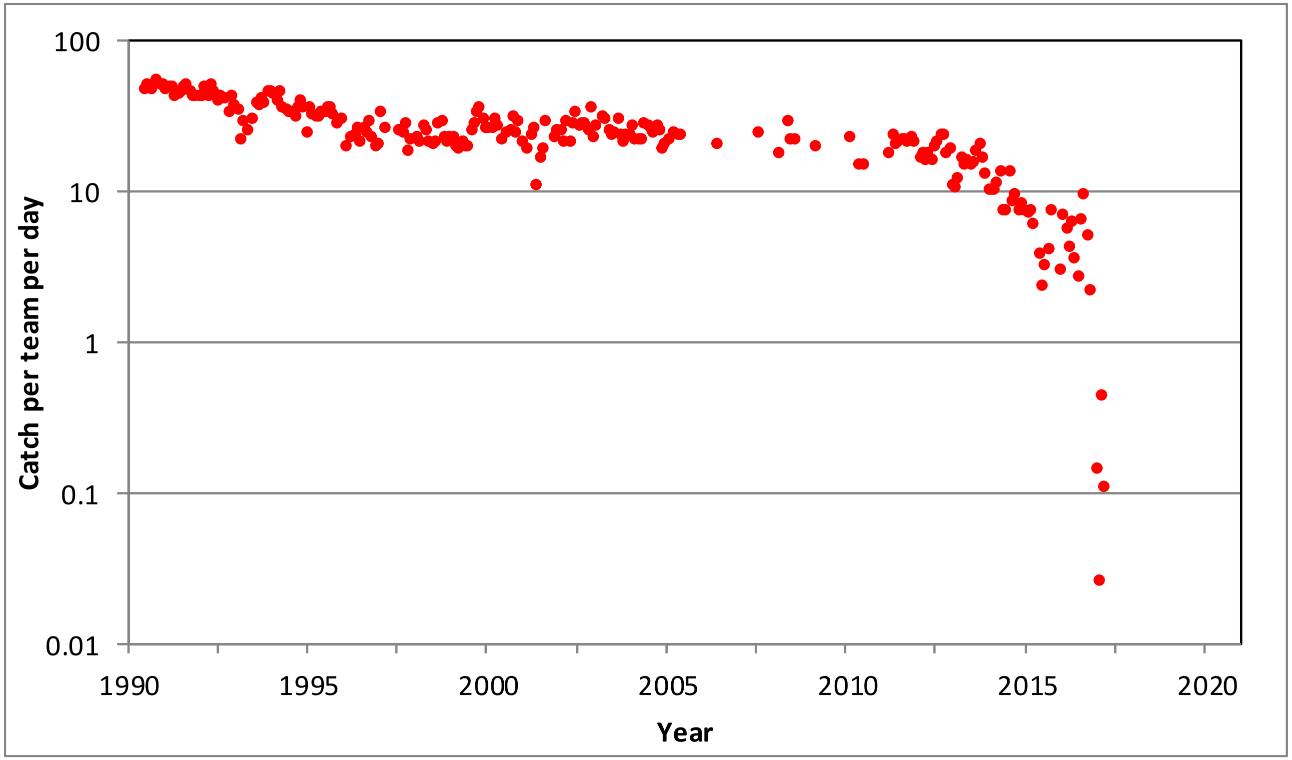
Jennifer Lord, Glyn Vale, Steve Torr, Damian Kajunguri
and Ekkehard Kopp

Goals

- To model the effects of increasing temperature on populations of tsetse flies, *Glossina pallidipes*, in the Zambezi valley of Zimbabwe
- To develop stochastic models in order to estimate the probability that the species will go extinct and, if so, when this is likely to happen
- To attempt to develop versions of these models that take account of continual changes in temperature

At Rekomitjie Research Station – from the 1970s until the present day – tsetse have been caught, by men armed with hand nets and using an ox as bait, to provide flies for bioassay testing of insecticides

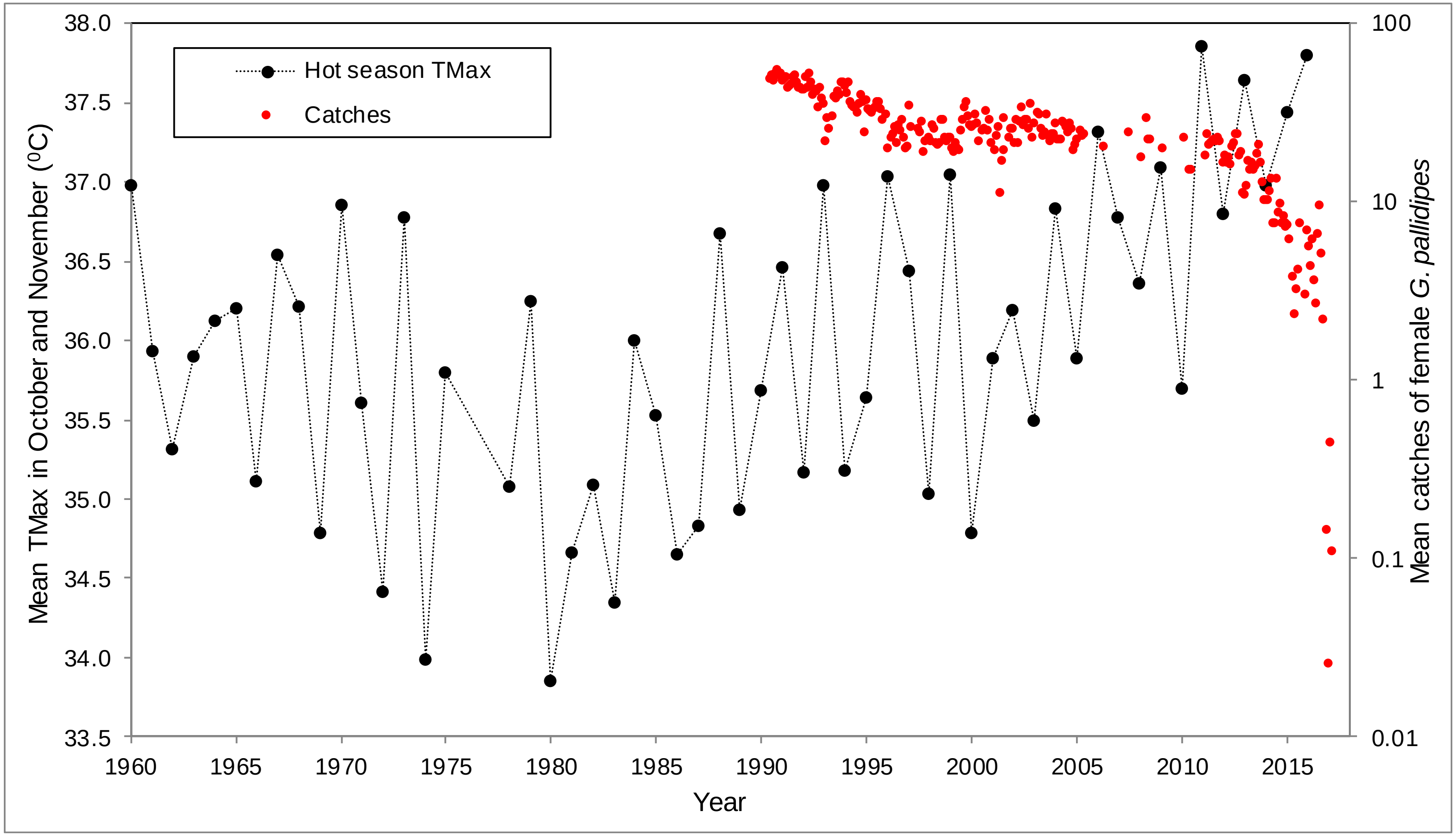
Each team is provided with about 50 collection tubes, and continues collecting each afternoon until all of the tubes are full – or the team has been out for 3 hours



Up until the end of the 1980s it was always the case that teams would fill their quota of tubes before the allotted sampling time was completed

After 1990, however, it started to become more difficult to reach the quota

The downward trend in catches has continued to the present day – and accelerated after 2010

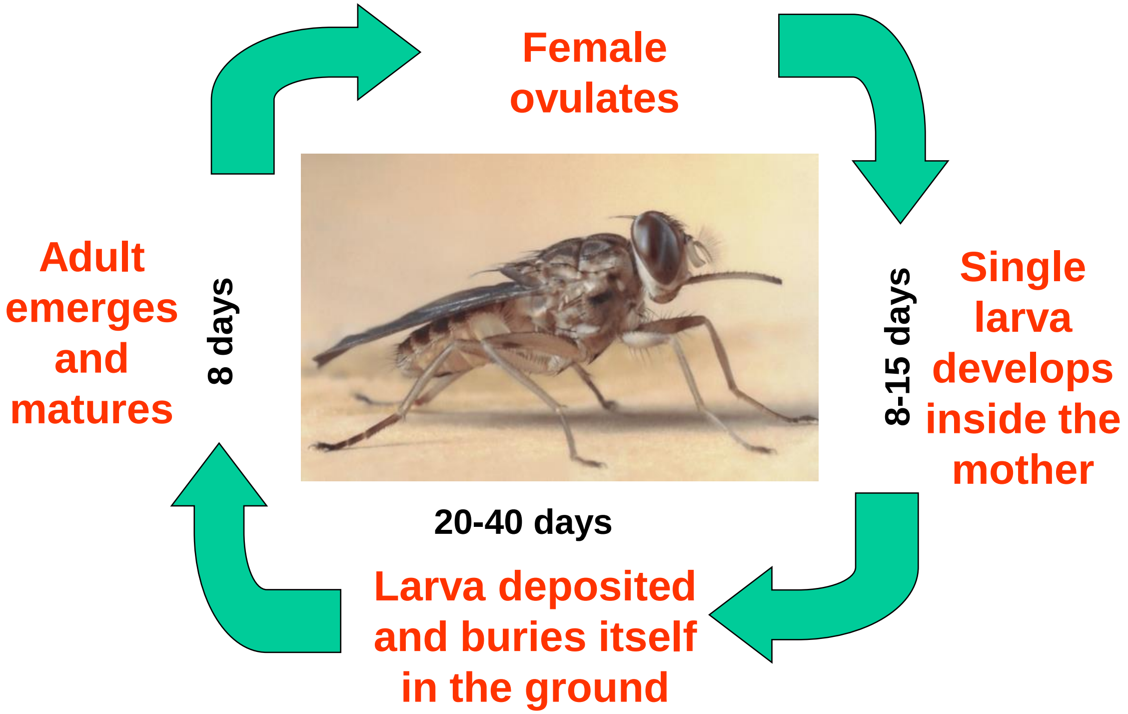


The decline in catches comes against a background of increasing temperatures

It looks as if the population is heading for extinction. But is it actually going to go extinct?

We have tried to answer this question using modelling approaches

TSETSE LIFE CYCLE



Female ovulates

8-15 days

Single larva develops inside the mother

20-40 days

Larva deposited and buries itself in the ground

8 days

Adult emerges and matures

Tsetse have a much simpler life cycle than most insects
They produce single large pupa at *c* 9-day intervals:
the pupa gives rise directly to a full-sized adult
This makes modelling population dynamics relatively easy

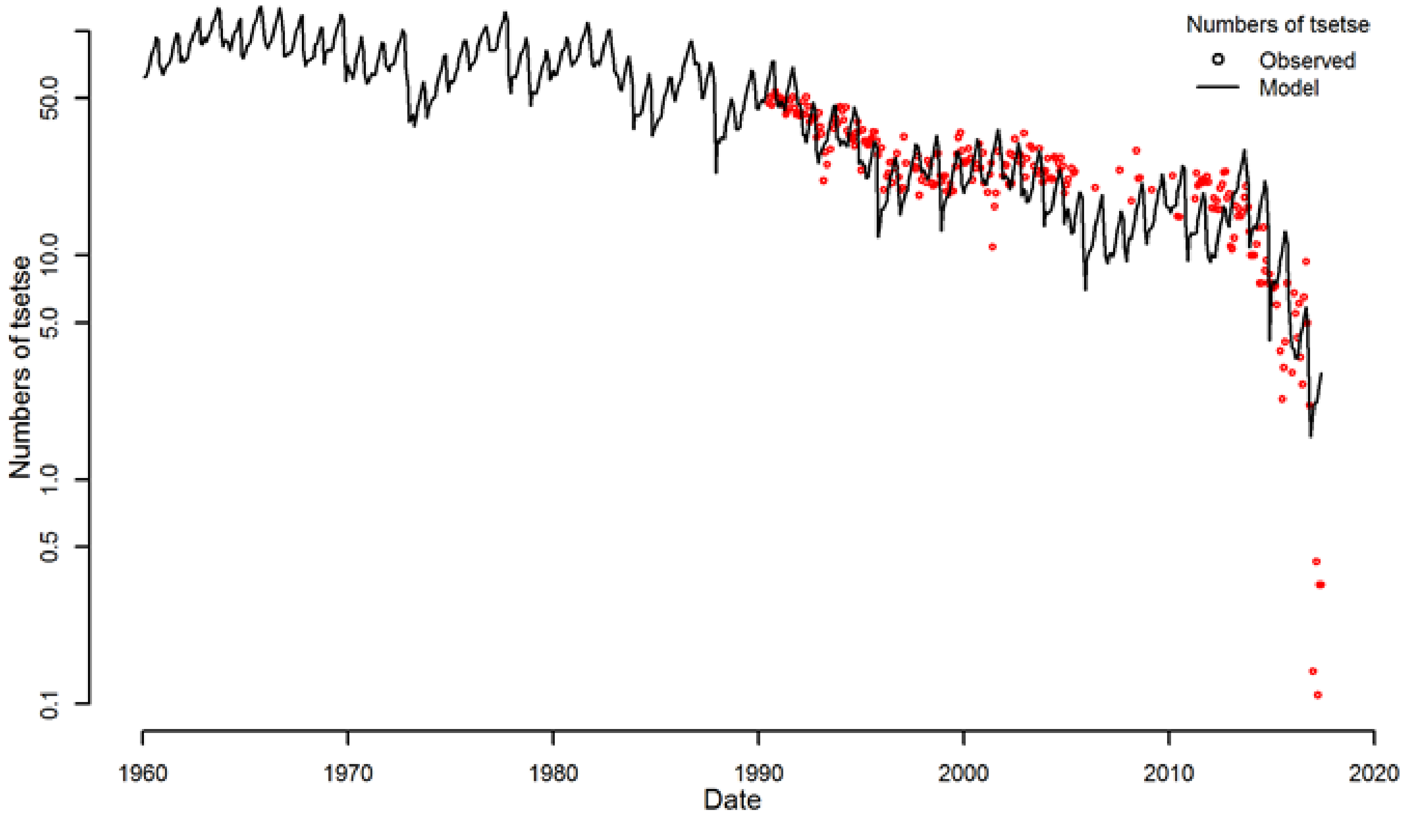
We modelled changes in the numbers of *G. pallidipes* female adults (*A*) and pupae (*P*) using two differential equations:

$$\frac{dP}{dt} = \rho(T)A - (\beta(T) + \delta P)P \qquad (1)$$

$$\frac{dA}{dt} = \beta(T)P\varphi(T) - \mu_A(T)A \qquad (2)$$

Pupae produced by adult females (*A*) at rate ρ, and die due to density-dependent mortality, with coefficient δ, and a temperature-dependent mortality, such that a proportion φ emerge

Adult females die at rate μ_A, assumed to be a function of temperature

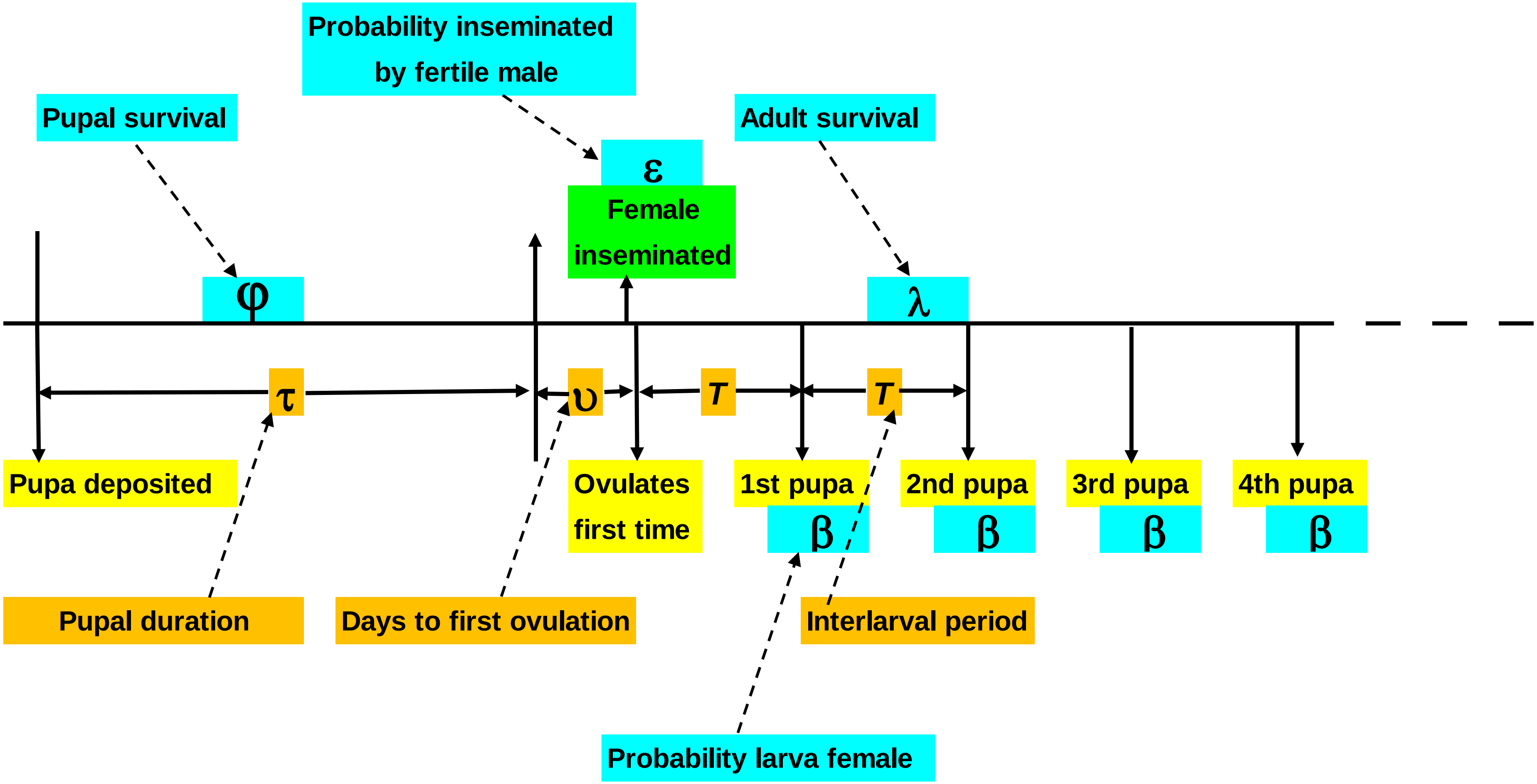


The model provides a reasonable fit to the catch data from 1990 onwards – but has problems fitting the very low catch levels

Would we *expect* to have problems when trying to fit this type of model to very low population levels? If so, what sort of problems?

Model Taxonomy

	Continuous treatment of individuals (averages, proportions, or population densities)	Discrete treatment of individuals
Deterministic	**CONTINUOUS TIME** **DISCRETE TIME**	
Stochastic	**CONTINUOUS TIME** **DISCRETE TIME**	**CONTINUOUS TIME** **DISCRETE TIME**



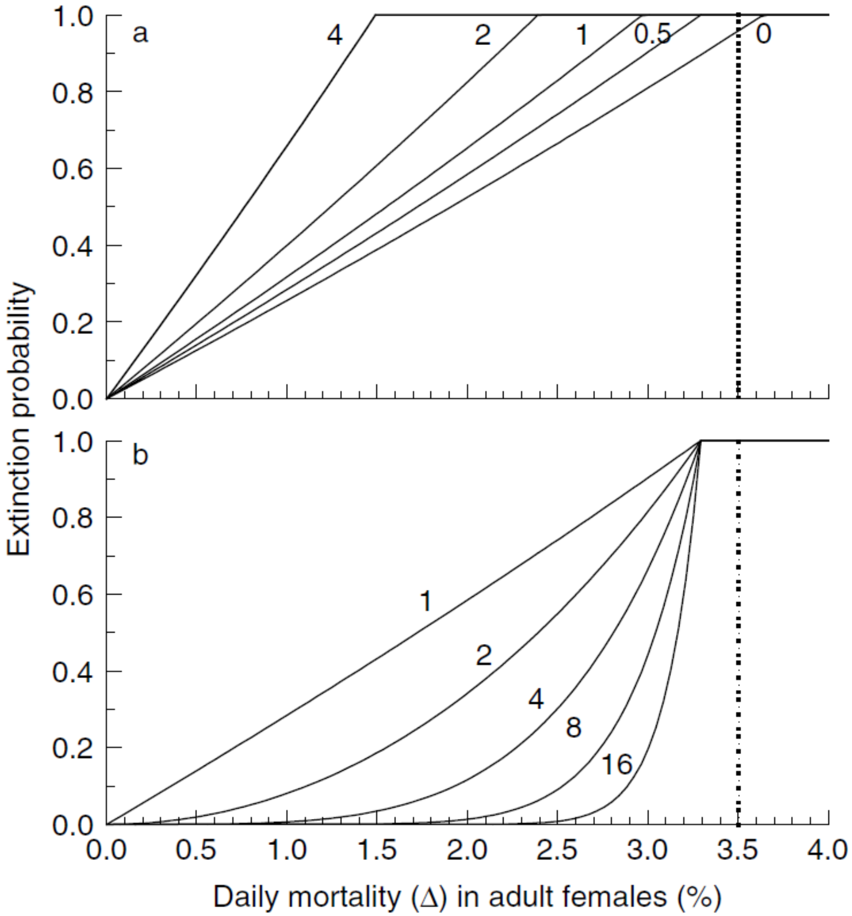
The picture above encapsulates all of the processes involved in the growth of a population of female tsetse.

Under what circumstances does such a population go extinct?

Probability of a population (species) going extinct

A population will go extinct if, and only if, every female present in the population at a given time fails to produce even a single surviving daughter

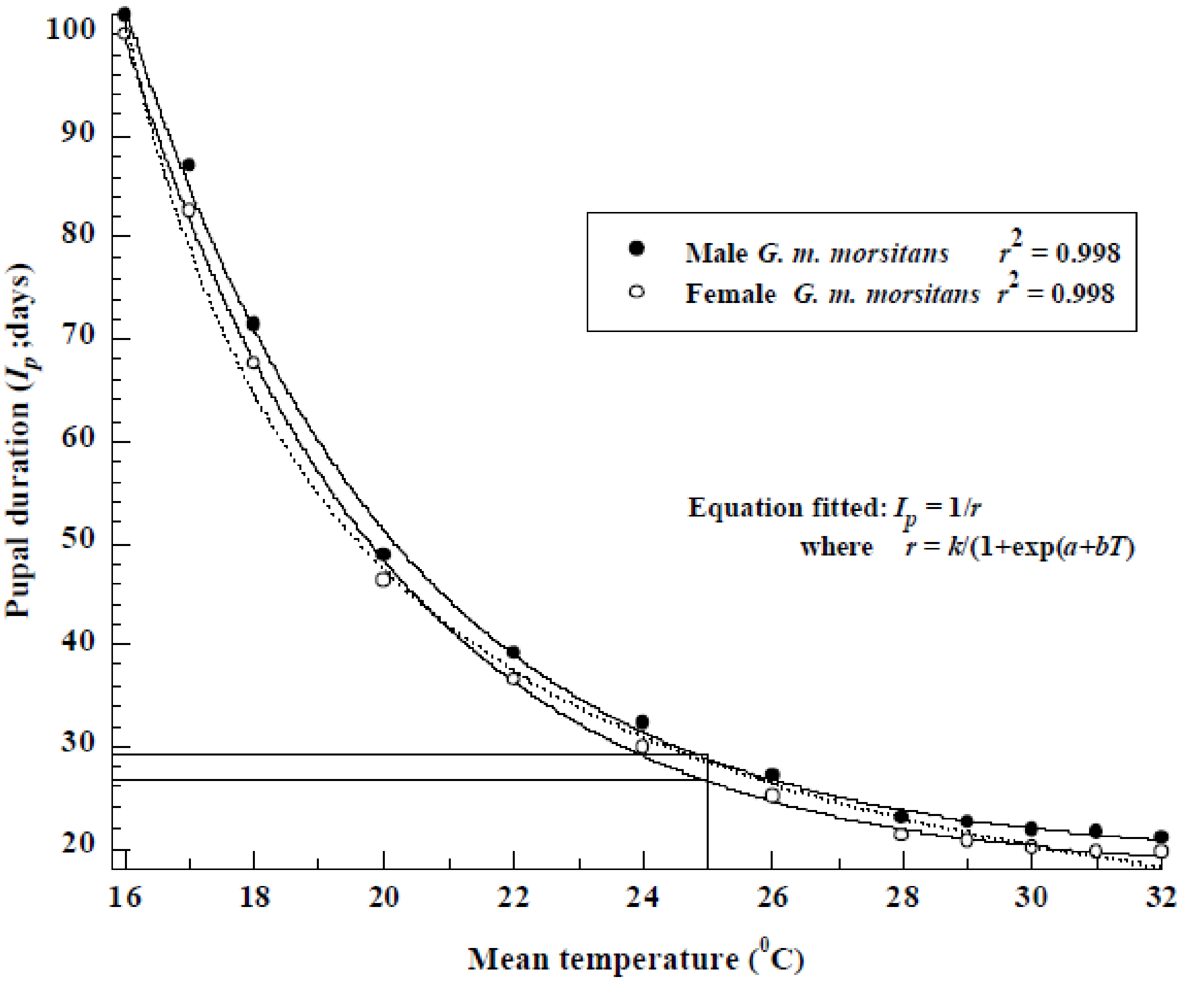
So, for the case of tsetse, we start by calculating the probability that a given female produces just a single surviving daughter at her first pregnancy



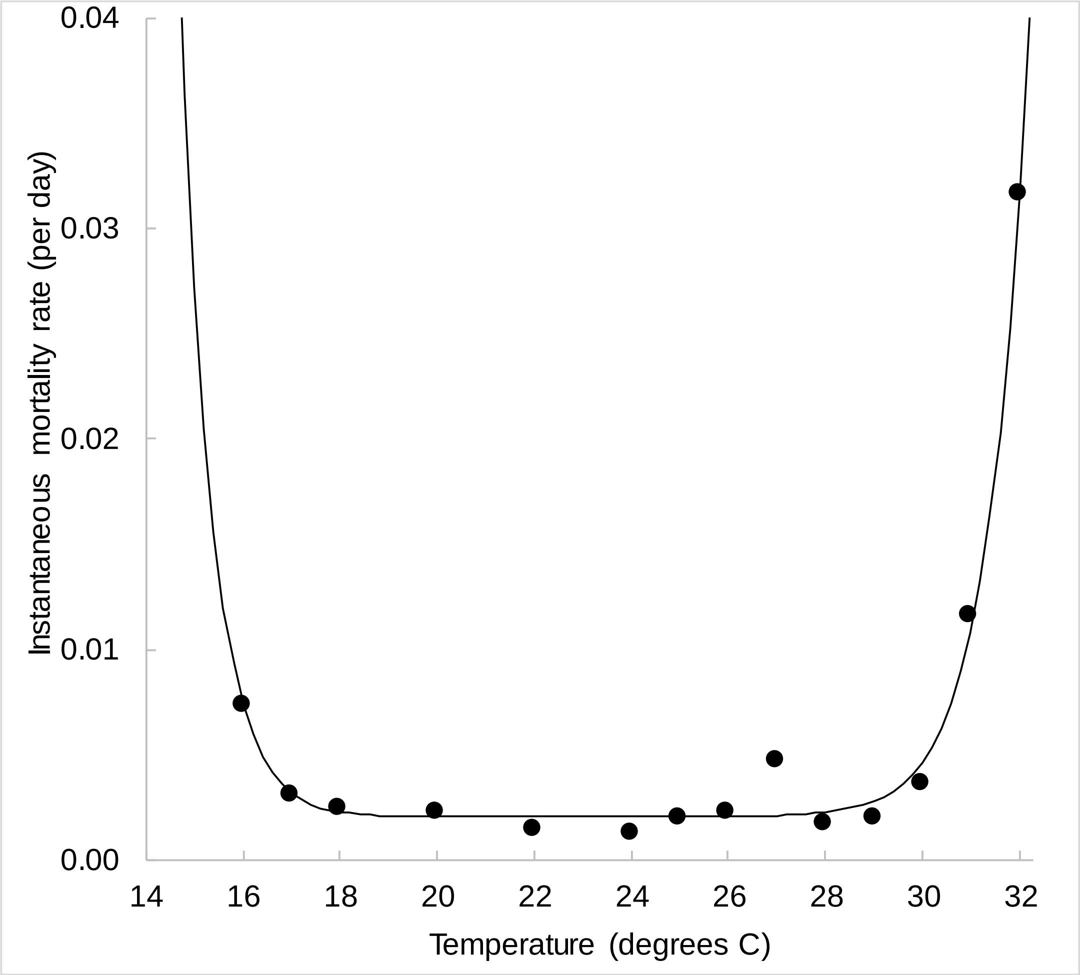
This figure shows how the extinction probability varies with adult mortality and (a) pupal mortalities for population *n* =1: (b) populations varying between 1 and 16 with a constant pupal mortality of 0.5% per day

Moving forward

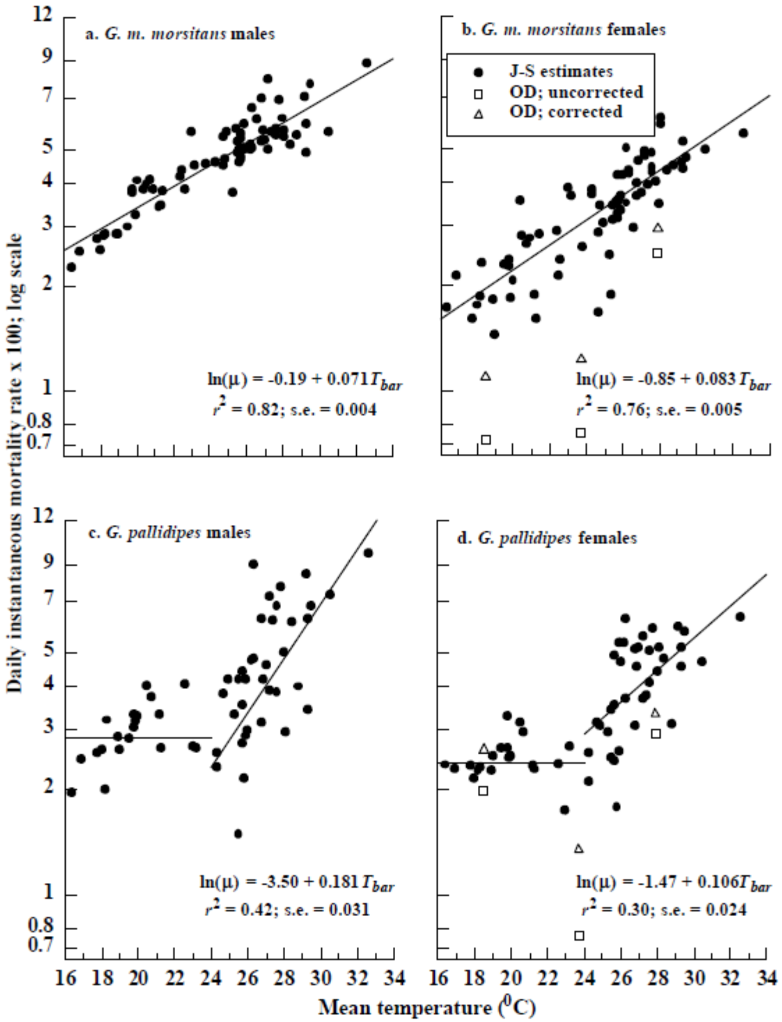
- Theoretical results presented above are all published
- Applications to tsetse assume, however, that we know what the various parameters are and that they are all fixed
- We could instead consider situations where, for example, we know the (mean) temperature profiles and use these to *estimate* the input parameters
- Important because so many things in tsetse biology are temperature dependent
- This could give information about where tsetse populations could, or could not, exist



Pupal duration at different constant lab temperatures



Pupal mortality at different constant lab temperatures



Adult mortality versus mean screen temperature

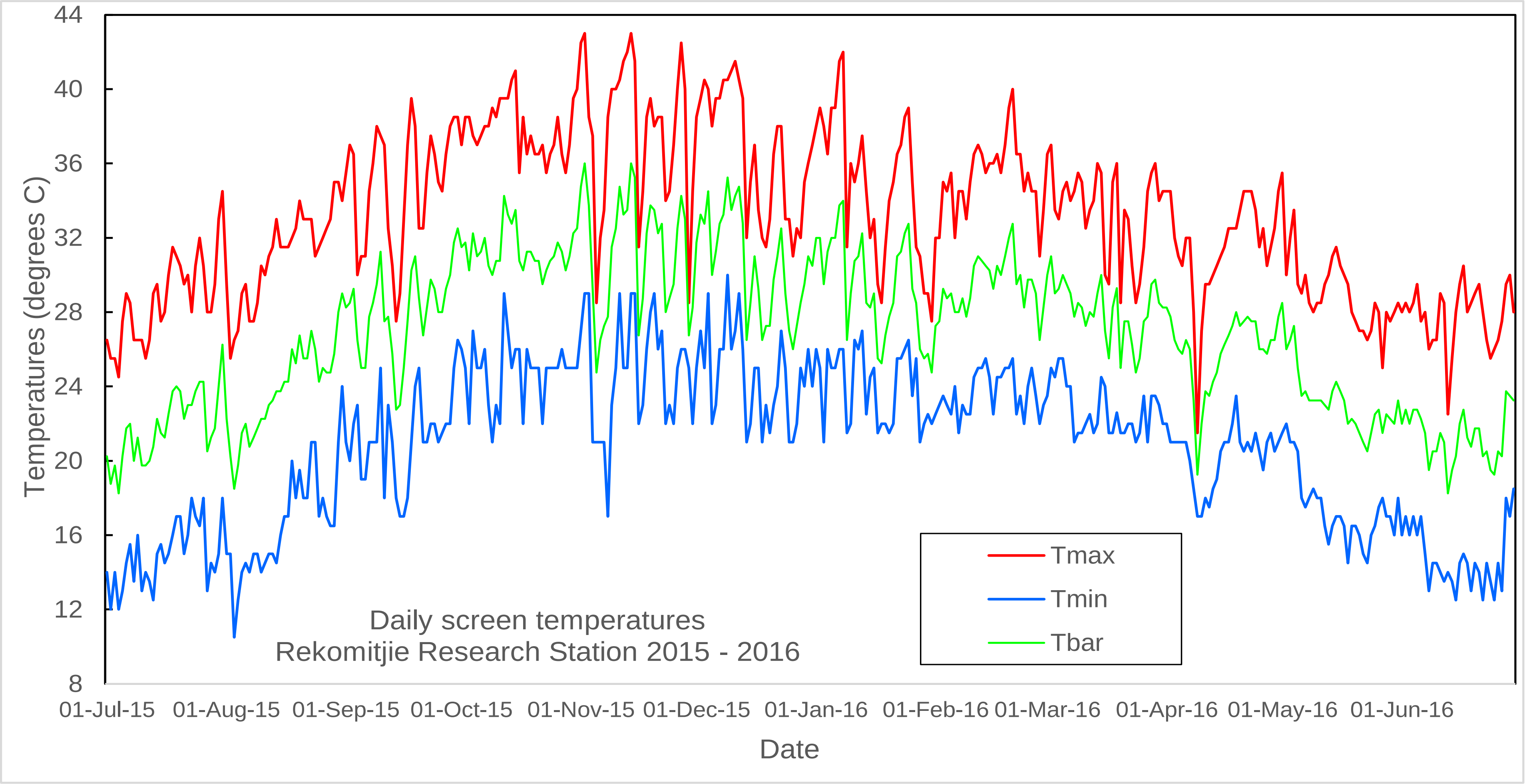
You tell me the temperature:
I'll give you the extinction probability

- Published work on extinction probability for tsetse has proceeded on the basis of calculating extinction probabilities given different combinations of input birth and mortality parameters
- We are suggesting a step removed where observed temperatures are used to *estimate* the input parameters

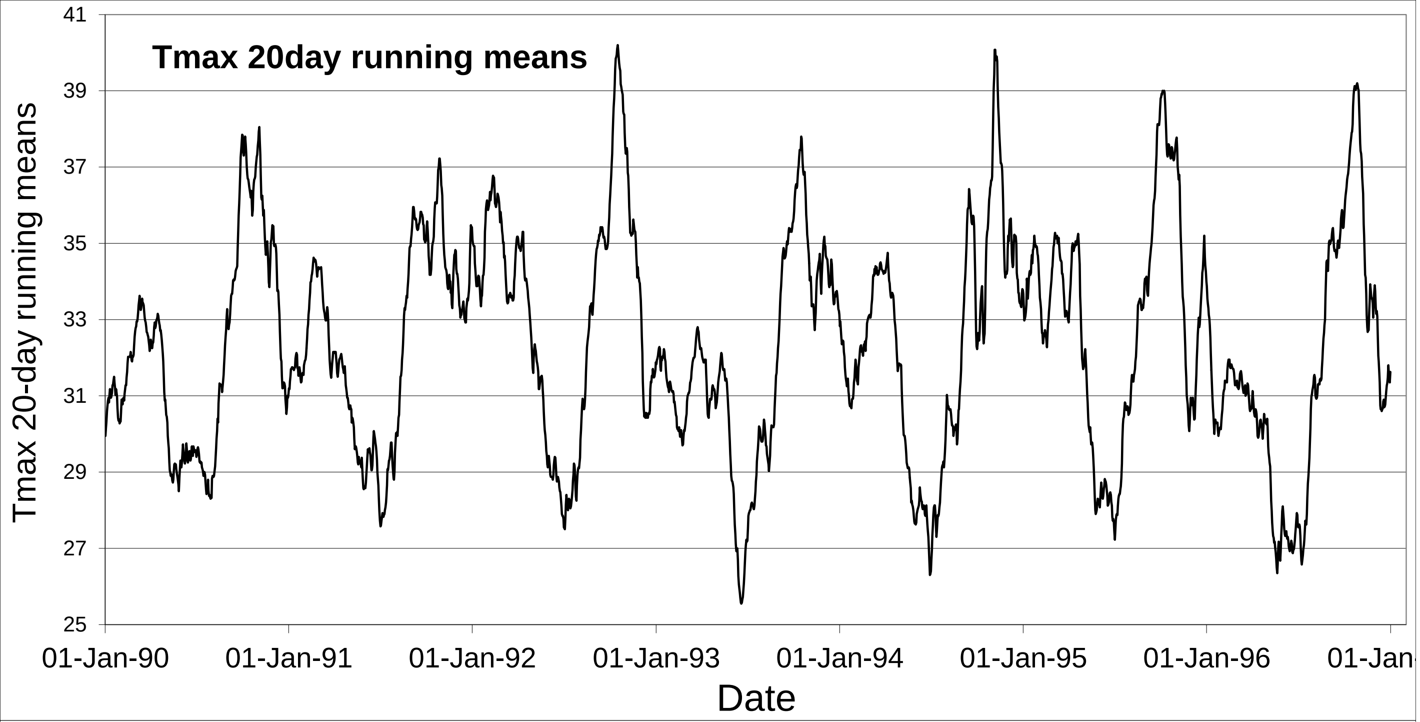
There are two problems associated with this approach:

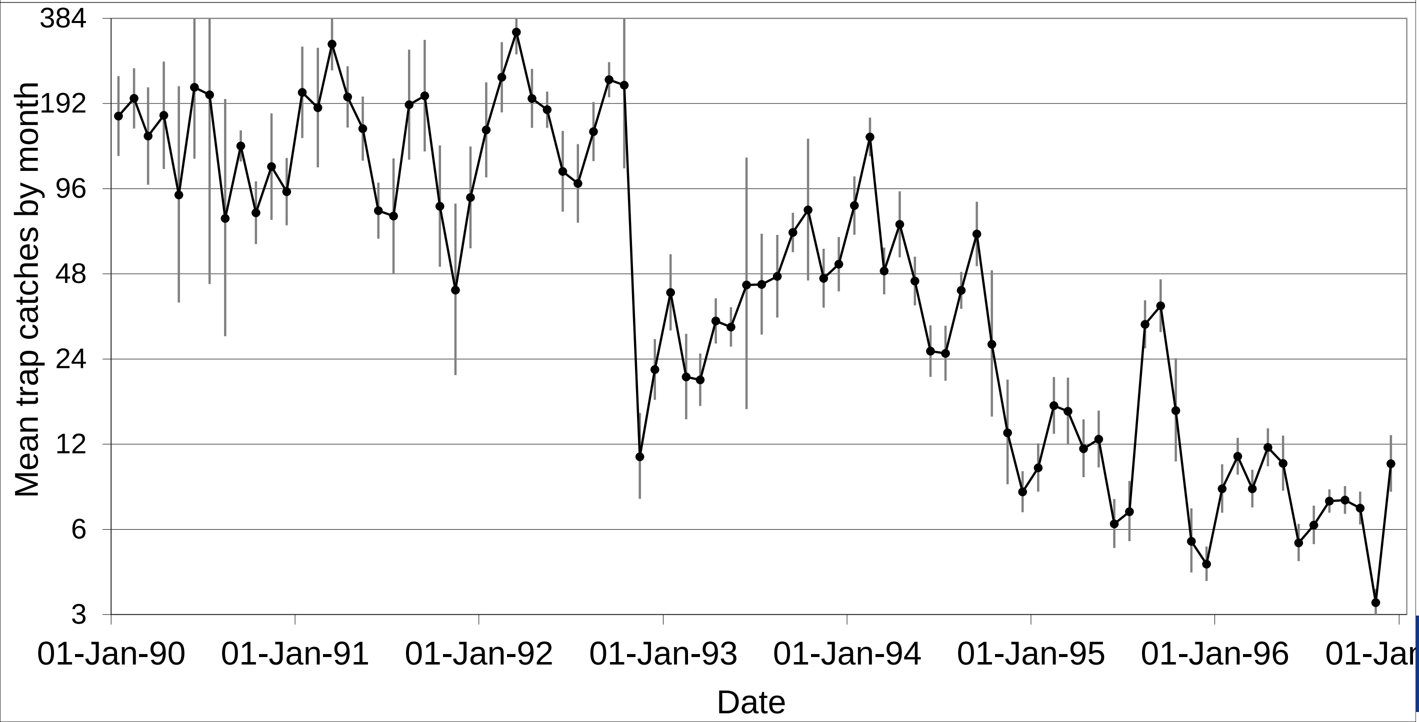
1. Temperatures are not constant over life of the fly
2. Measured temperatures will seldom reflect the temperature being experience by the flies

- This will make the calculation of extinction probabilities much more difficult



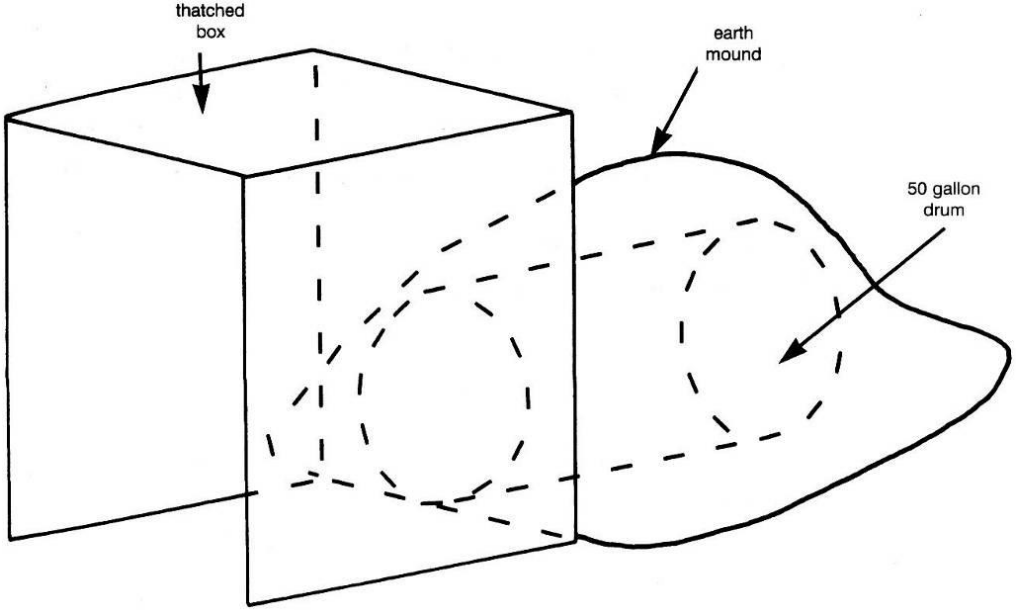
There are three aspects to the problem: (i) Even during the production of a ***single*** offspring the temperature will be changing (ii) The temperature regimes experienced during the production of ***successive*** offspring will be quite different (iii) The temperatures we measure in a Stevenson screen often bears little relation to the temperatures being experienced by a tsetse fly



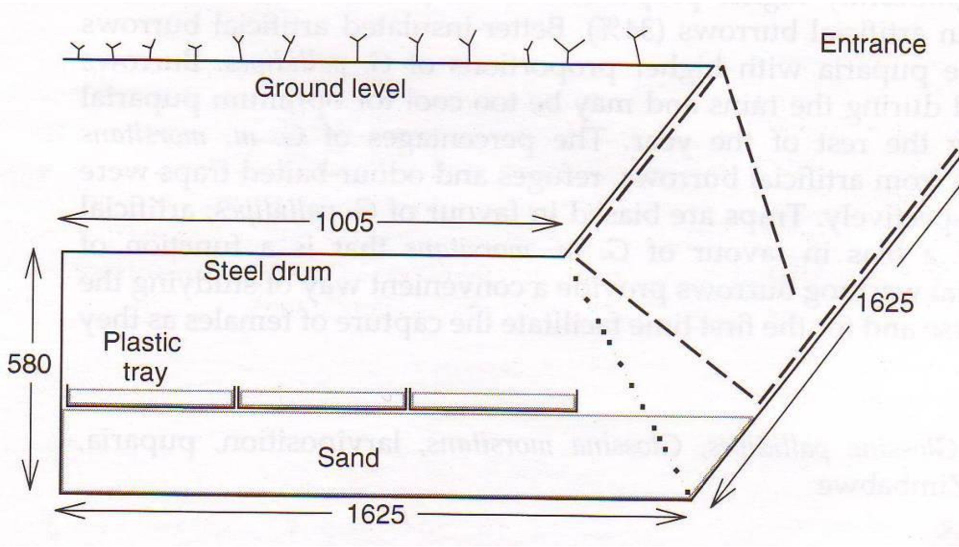


The importance of extreme events in for population dynamics demonstrated by looking at Rekomitjie trap catches during the 1990s

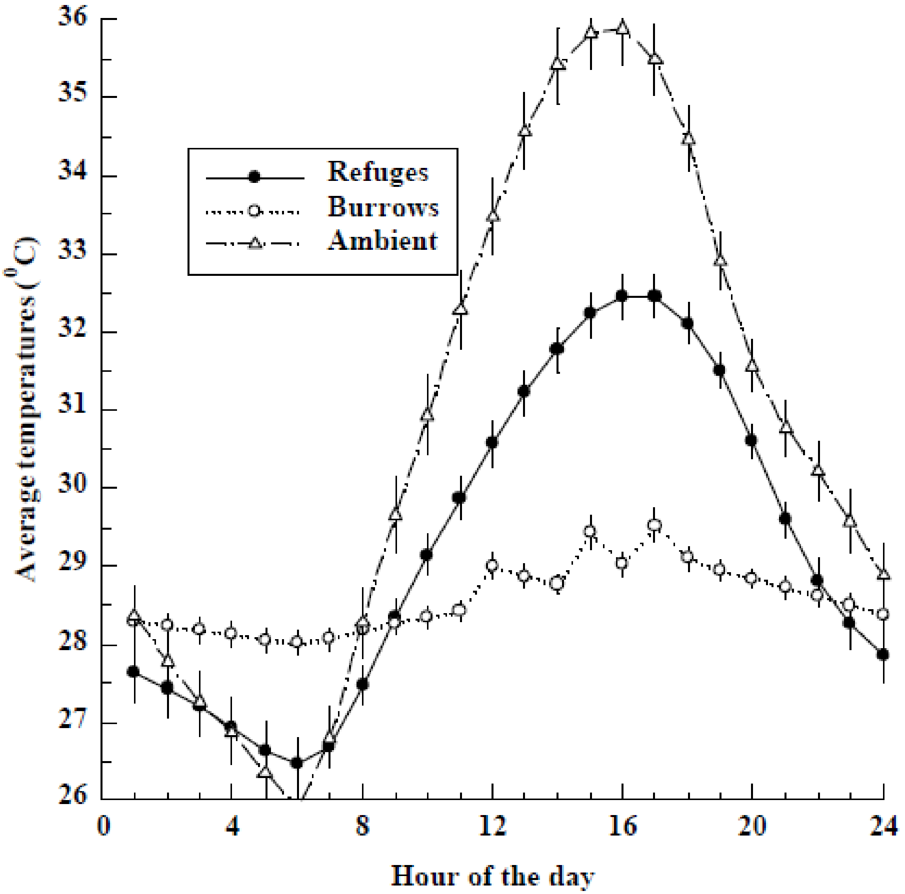
In Oct/Nov 1992 the 20-day running mean of maximum temperature approached 40^0C – for the first time since records began – and trap catches fell by >90% in a single month



When temperatures exceed 32^0C tsetse seek out dark places, which are cool. Artificial “refuges“ can be used to sample large numbers of flies in the hot dry season



In the hot dry season tsetse deposit their larvae in burrows. Artificial warthog burrows can be used to collect pupae – and also to capture females as they are about to larviposit



The day-time temperatures in "refuges" are much lower than ambient – and temperatures in burrows are even lower

Night-time temperatures in the burrows are slightly higher than ambient, and in "refuges"

Summary

- When modelling the dynamics of biological populations close to zero we need to consider stochastic processes treating individuals, and time, as discrete units
- We consider the general theory pertaining to branching processes, applying results to the particular case of tsetse
- So far such work has been restricted to situations where birth and death rates have been assumed constant
- We need to consider situations where conditions, particularly temperature, change with time – even during the life of individual flies
- For the simple situation closed form solutions are possible: it may be necessary to use numerical methods to solve the more general case