Modelling the spread, detection and control of exotic and endemic plant pests

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National Fruit Fly Council webinar, 6th September 2021

Overview

Background on the AADIS animal disease model

The APPDIS pest modelling framework

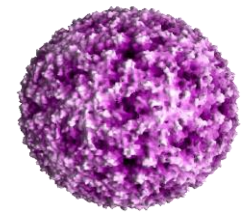
Case study 1: Oriental fruit fly

Case study 2: yellow crazy ant

Australian Government

Department of Agriculture, Water and the Environment

AADIS origins



- Department of Agriculture, Water and the Environment funded a project (2012-2015) to develop a national-scale model of emergency animal disease.

- The outcome was AADIS - an agent-based model that can simulate the introduction of virus into any herd in Australia at any time.

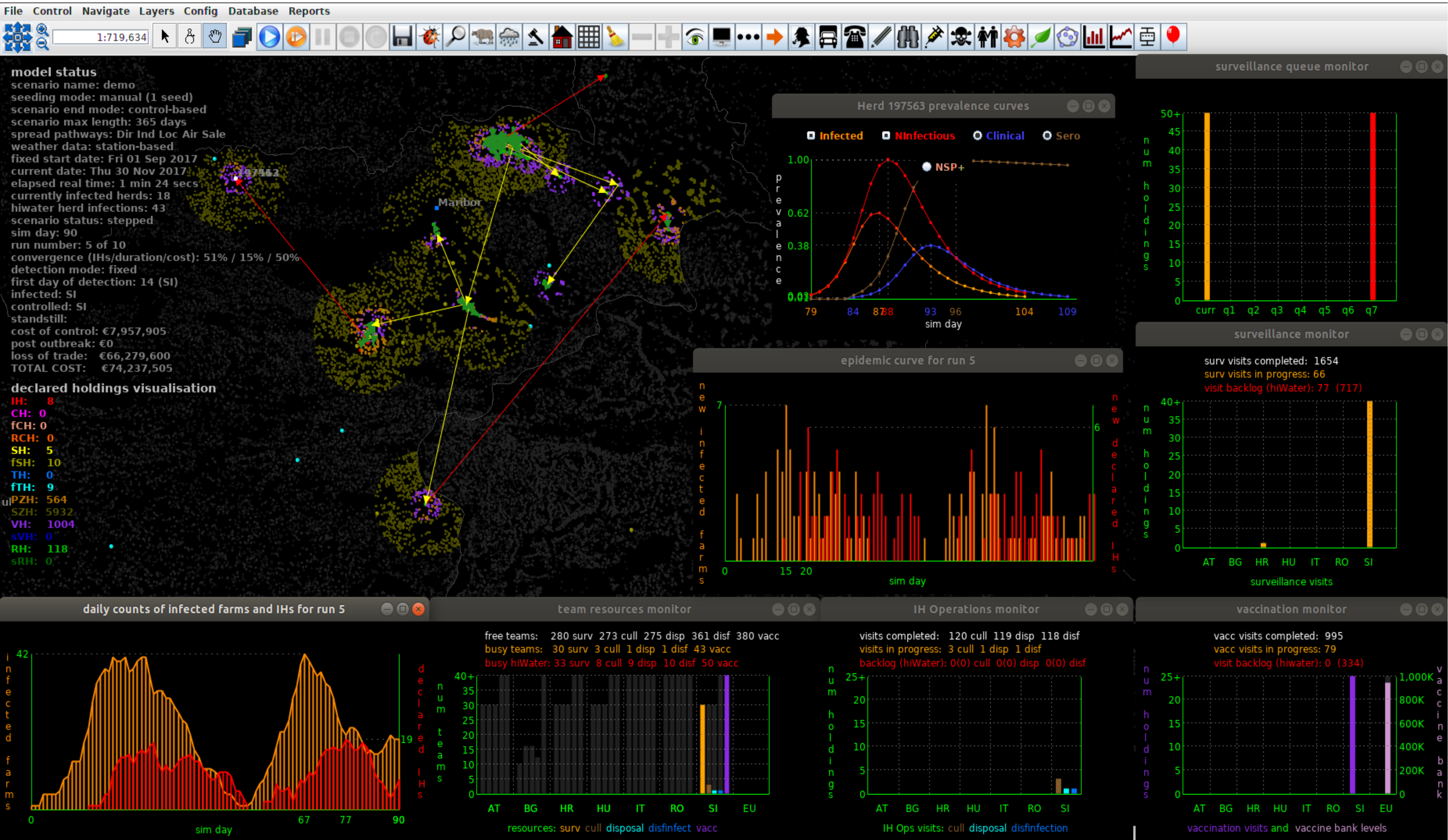
- AADIS simulates:
  -> spread
  -> detection
  -> control
  -> 'proof' of freedom
  -> resourcing & costing

- www.aadis.org.au

AADIS
AUSTRALIAN ANIMAL DISEASE SPREAD MODEL

Bradhurst et al (2015). A hybrid modelling approach to simulating foot-and-mouth disease outbreaks in Australian livestock. Frontiers in Environmental Science, 3(17).

AADIS-FMD (foot-and-mouth disease)



How might a model inform policy?

- A simulation model such as AADIS allows very specific questions to be posed:

  - what are the benefits of early detection?
  - what are the consequences of late detection?
  - what resources needed for a big outbreak?
  - how will resource shortfalls impact control?
  - are the controlled areas the right size?
  - what is the impact of illegal movements?
  - will suppressive vaccination help?

- Outbreak & policy experiments are conducted via user dials, i.e., no need for specialist model reformulation or programming.

AADIS collaborators

Australian Government
Department of Agriculture, Water and the Environment

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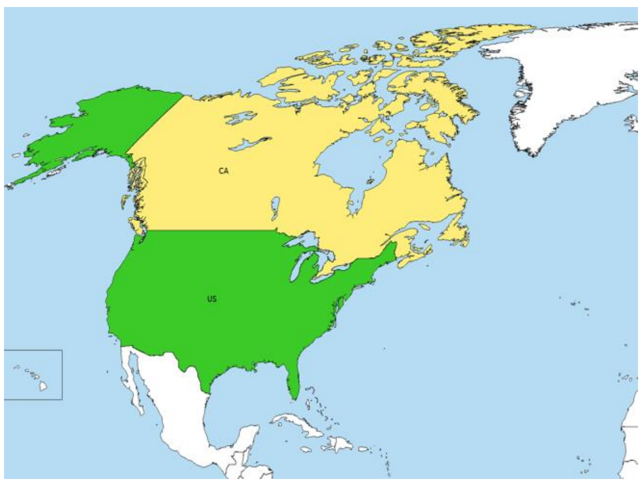
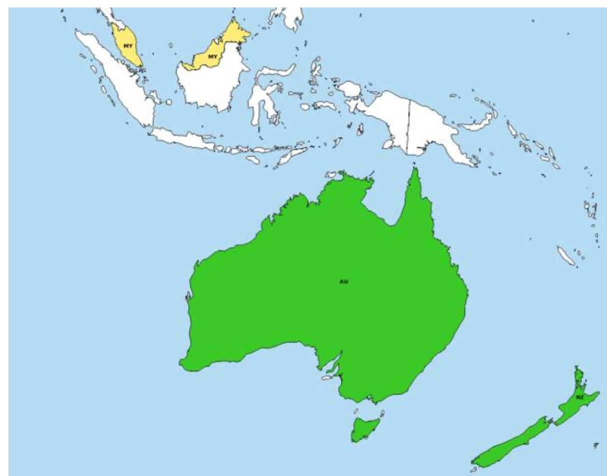
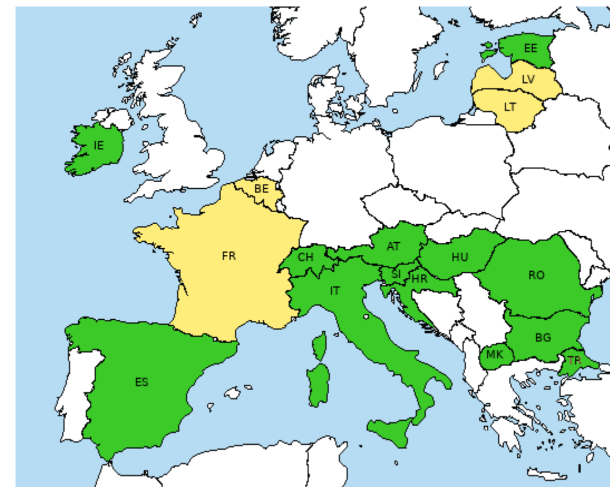






Canadian Food Inspection Agency
Agence canadienne d'inspection des aliments
Canada

Biosecurity Queensland
Queensland Government

CSIRO

Doherty Institute

AUSVET

AGRICULTURE VICTORIA

NSW GOVERNMENT
Department of Industry

eufmd
european commission for the control of foot-and-mouth disease

Ministry for Primary Industries
Manatū Ahu Matua

GOVERNMENT OF WESTERN AUSTRALIA
Department of Primary Industries and Regional Development

THE UNIVERSITY OF MELBOURNE
FACULTY OF VETERINARY & AGRICULTURAL SCIENCES

USDA
United States Department of Agriculture

UNITED NATIONS

AADIS: evolution

- contagious livestock diseases (e.g., foot-and-mouth disease)
- insect vector-borne livestock disease (e.g., bluetongue)
- disease in both domestic & wild populations (e.g., African swine fever)
- plant and environmental pests (e.g., tramp ants, fruit flies)
- other countries (Europe (EuFMDiS), USA, Canada, NZ)
- classroom tool (Australia, Europe, Malaysia)
- student projects (honours, Masters, PhD)

Expansion of AADIS to model the spread and control of pest species

- APPDIS (Australian Priority Pest & Disease model) arose through a DAWE/CEBRA project (2018/19).

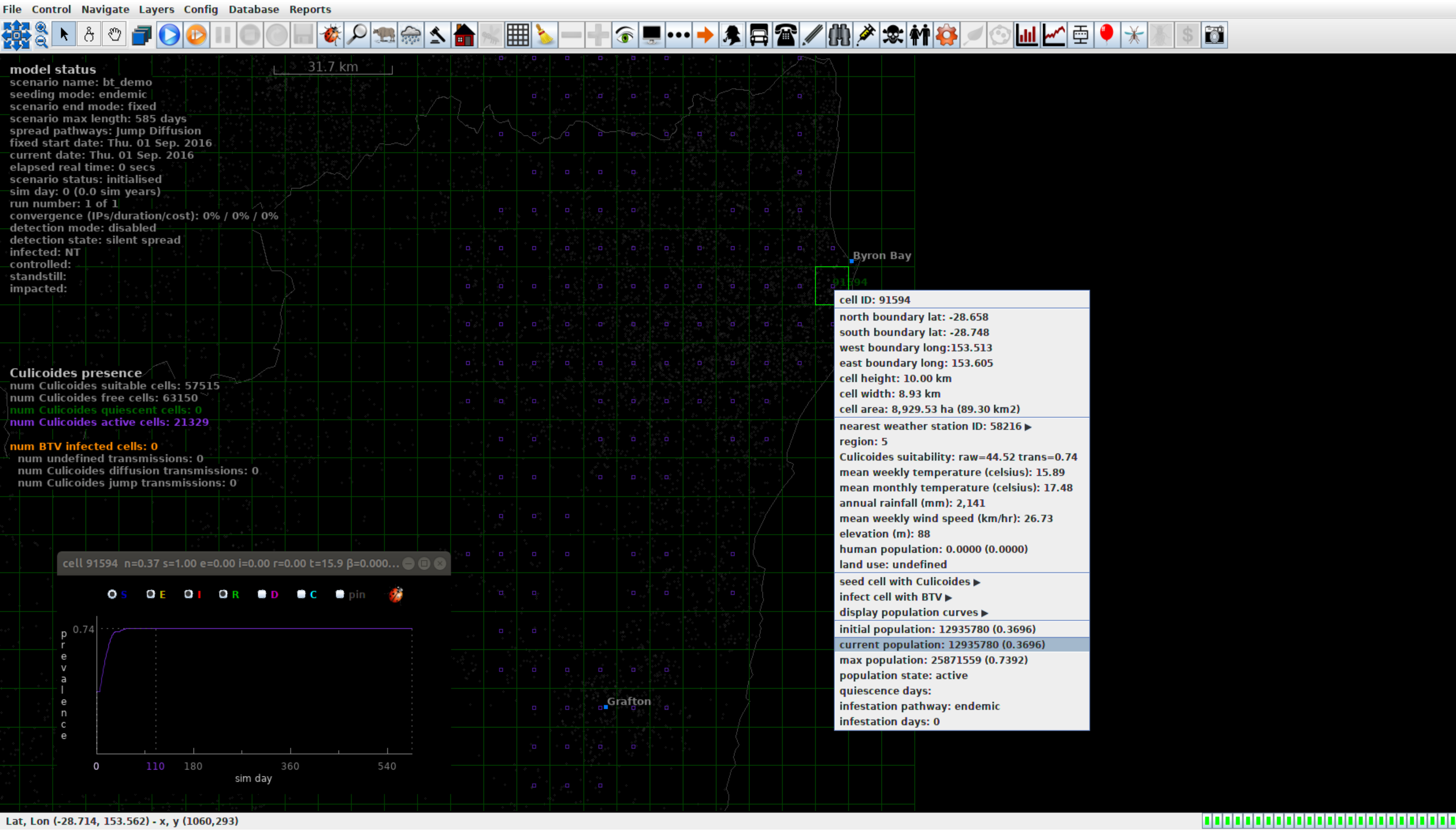
- Whereas AADIS is (herd) agent-based, APPDIS is a geographic automata where a user-configurable grid overlays a study area. The modelling unit of interest is the cell.

- A cell can have a range of biotic/abiotic attributes.

- A cell may also have a population of the pest under study.

Bradhurst et al (2021). A generalised and scalable framework for modelling incursions, surveillance and control of plant and environmental pests. Environmental Modelling & Software, 139.

Geographic automata



Modelling pest populations with a geographic automata

- how is the pest distributed? (i.e., which cells are initially populated?)
- how does within-cell abundance change over time?
- when/how might the population spread between cells?
- how effective are surveillance activities at detecting cell populations?
- how effective are treatment programs at controlling/eradicating cell populations?
- how effective are surveillance activities at detecting residual populations?
- how do resource constraints affect surveillance & control effectiveness?

Initial pest distribution

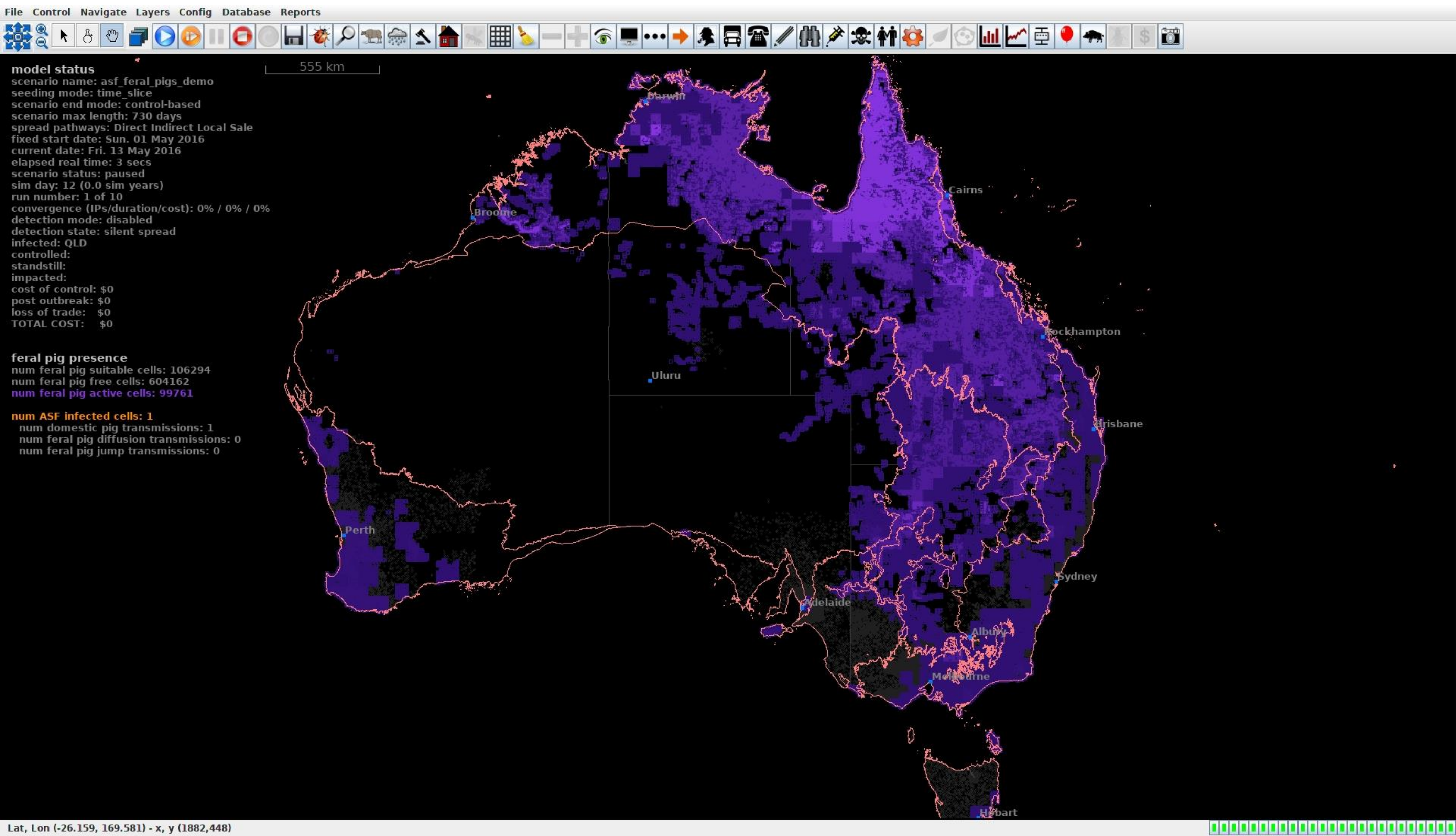
APPDIS provides three methods to distribute a pest:

1) point incursion – one or more cells can be explicitly seeded with a pest propagule, e.g., post-border arrival of an exotic fruit fly at a port.

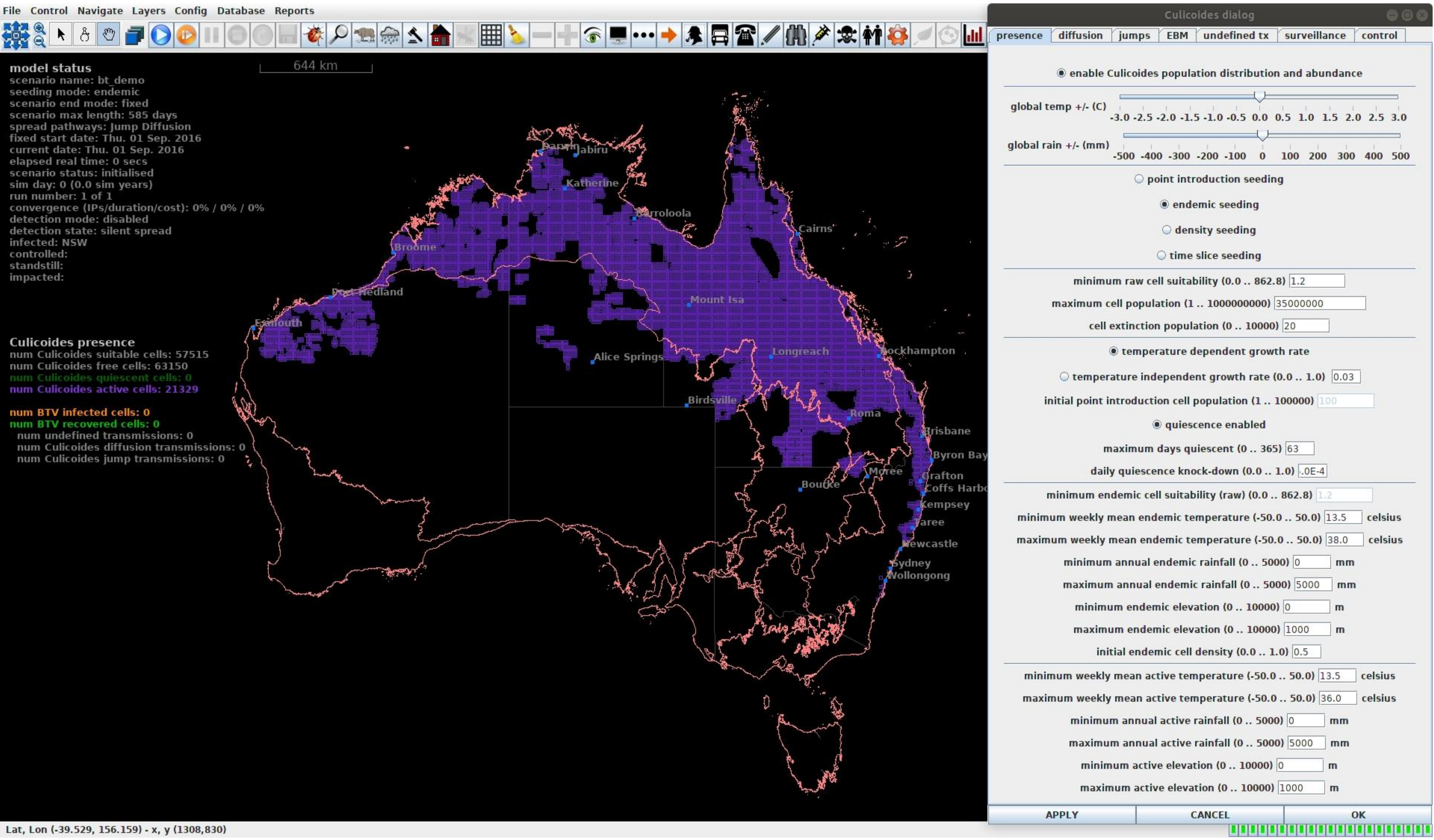
2) established population – externally generated population densities/counts per cell, perhaps informed by trapping data, census data, or habitat suitability studies.

3) built-in species distribution model (SDM) – mechanistic estimation based on configurable ranges of environmental criteria such as temperature, vegetation, elevation, rainfall, land use, etc.

Distribution of feral pigs via an external habitat model



Distribution of *Culicoides brevitarsis* via the built-in SDM

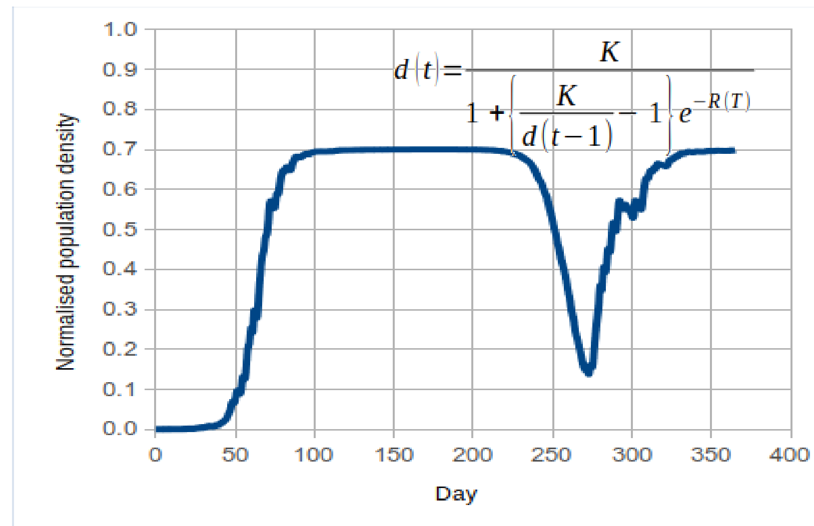


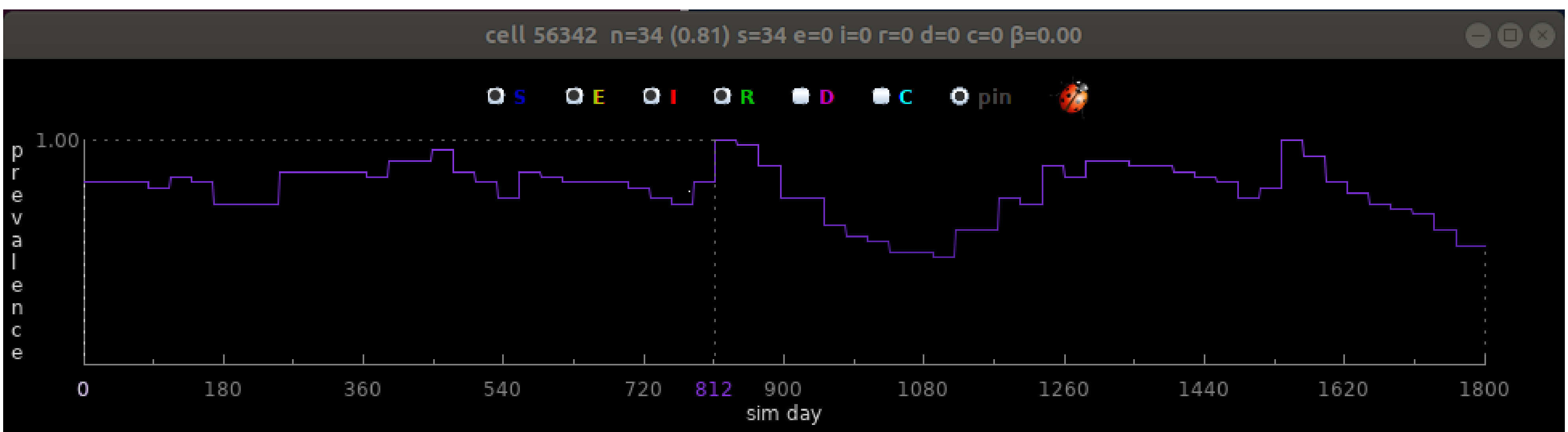
Within-cell abundance

- APPDIS provides two ways of estimating within-cell pest abundance over time:

1) mathematically e.g., temperature-dependent logistic growth with carrying capacity based on cell habitat suitability

2) externally generated 'time slices' that specify each cell's population count at a configurable interval





Natural dispersal between-cells

- As the pest population in a cell increases so too does the dispersal pressure to other cells.

- Natural short-range dispersal (e.g., tramp ant budding, fruit fly unaided flight) is modelled via a stochastic spatial diffusion kernel. Spread depends on the source cell pest density and destination cell suitability

- Optional dependencies include land use, temperature, elevation, gradient, wind speed & rainfall.

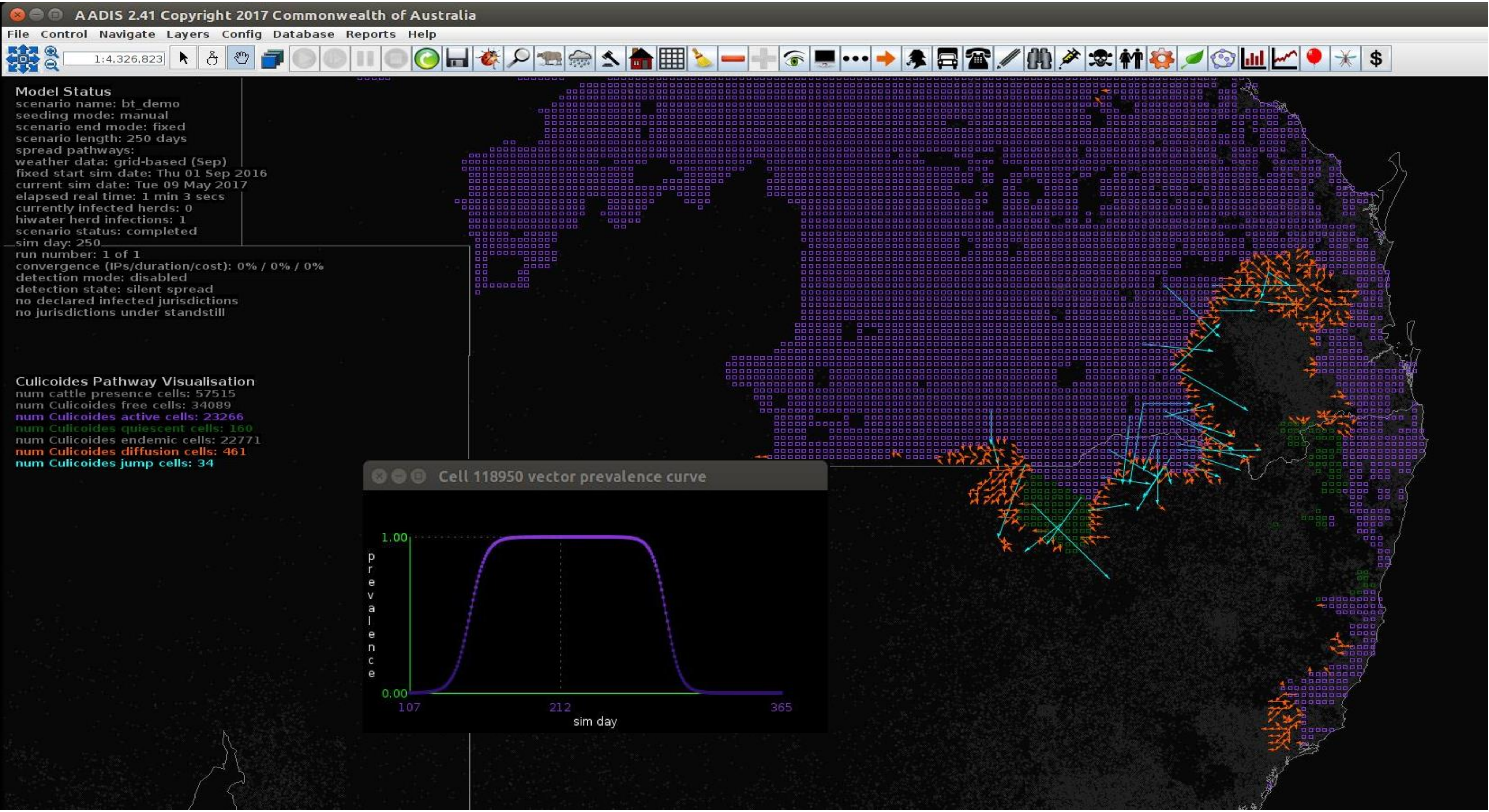
Assisted dispersal between cells

- Sporadic longer-range dispersal (e.g., hitchhiking, rafting, nuptial flight, specific market/agricultural activities) is modelled via one or more stochastic jump processes.

- Spread depends on the source cell pest density & destination cell suitability.

- Optional dependencies include human population density, land use, watercourses, temperature, elevation, gradient, wind direction/speed, rainfall.

Jump-diffusion spread of *Culicoides brevitarsis*



Detection and control

- Once the spread mechanisms have been calibrated to the satisfaction of domain experts the next step is configuring detection & control mechanisms.

- APPDIS simulates:

  → general surveillance
  → early detection surveillance (via a permanent trapping grid)
  → delimiting surveillance in response to detections
  → treatment programs in response to detections
  → post-treatment surveillance (to assess absence/presence)

- Control actions are user-configurable with respect to mode, extent, periodicity, cost & effectiveness.

- Response imperfections are included e.g., false positive reports, resource constraints, hard-to-detect residual populations, escapes from managed areas.

Case Study 1
Oriental fruit fly

- National grid with 5x5 km^2 cells.

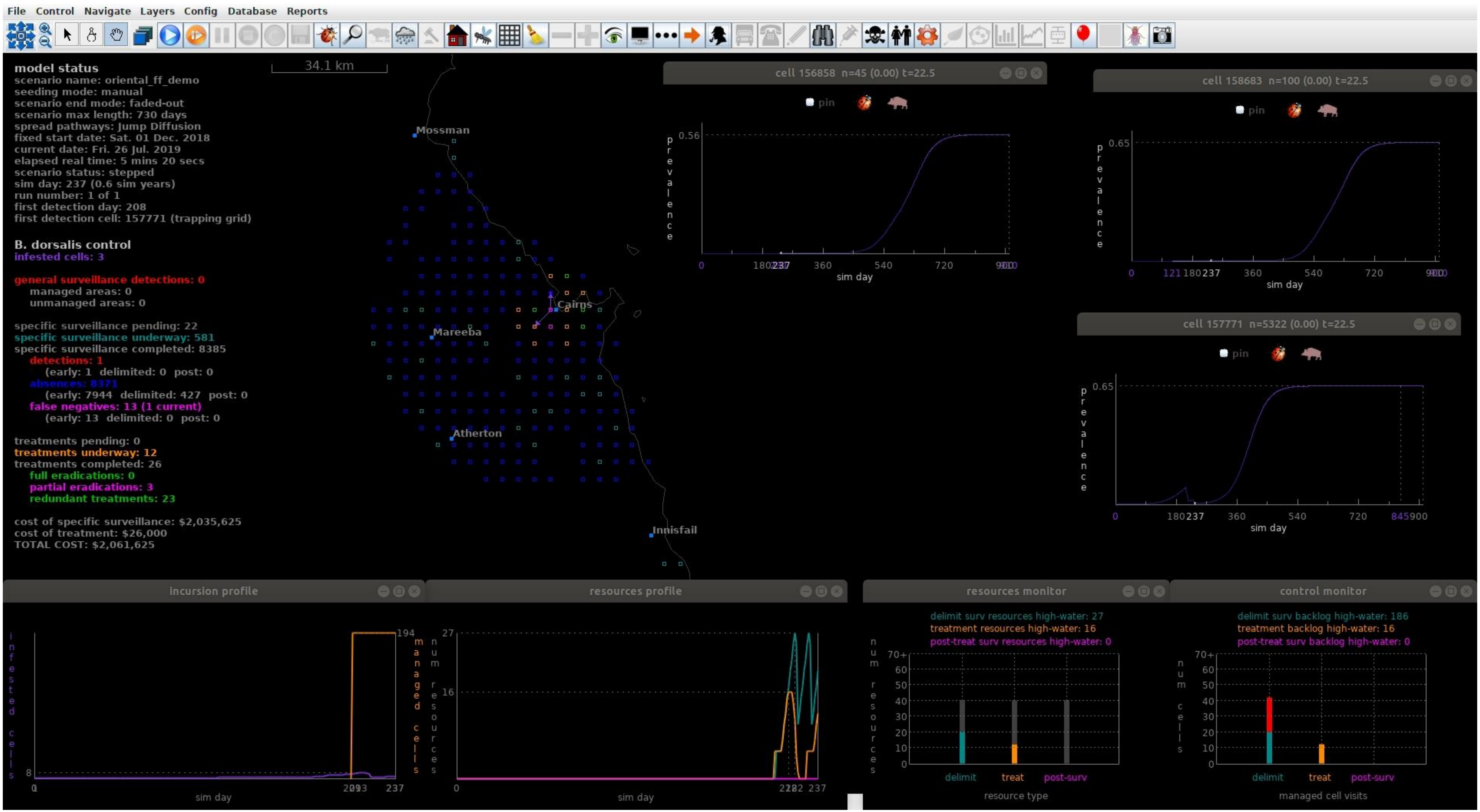
- Point introduction an oriental fruit fly propagule (arbitrarily n=25) at the Port of Cairns.

- Within-cell abundance:
  → temperature dependent logistic growth
  → carrying capacity determined by suitability layer (land use and NDVI)

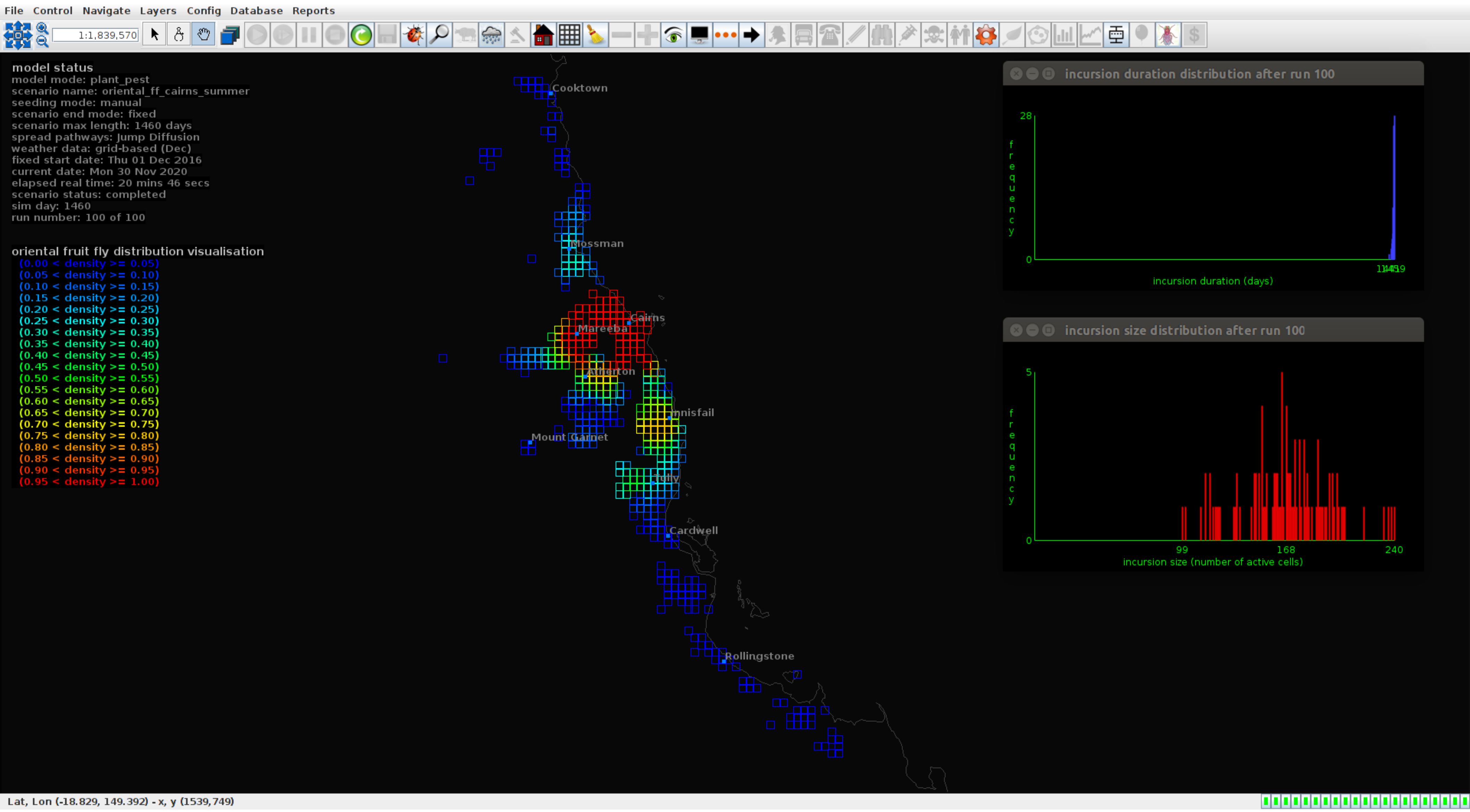
- Spread: natural dispersal (diffusion) + human-mediated hitchhiking (jumps)

- Surveillance and control:
  → general surveillance
  → early detection surveillance (trapping grid)
  → delimiting surveillance (50km radius)
  → treatment (10km radius)
  → post-treatment surveillance

Detection and control of Oriental fruit fly



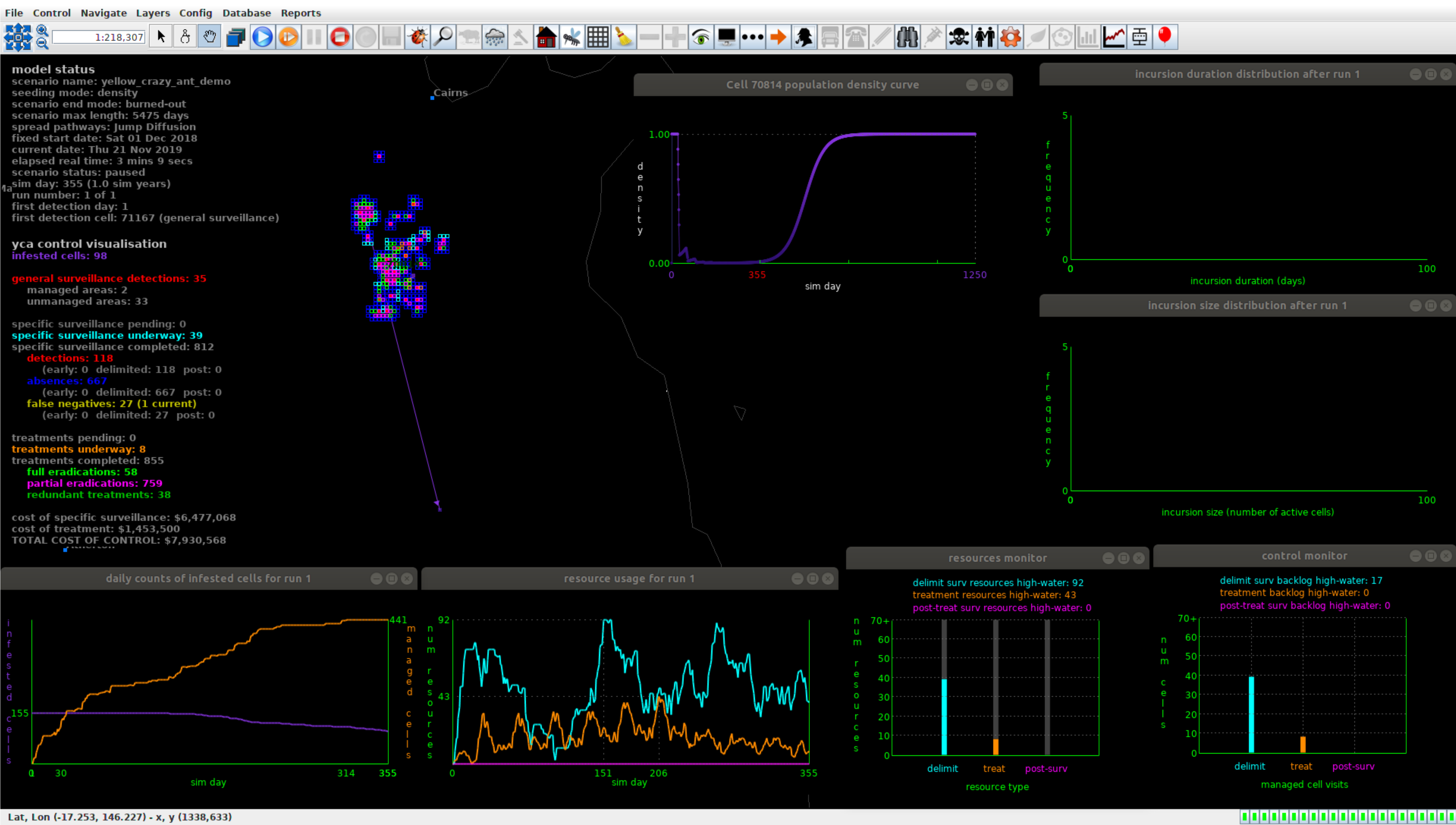
Risk map of Oriental fruit fly spread after introduction in Cairns



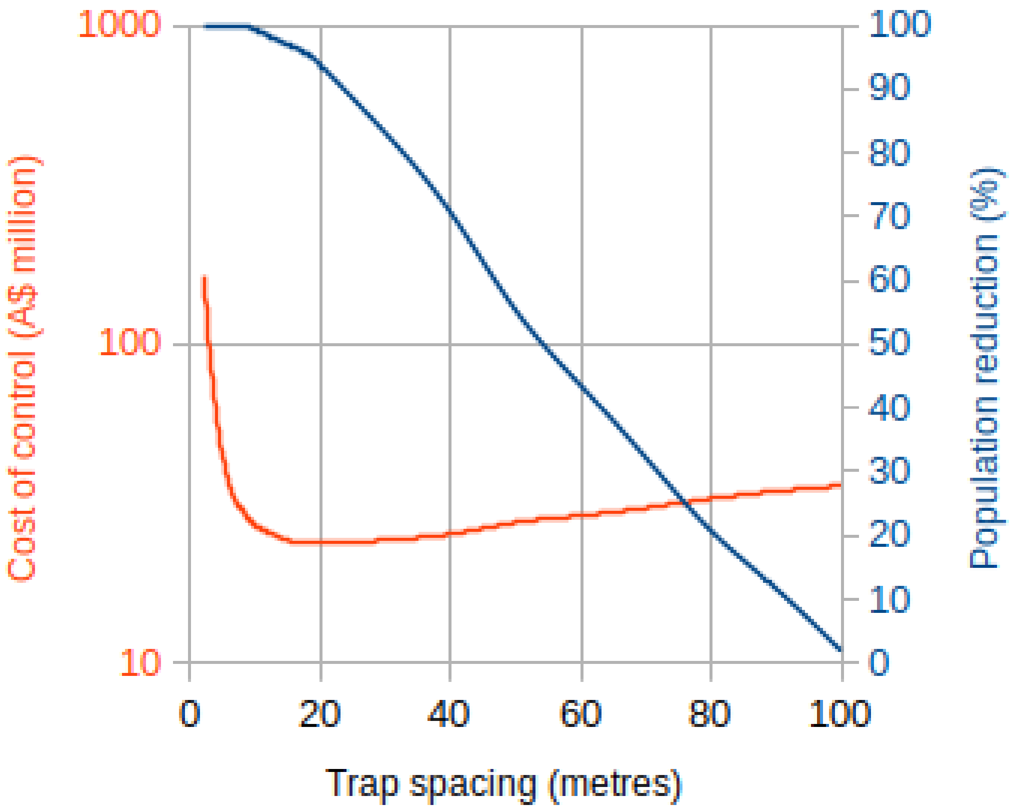
Case Study 2: yellow crazy ant

- Regional grid with 10 ha cells
- Established population across 1540 ha
- Within-cell abundance:
  → temperature independent logistic growth
  → very simple suitability layer
- Spread: budding (diffusion) + hitchhiking, agricultural & rafting jumps
- Surveillance and control:
  → general surveillance
  → delimiting surveillance
  → treatment
  → post-treatment surveillance

Control of yellow crazy ant

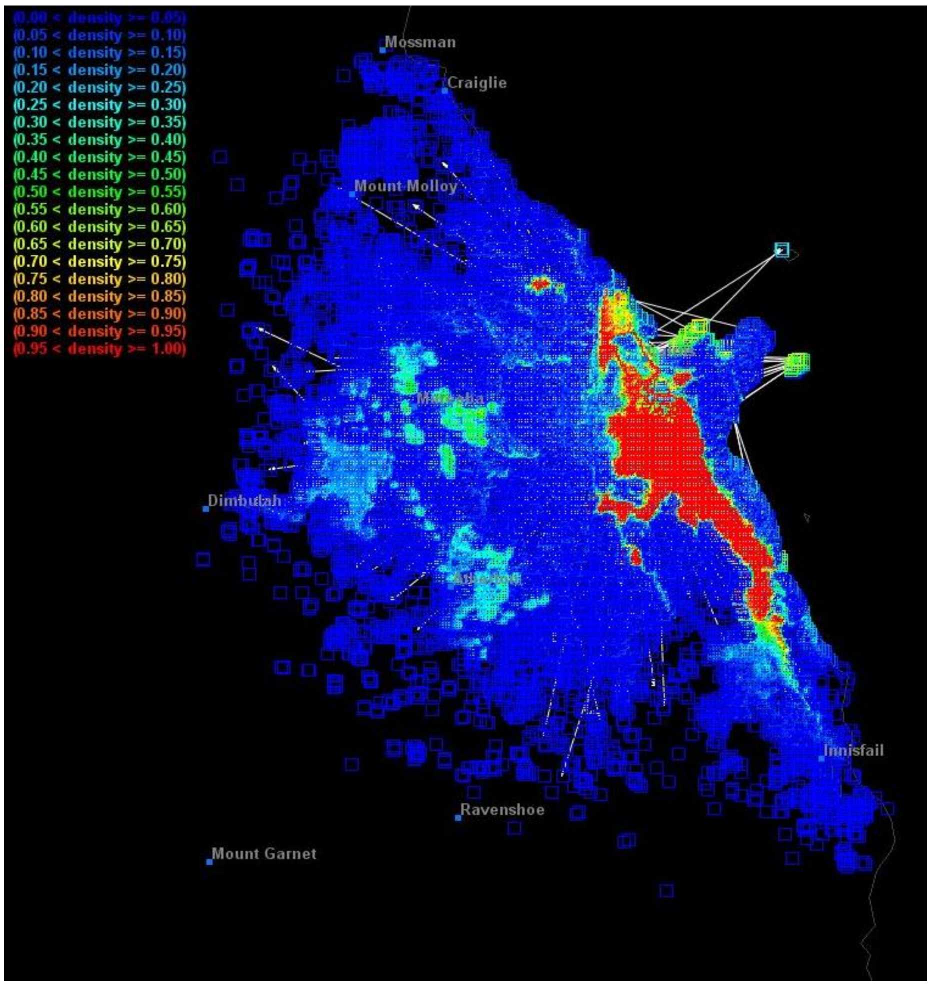


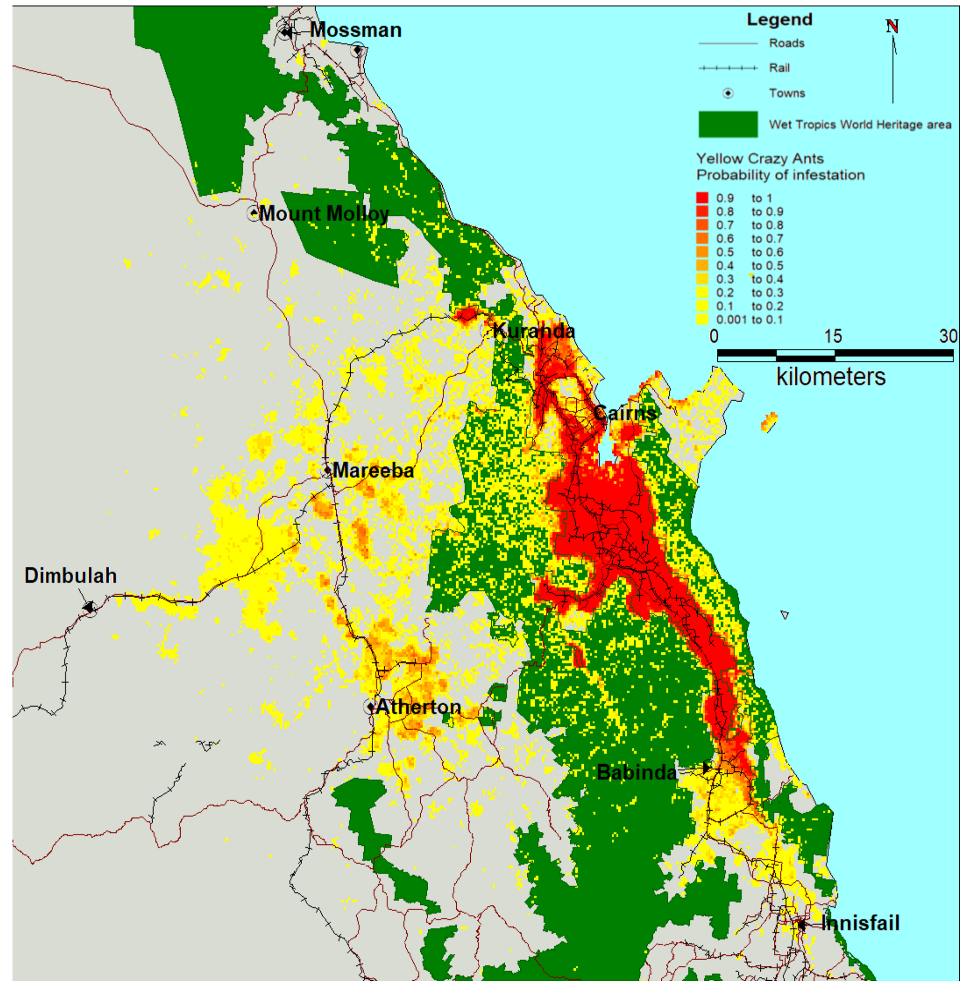
Post-treatment surveillance of yellow crazy ant



- The post-treatment surveillance trap spacing was systematically varied between 2 m and 100 m
- The model suggests that an 18 m spacing was the most cost-efficient.

Risk map of yellow crazy ant spread after 30 years





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