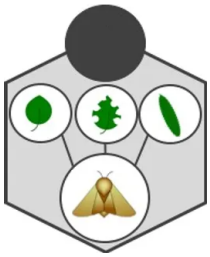
resevol: an R package for spatially explicit models of pesticide resistance given evolving pest genomes

A. Bradley Duthie[1], Rosie Mangan[1], C. Rose McKeon[1], Matthew C. Tinsley[1], and Luc F. Bussière[2,3]

[1] University of Stirling [2] University of Gothenburg [3] Gothenburgh Global Biodiversity Centre
alexander.duthie@stir.ac.uk, @bradduthie@ecoevo.social
http://bradduthie.github.io/talks/BES2022.pdf

Pesticide resistance evolution



Impact on agriculture

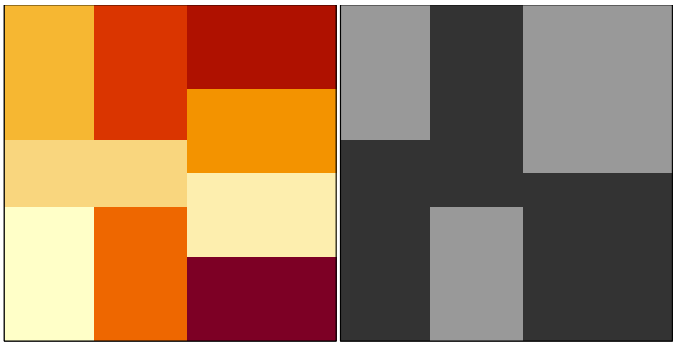
- Resistance wicked & widespread[1]
- Obstacle to food security[2]

Manage resistance evolution

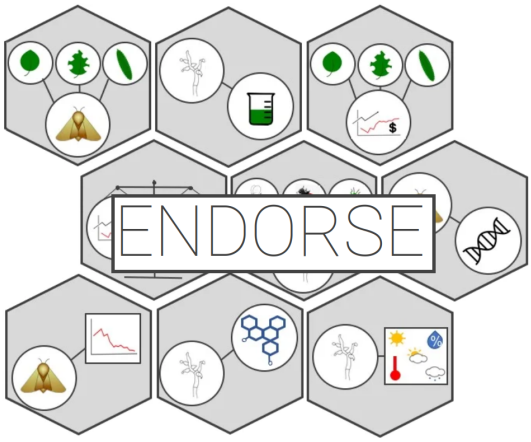
- Vary biopesticide application[3,4]
- Polygenic resistance traits[5]
- Negative cross-resistance[6]

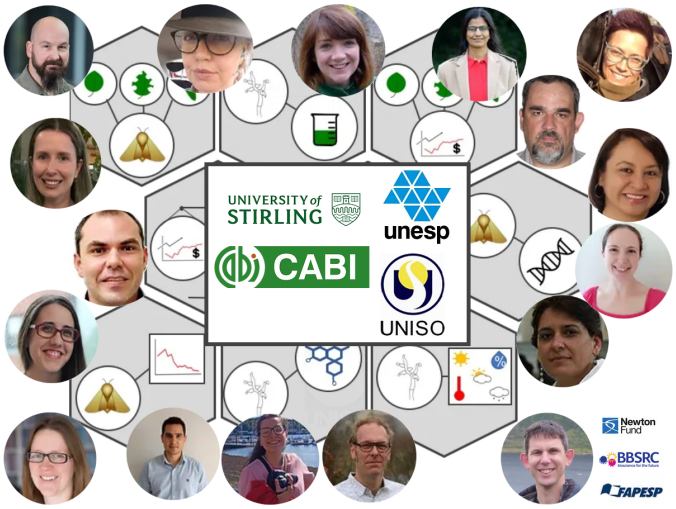
[1]Gould et al. 2018. *Ecol. Appl.* 13:1791-1805.
[2]Bradshaw et al. 2016. *Nat. Commun.* 7:12986.
[3]Carroll et al. 2014. *Science* 346:1245993.
[4]Saikai et al. 2021. *Pest Manag. Sci.* 77:273-284.
[5]Boots, M. 2011. *Am. Nat.* 178:214-220.
[6]Via, S. 1986. *Pesticide resistance.* 222-235.

Agricultural heterogeneity to overcome resistance evolution



Unique farms Biopesticide applied



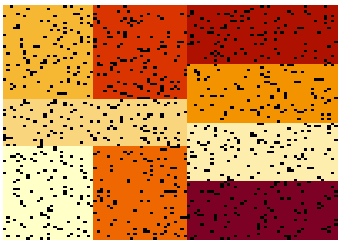


Modelling as a proof of concept before scaling up

[1] Image: Public Domain

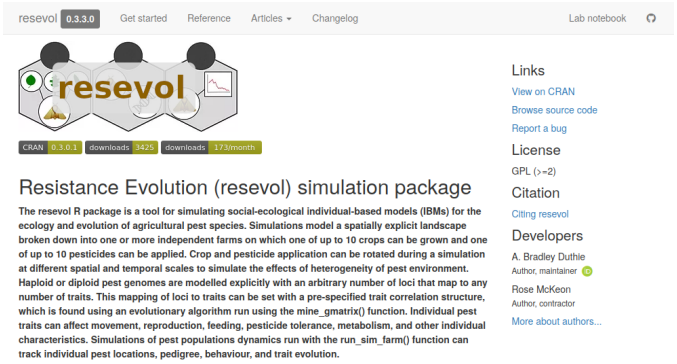
Agent-based modelling

Simulate a complex system *in silico* with code



- Agents as discrete entities
- Individual variation
- Spatially explicit landscapes
- Stochastic processes
- High model complexity

resevol: An R package for modelling agricultural pests

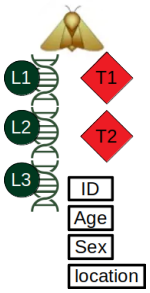


[1]Duthie AB, McKeon CR (2022). resevol: Simulate Agricultural Production and Evolution of Pesticide Resistance. R package version 0.3.3.0, https://bradduthie.github.io/resevol/.

resevol: An R package for modelling agricultural pests

Complex individuals

- Complete genomes
- Highly polygenic traits
- Set trait covariances
- Flexible life-history
- Flexible mating system



[1]**Image**: Public domain

resevol: An R package for modelling agricultural pests

Complex individuals

- Complete genomes
- Highly polygenic traits
- Set trait covariances
- Flexible life-history
- Flexible mating system

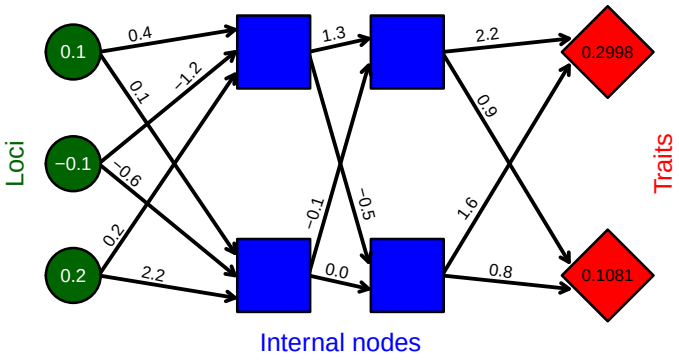
Dynamic landscapes

- Custom land dimensions
- Custom pesticide rotation
- Custom crop rotation
- Individual farms tracked
- Raster landscape maps

[1]Duthie AB, McKeon CR (2022). resevol: Simulate Agricultural Production and Evolution of Pesticide Resistance. R package version 0.3.3.0, https://bradduthie.github.io/resevol/.

[2]Duthie, AB, R Mangan, CR McKeon, MC Tinsley, LF Bussière. 2022. resevol: an R package for spatially explicit models of pesticide resistance given evolving pest genomes. bioRxiv 2022.08.22.504740; doi: https://doi.org/10.1101/2022.08.22.504740

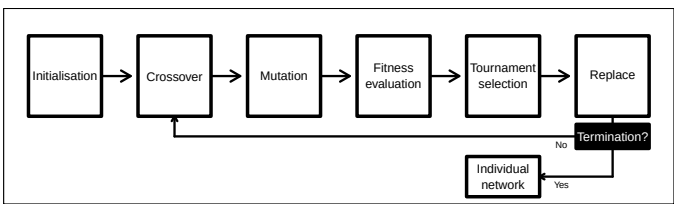
A genetic architecture for pre-specified trait covariances



[1]resevol R package vignette: https://bradduthie.github.io/resevol/articles/evolutionary_algorithm.html

Evolutionary algorithm to find genetic architecture

Initialise a population of multiple potential networks from loci to traits.



Evolve values between nodes, mapping loci to traits.

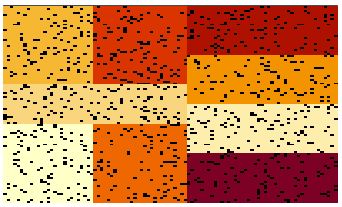
[1]resevol R package vignette: https://bradduthie.github.io/resevol/articles/evolutionary_algorithm.html

Evolutionary algorithm to find genetic architecture

```
gmt <- matrix(data = c( 1.0, -0.5, -0.5, 2.0),
              nrow = 2);
```

```
mg  <- mine_gmatrix(gmatrix = gmt, loci = 3,
                    indivs = 2000, npsize = 12000,
                    max_gen = 5400, sampleK = 1200,
                    chooseK = 6, layers = 4,
                    mu_pr = 0.2, pr_cross = 0.2,
                    mu_sd = 0.004, term_cri = -8);
```

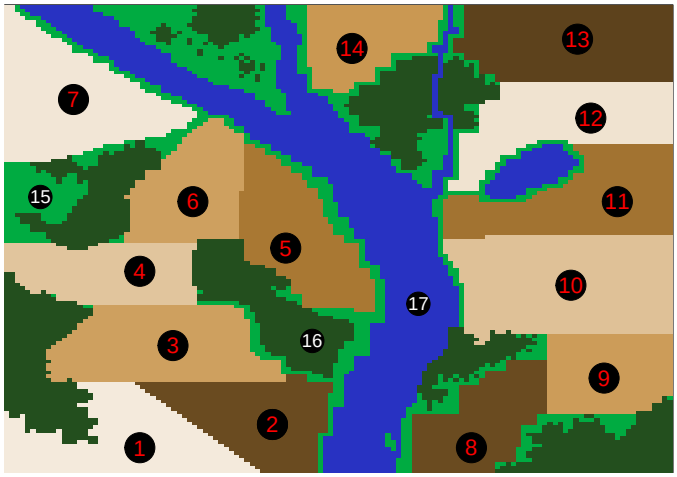
Constructing a landscape: Default options



- Specify ‘farms‘, ‘xdim‘, ‘ydim‘.
- Shortest splitline algorithm
- Land edge: torus, leaky, reflect

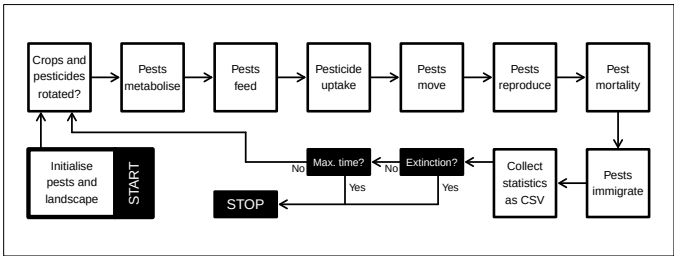
Each farm can use up to one crop and one pesticide, and the timing and rotation rules for crops and pesticide allow any Markov process.

Constructing a landscape: Advanced options



Pest life-history events defined within an age range

Within a time step, order of events are specified.



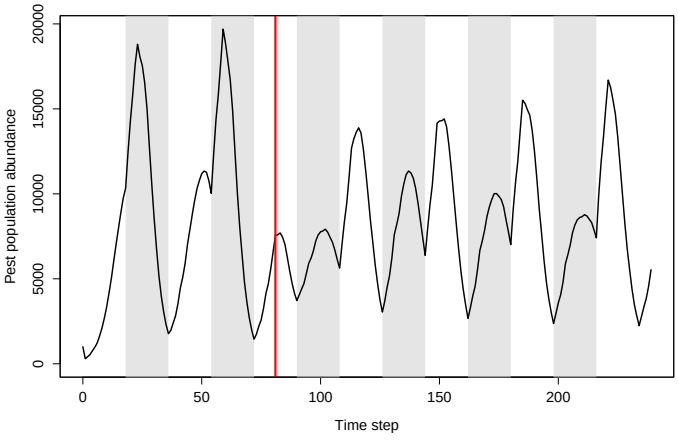
Specific events can be restricted to age ranges:

Feed: 0-2, Move: 3-8, Mate: 7-9

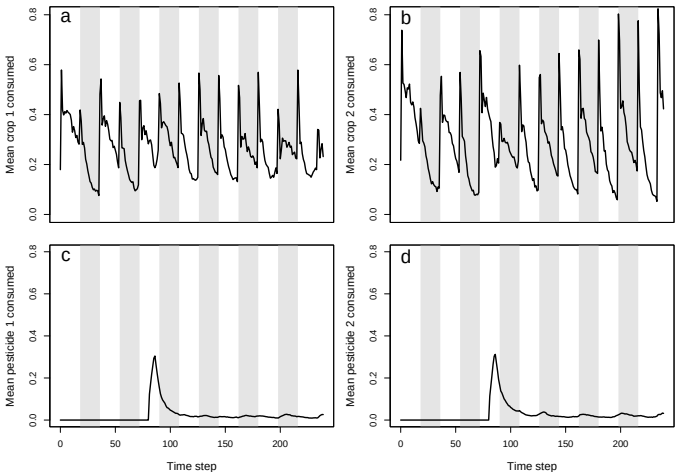
Running a simulation in resevol

```
run_farm_sim(mine_output = mg, repro = "asexual",
             pesticide_number = 2, time_steps = 160,
             farms = 9, pesticide_init = "random",
             pesticide_consume = c("T1", "T2"),
             pesticide_rotation_time = 16, xdim = 64,
             pesticide_rotation_type = 3, ydim = 64,
             pesticide_tolerated_surv = 0, max_age = 4,
             pesticide_per_cell = 1, crop_number = 1,
             crop_rotation_time = 16, crop_per_cell = 4,
             food_consume = 1, food_needed_surv = 1,
             reproduction_type = "food_based",
             food_needed_repr = 1, land_edge = "torus",
             min_age_feed = 0, max_age_feed = 2,
             min_age_move = 3, max_age_move = 4,
             min_age_reproduce = 4, print_gens = FALSE,
             max_age_reproduce = 4, rand_age = TRUE,
             age_pesticide_threshold = 2,
             immigration_rate = 10, move_distance = 2,
             print_last = TRUE, trait_means = c(0.1, 0.1));
```

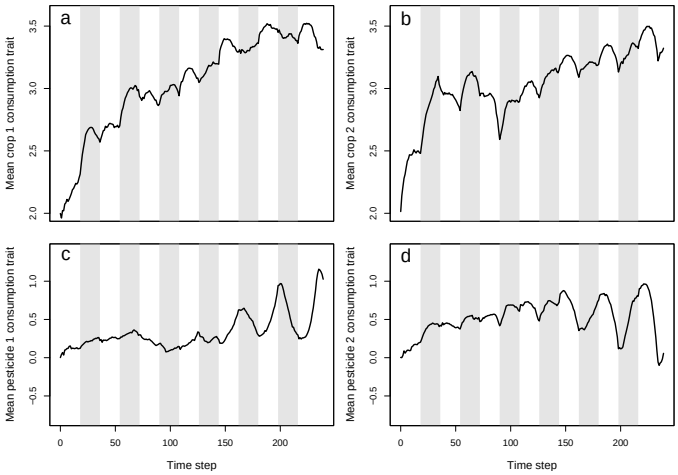
Simulating ecology, evolution, crop yields



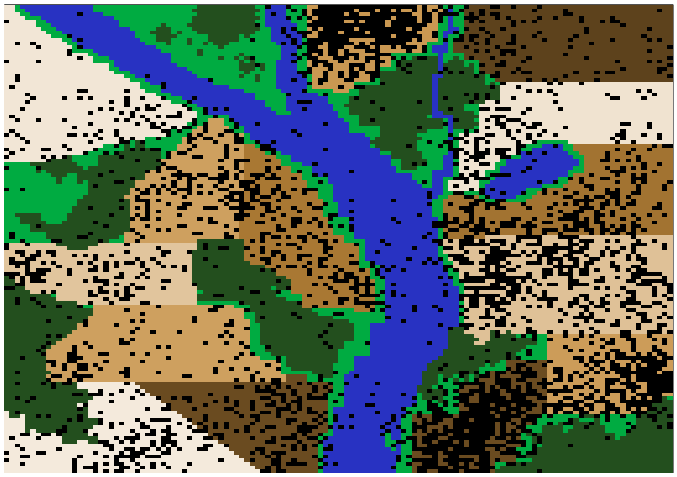
Simulating ecology, evolution, crop yields



Simulating ecology, evolution, crop yields



Simulating ecology, evolution, crop yields



The resevol R package: summary

- Simulations of pest ecology, resistance evolution, and agricultural production
- Covarying polygenetic traits
- Flexible pest life-histories, mating systems, traits
- Highly customisable, detailed landscapes
- Free to use[1], open source[2] (GPL >= 2), documented[1,3], actively maintained[4]

---

[1] **Website**: https://bradduthie.github.io/resevol/
[2] **Code**: https://github.com/bradduthie/resevol
[3] **Lab Notebook**: https://bradduthie.github.io/resevol/notebook/
[4] **Email**: alexander.duthie@stir.ac.uk **Mastodon**: @bradduthie@ecoevo.social