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Swiss Tropical and Public Health Institute
Schweizerisches Tropen- und Public Health-Institut
Institut Tropical et de Santé Publique Suisse

Department of Epidemiology and Public Health
Health Systems Research and Dynamical Modelling Unit

Does clustering of vector control interventions improve their effectiveness?

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SMIDDY 2012

30th August, 2012

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Background

- Mosquitoes transmit several vector borne diseases including malaria

– Various efforts on vector control have been made and coverage of interventions have been scaled up in several countries

– Vector control interventions considered include
    - Insecticide residual spraying (IRS),
    - Insecticide treated nets (ITNs),
    - Spatial repellents, and
    - Larviciding

Objectives

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– What role does the spatial arrangement of these interventions play?

– What is the optimal deployment given the resources (coverage) you have?

How?

Use modelling to:

- Determine the effects of spatial distribution and clustering of interventions on mosquito populations
- Provide a guide to strategic deployment of interventions for maximum benefits

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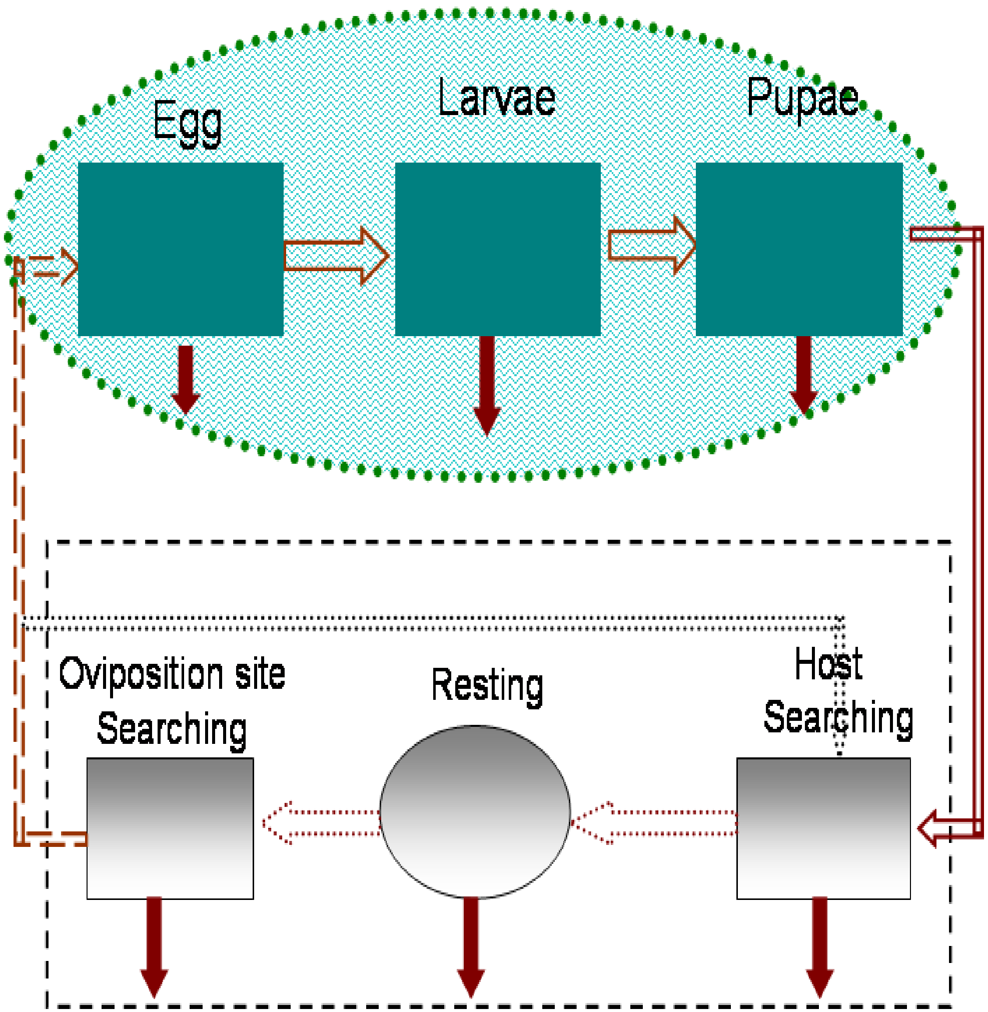
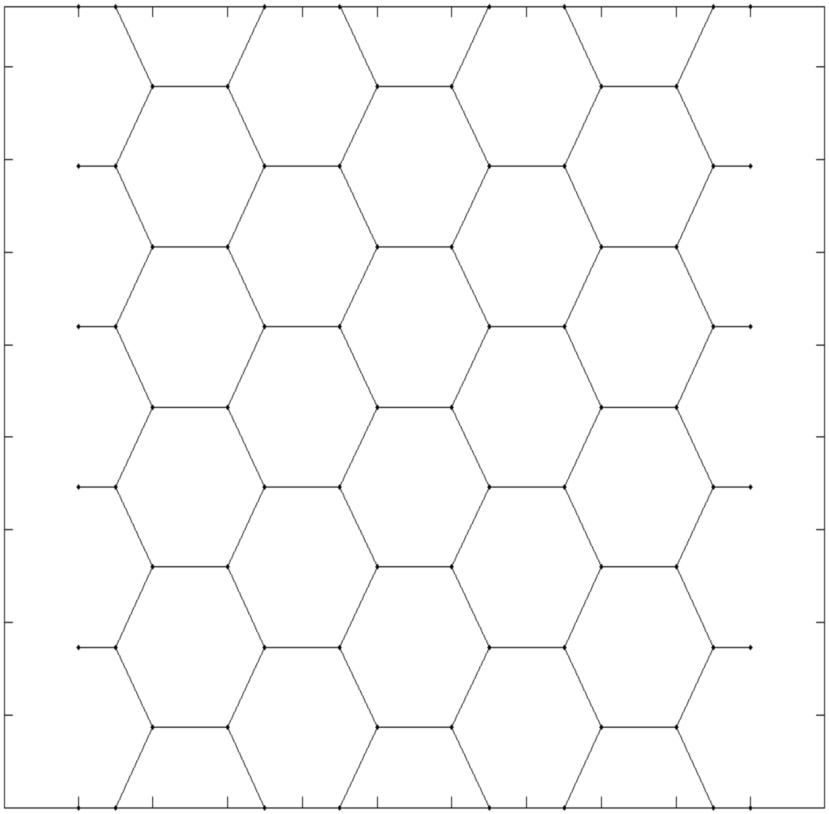
Mosquito population dynamics



- Main stages: Egg, Larvae, Pupae, Adult.
- We use ODEs to model the population dynamics in each stage.
- Vital dynamics: mortality, density dependent mortality in the larval stage, and birth of new eggs.
- Progression rates between stages.
- Interventions affect progressions

Methods

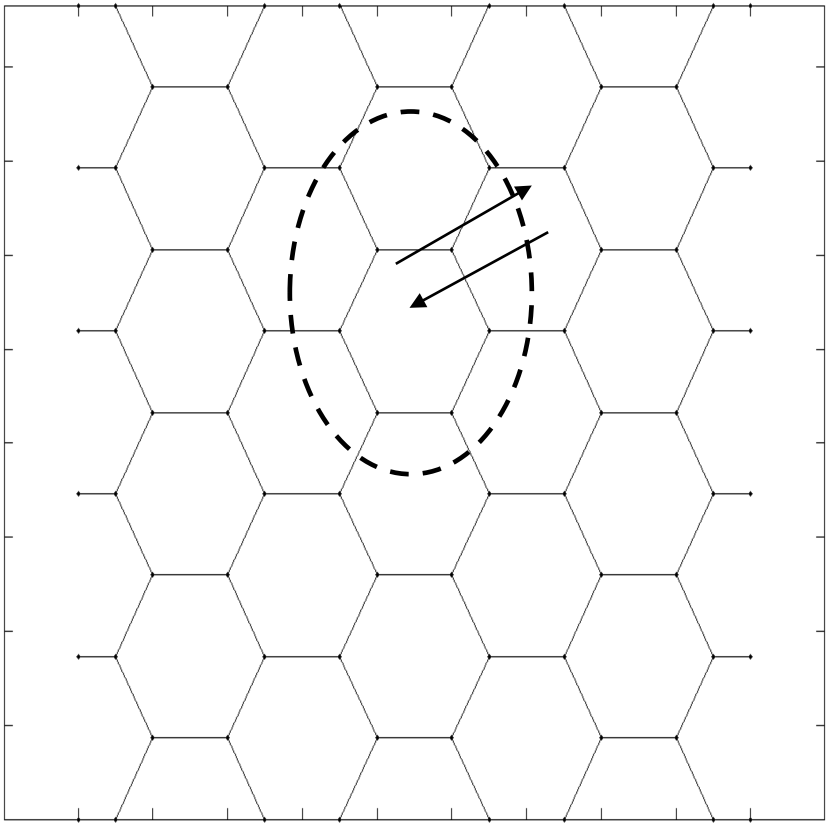
Spatially explicit model – population dynamics



- Allows modelling of any distribution of hosts and breeding sites on the grid.
- Population dynamics replicated in each patch.
- Progression from host seeking stage to the resting stage is only possible if a patch contain hosts.
- Egg oviposition is only possible if a patch contains breeding sites.

Methods

Spatially explicit model – dispersal dynamics



- Movement to and from neighbouring patches only.
- Movement is driven by relative availability of hosts and breeding sites
  - only host seeking and breeding site searching stages of the life cycle are allowed to move.
- Periodic boundary conditions.

Methods

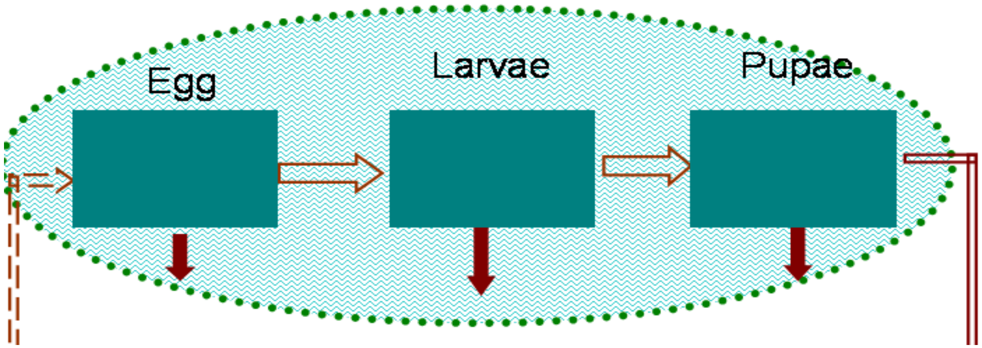
Dispersal model – aquatic stage with interventions

$$\frac{dE_{(i,j)}}{dt} = b_{(i,j)}\rho_{A_o(i,j)}A_{o(i,j)} - \left(\mu_{E(i,j)} + \rho_{E(i,j)}\right) E_{(i,j)}$$

$$\frac{dL_{(i,j)}}{dt} = \rho_{E(i,j)}E_{(i,j)} - \left(\mu_{L_1(i,j)} + \mu_{L_2(i,j)}L_{(i,j)} + \rho_{L(i,j)}\right) L_{(i,j)}$$

$$\frac{dP_{(i,j)}}{dt} = \boxed{(1-\epsilon_{LV})\rho_{L(i,j)}L_{(i,j)}} - \left(\mu_{P(i,j)} + \rho_{P(i,j)}\right) P_{(i,j)}$$

Intervention = Larvicide
Acting on the larval stage



Dispersal model – adult stage with interventions

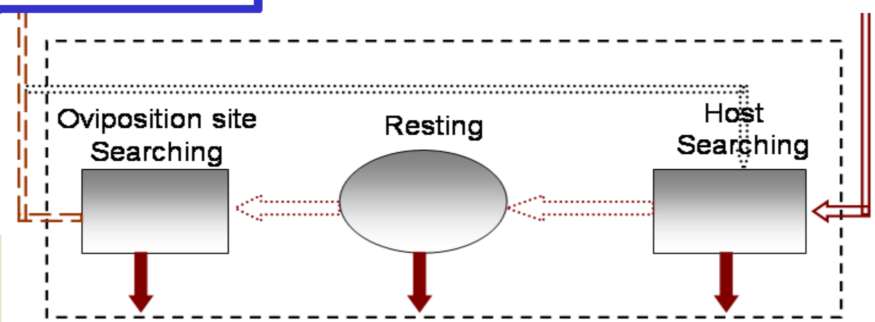
$$\frac{dA_{h(i,j)}}{dt} = \rho_{P(i,j)}P_{(i,j)} + \psi^{B}_{(i,j)}\rho_{A_o(i,j)}A_{o(i,j)} - \left(\mu_{A_{h(i,j)}} + \psi^{H}_{(i,j)}\rho_{A_{h(i,j)}}\right)A_{h(i,j)} - \gamma_{ITN(i,j)}\mu_{A_{h(i,j)}}A_{h(i,j)}$$

$$- \left(\sum_{\xi' \in N(i,j)} \beta^{H}_{(i,j)/\xi'}\right)A_{h(i,j)} + \left(\sum_{\xi' \in N(i,j)} \beta^{H}_{\xi'/(i,j)}A_{h\xi'}\right)$$

$$\frac{dA_{r(i,j)}}{dt} = \psi^{H}_{(i,j)}\rho_{A_{h(i,j)}}A_{h(i,j)} - \left(\mu_{A_{r(i,j)}} + \rho_{A_{r(i,j)}}\right)A_{r(i,j)} - \gamma_{IRS(i,j)}\mu_{A_{r(i,j)}}A_{r(i,j)}$$

$$\frac{dA_{o(i,j)}}{dt} = \rho_{A_{r(i,j)}}A_{r(i,j)} - \left(\mu_{A_{o(i,j)}} + \psi^{B}_{(i,j)}\rho_{A_{o(i,j)}}\right)A_{o(i,j)}$$

$$- \left(\sum_{\xi' \in N(i,j)} \beta^{B}_{(i,j)/\xi'}\right)A_{o(i,j)} + \left(\sum_{\xi' \in N(i,j)} \beta^{B}_{\xi'/(i,j)}A_{o\xi'}\right)$$



Methods

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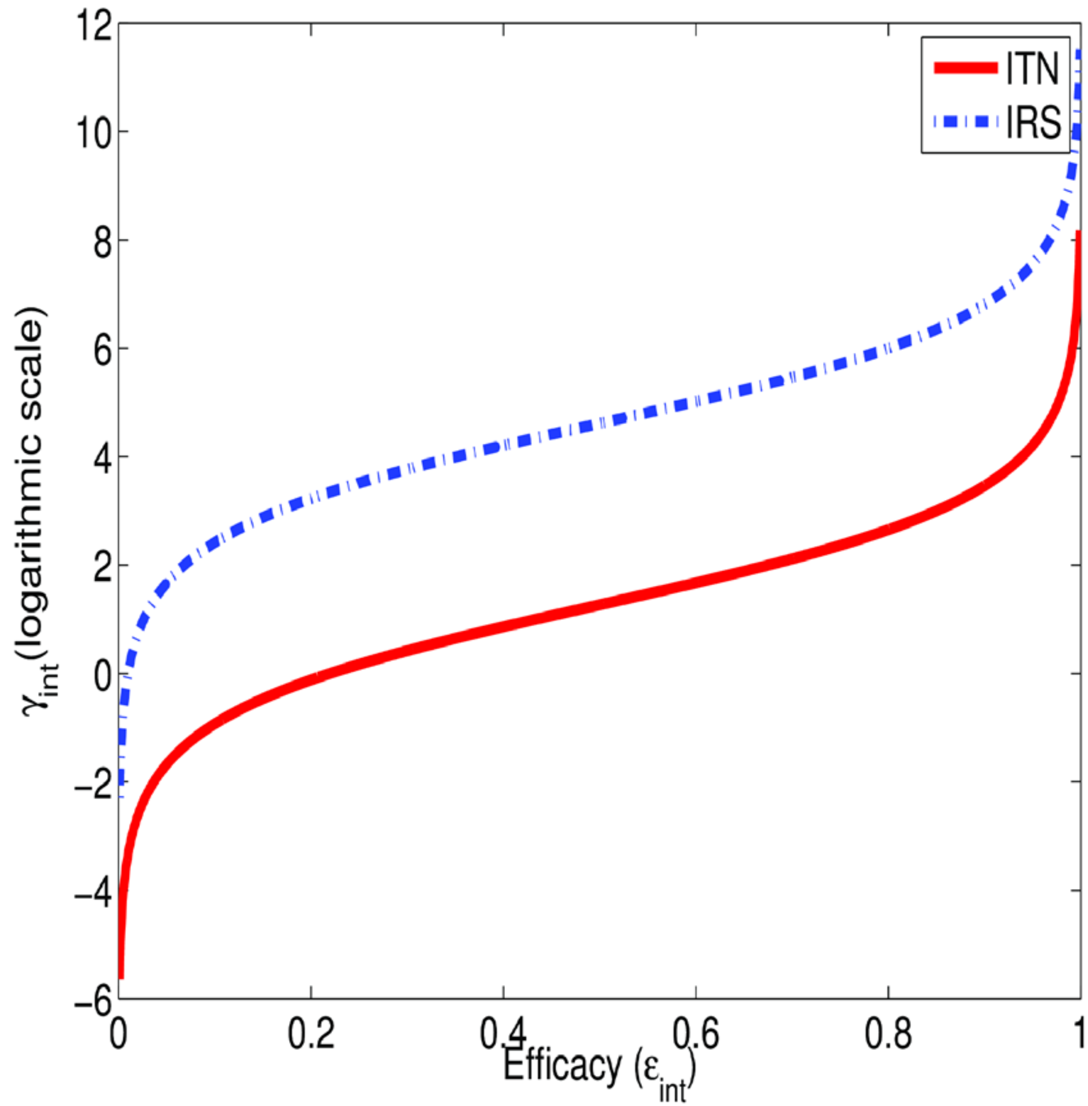
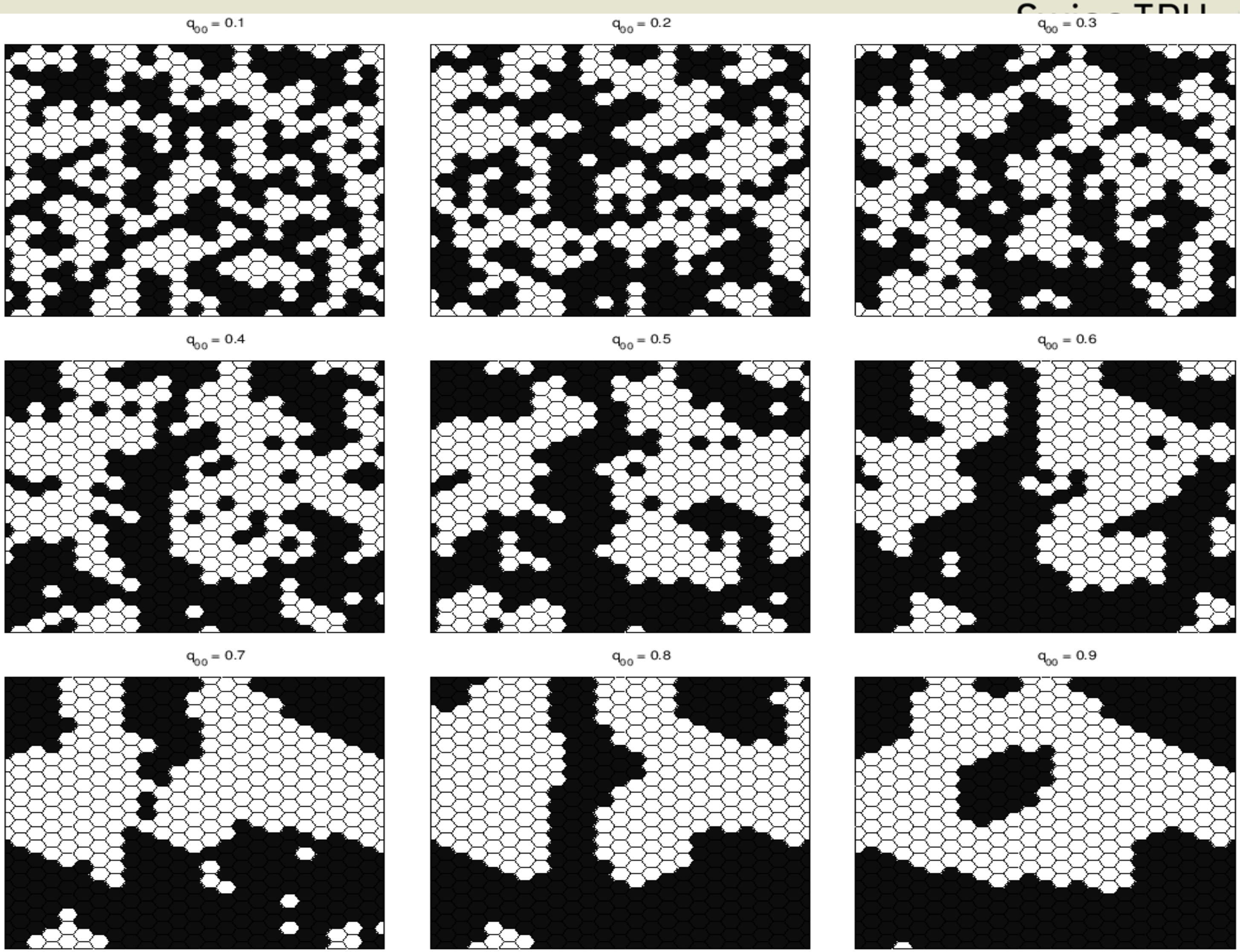
Intervention parameters

$$\gamma_{int} = \frac{\epsilon_{int}(\rho_s + \mu_s)}{\mu_s(1 - \epsilon_{int})}$$



For comparison, efficacy is 0.8 for all intervention simulations

Spatial Clustering of interventions



- An example of 50% coverage, q00 -> degree of clustering, increasing q00 –> high degree of clustering

Hiebeler, D., 2000. Populations on fragmented landscapes with spatially structured heterogeneities: Landscape generation and local dispersal. Ecology 81 (6).

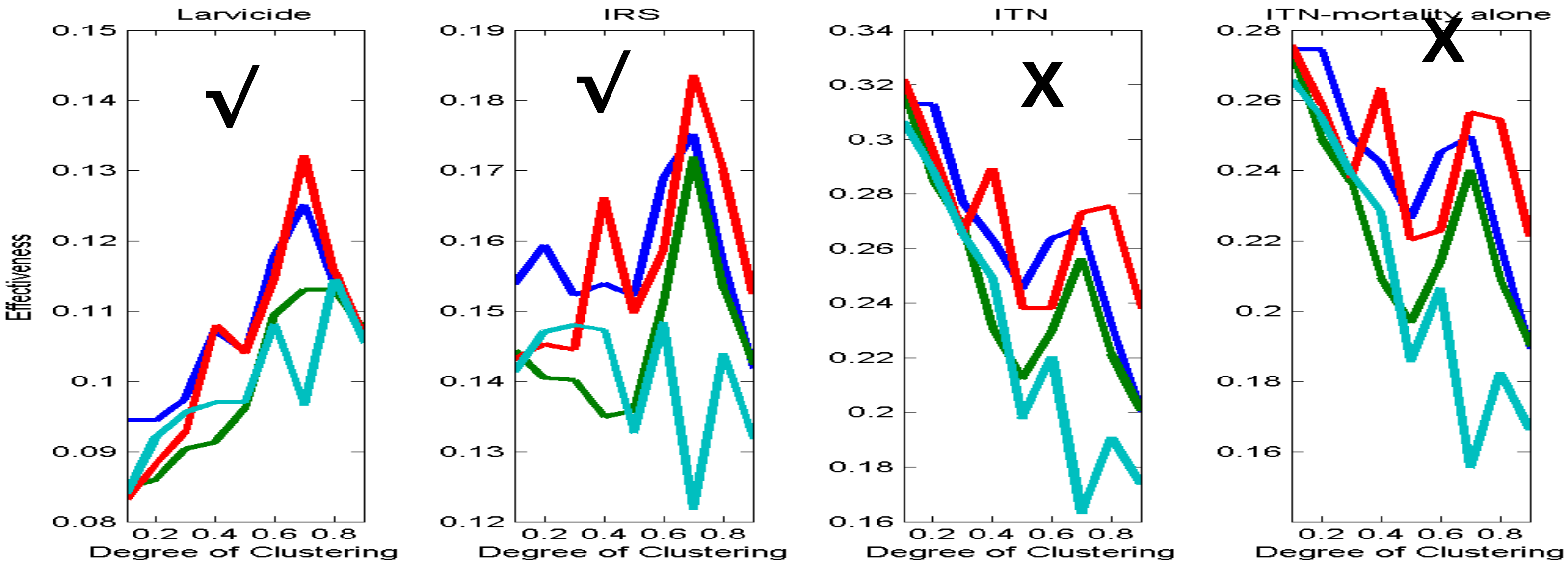
Simulations

- All patches on the grid contain hosts and habitats – homogeneous distribution of resources
- We use several generated spatial clusters for distribution of interventions (ranging from no clustering to high clustering)
- Measure of effectiveness of intervention - Proportionate reduction of equilibrium population of host seeking mosquitoes

$$ef = 1 - \frac{A_h^{*(\mathrm{int})}}{A_h^{*(\mathrm{noint})}}$$

Results – does clustering improve effectiveness?

10%
coverage



Results – does clustering improve effectiveness?

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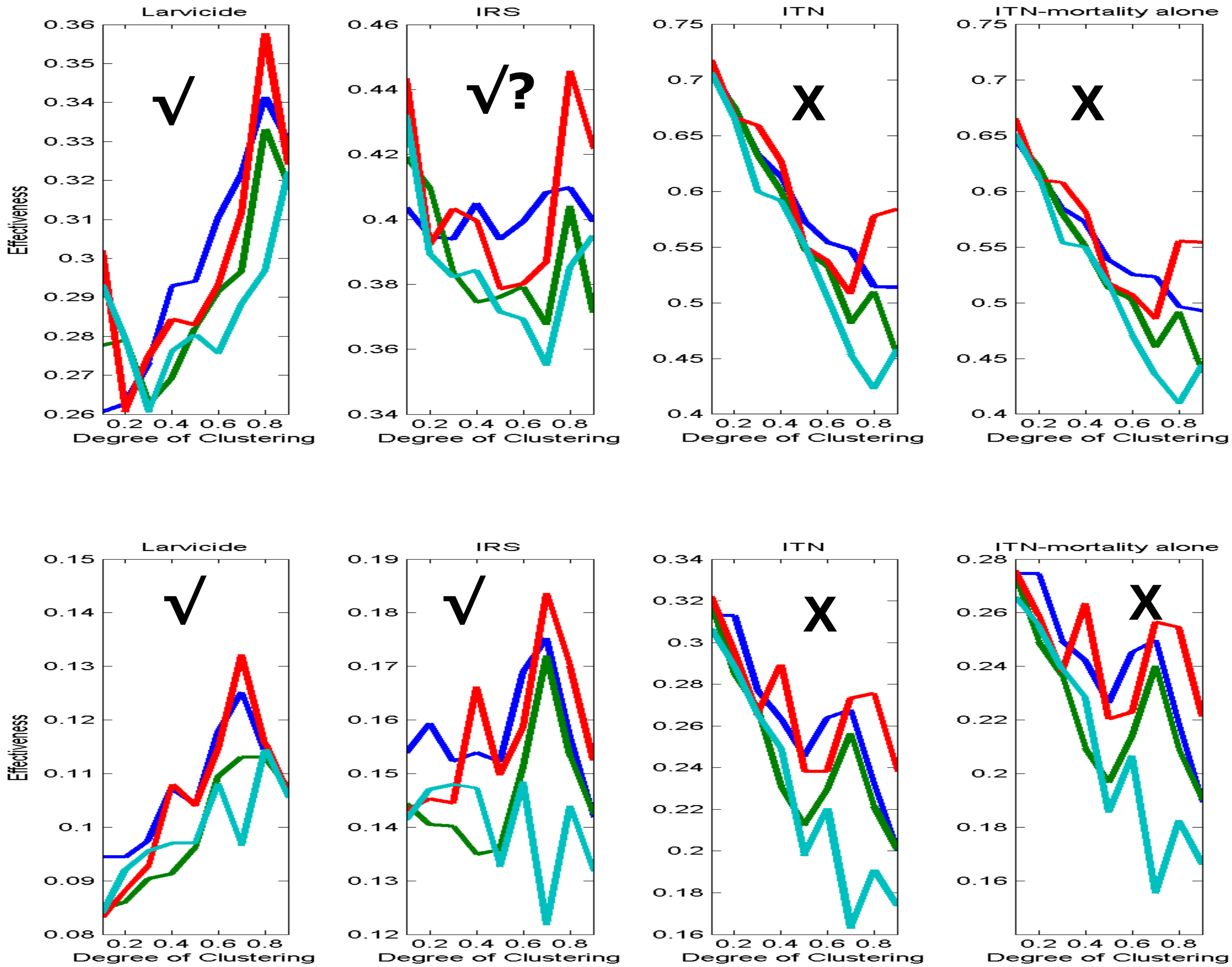
30% coverage

10% coverage



Results – does clustering improve effectiveness?

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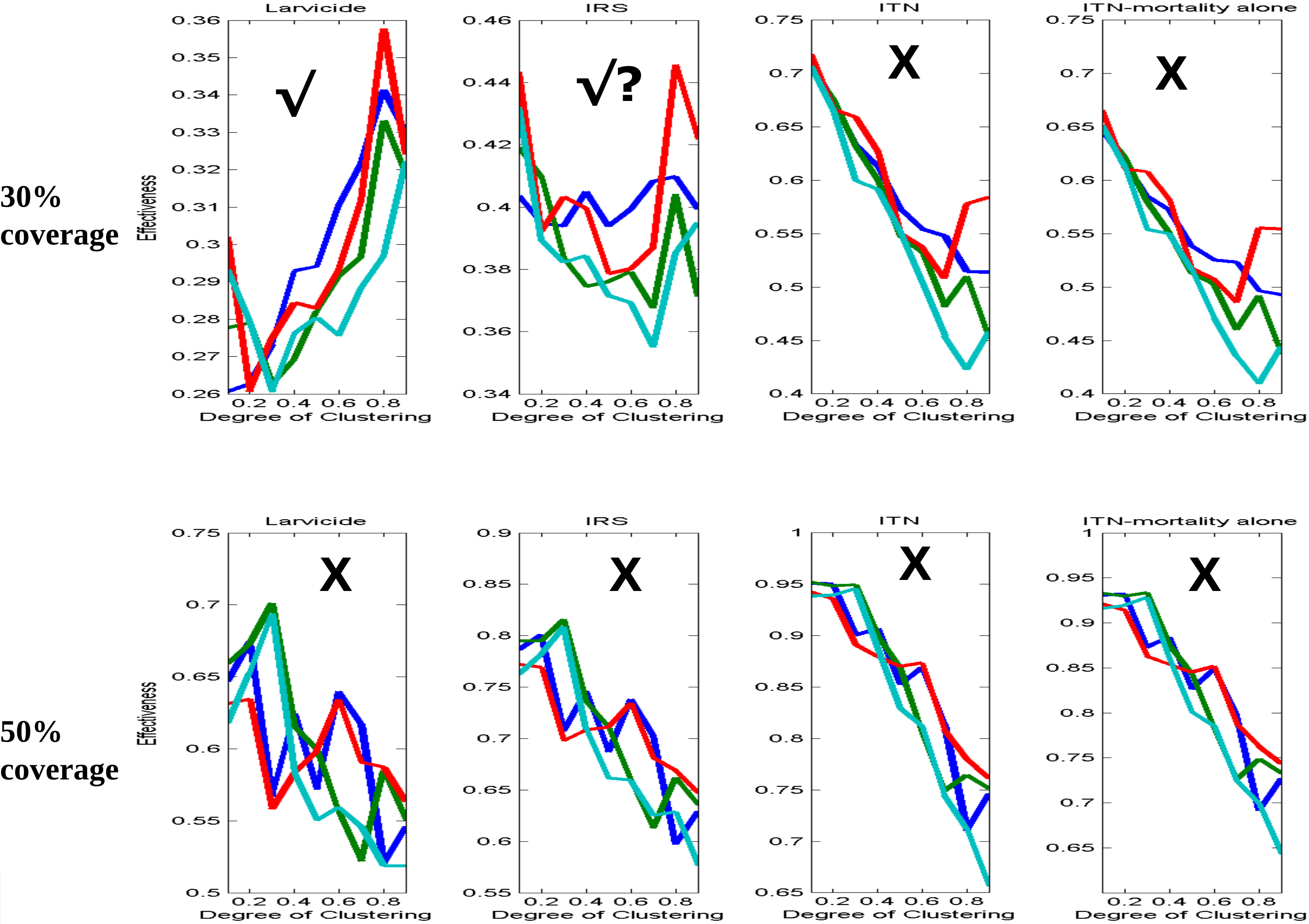

Results – does clustering improve effectiveness?

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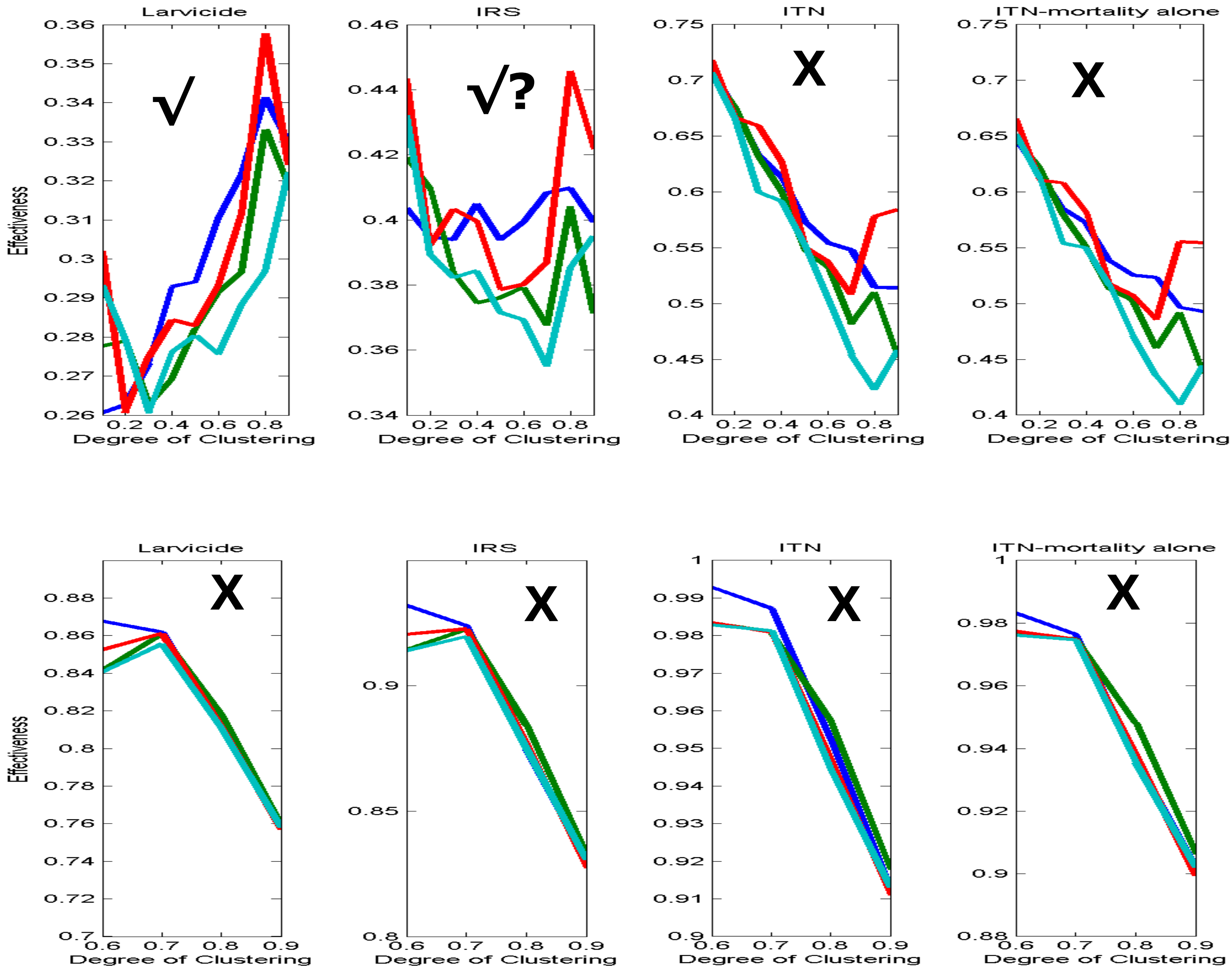
30% coverage

70% coverage



Conclusions – optimal deployment

- These results provide evidence that the effectiveness of an intervention can be highly dependent on its spatial distribution

Under homogeneous distribution of water resources and humans hosts:

- IRS and Larvicide
  - when only low coverage is possible, it is more beneficial to cluster the intervention than to randomly deploy
  - with moderate to high coverage random deployment is optimal
- For ITNs,
  - Random deployment of ITNs to humans is more beneficial than clustering for all level of coverage

Acknowledgments

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Thank you

Thanks to
Members of the Malaria Modelling group

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Backup slides

Methods

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Repellence

- Dispersal rate is multiplied by

$$\varphi_{i,j} = 1 - p_{i,j}$$

$p_{i,j} \in [0,1]$ is a blocked ability of mosquitoes to enter patch i,j

Note: repellence effect is in patches only if intervention is ITN

Results

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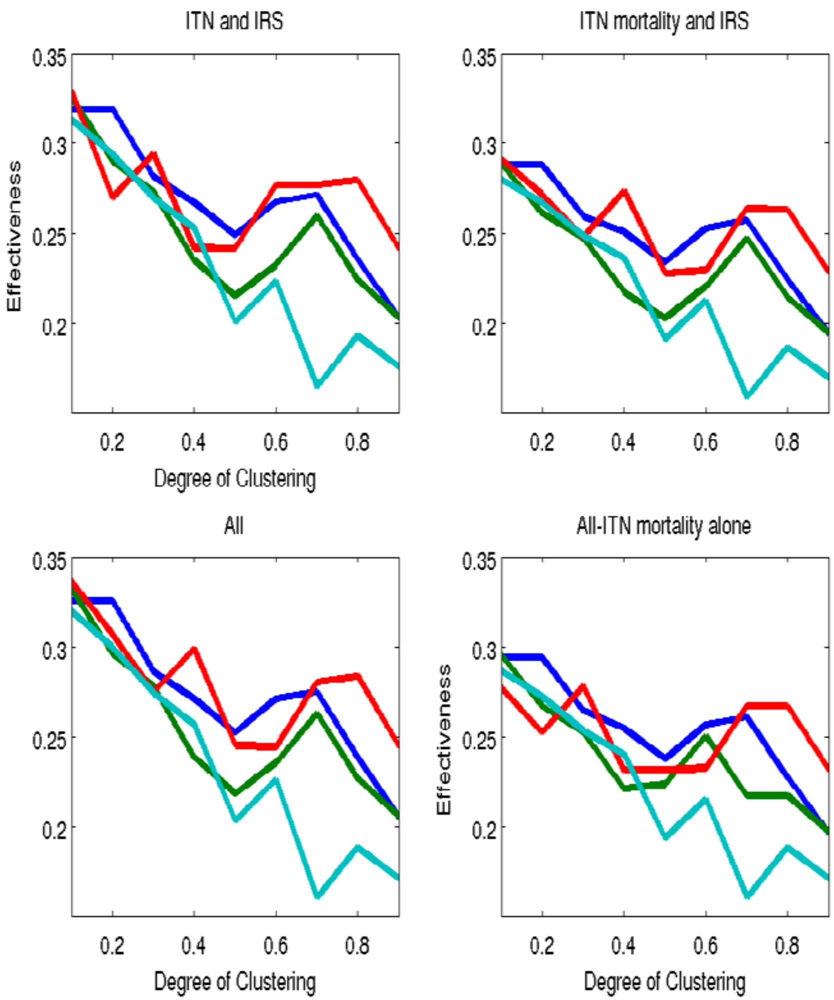
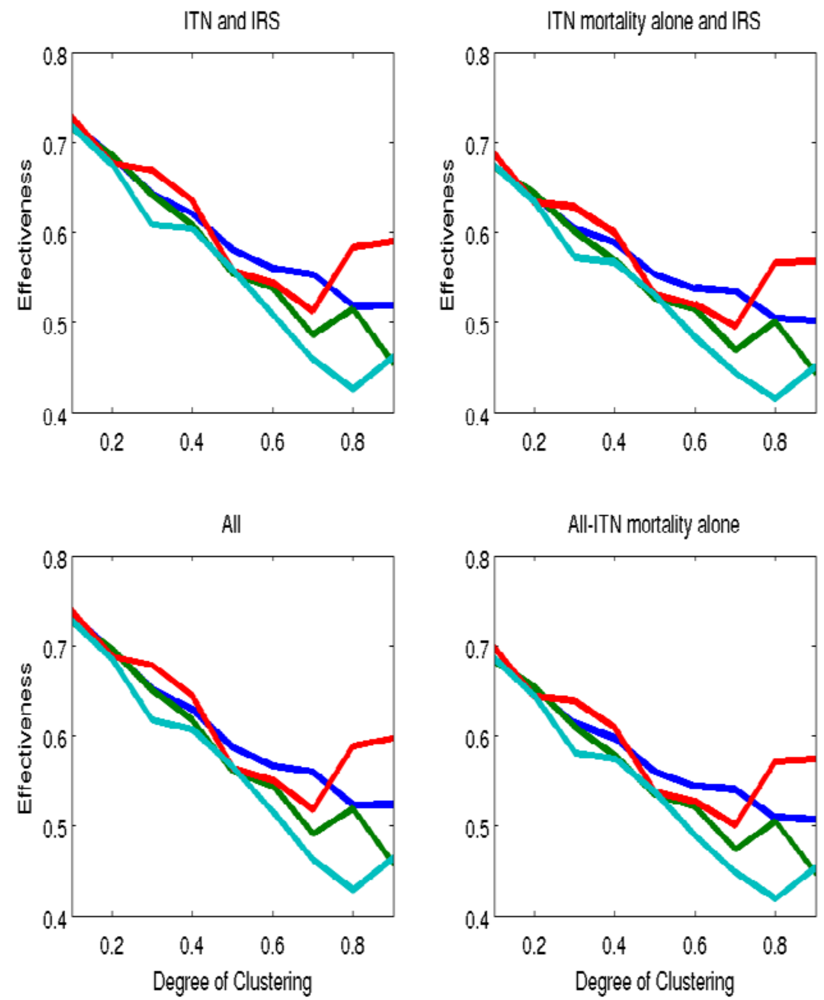
10% coverage



30% coverage



Results

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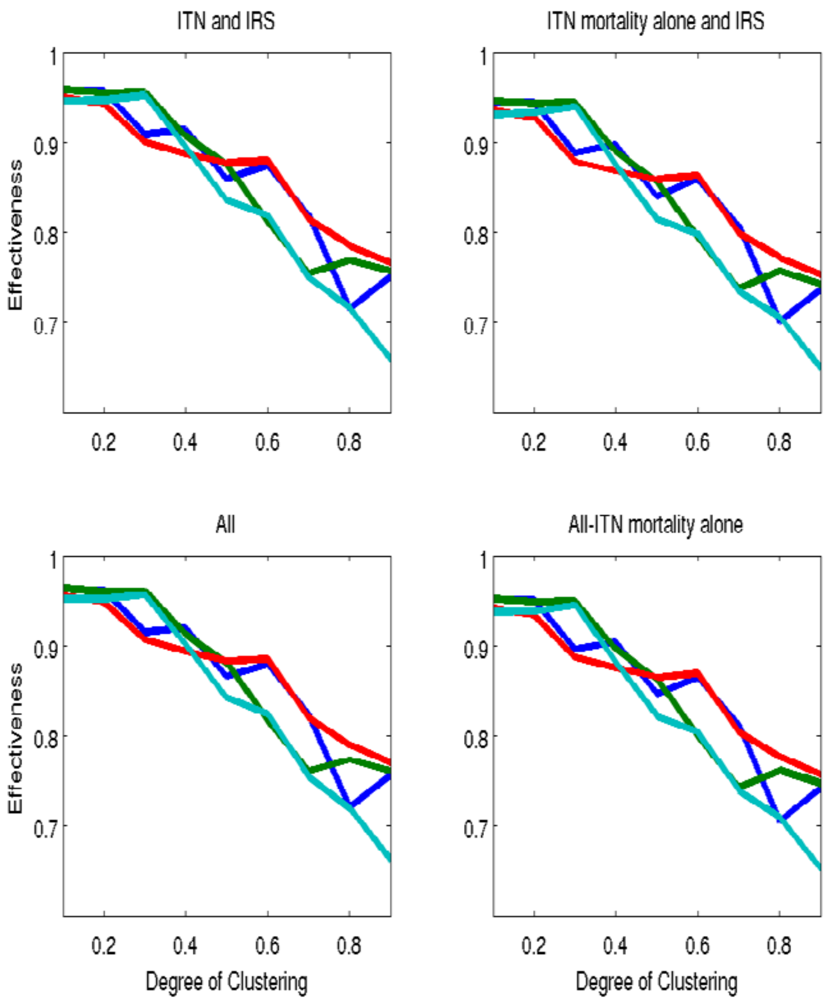
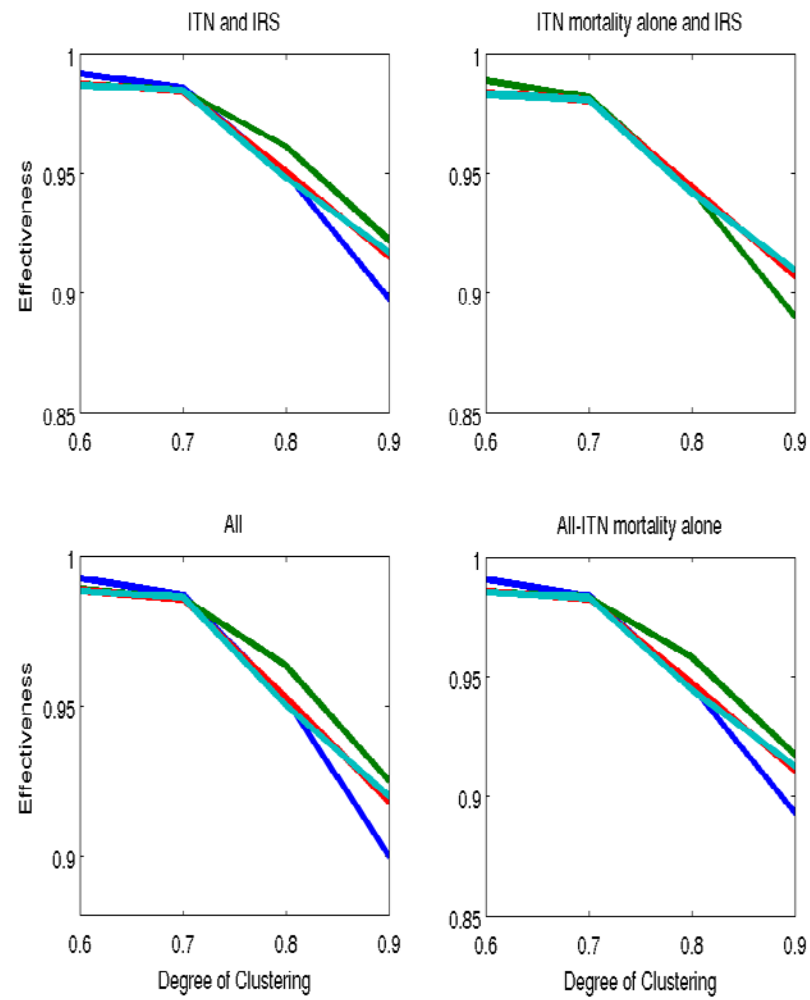
50 % coverage



70 % coverage



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Parameter Values

Parameter	Dimension	Baseline	Range
b		100	$50 - 300$
ρ_E	day^{-1}	0.50	$0.33 - 1.0$
ρ_L	day^{-1}	0.14	$0.08 - 0.17$
ρ_P	day^{-1}	0.50	$0.33 - 1.0$
μ_E	days^{-1}	0.56	$0.32 - 0.80$
μ_{L_1}	days^{-1}	0.44	$0.30 - 0.58$
μ_{L_2}	days^{-1} mosquitoes^{-1}	0.05	$0.0 - 1.0$
μ_P	days^{-1}	0.37	$0.22 - 0.52$
ρ_{A_h}	day^{-1}	0.46	$0.322 - 0.598$
ρ_{A_r}	day^{-1}	0.43	$0.30 - 0.56$
ρ_{A_o}	day^{-1}	3.0	$3.0 - 4.0$
μ_{A_h}	days^{-1}	0.18	$0.125 - 0.233$
μ_{A_r}	days^{-1}	0.0043	$0.0034 - 0.01$
μ_{A_o}	days^{-1}	0.41	$0.41 - 0.56$

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Parameter description

Parameter	Description	Dimension
b	number of female eggs laid per oviposition mosquitoes	dimensionless
ρ_E	egg hatching rate into larvae	per time
ρ_L	rate at which larvae develop into pupae	per time
ρ_P	rate at which pupae develop into adult/emergence rate	per time
ρ_{A_h}	rate at which host seeking mosquitoes enter the resting state	per time
ρ_{A_r}	rate at which resting mosquitoes enter oviposition searching state	per time
ρ_{A_o}	oviposition rate	per time
μ_E	egg mortality rate	per time
μ_{L_1}	larvae mortality rates	per time
μ_{L_2}	larvae density dependent mortality rates	$\text{time}^{-1}\text{animals}^{-1}$
μ_P	pupae mortality rates	per time
μ_{A_h}	mortality rates of mosquitoes of searching for hosts	per time
μ_{A_r}	mortality rates of resting mosquitoes	per time
μ_{A_o}	mortality rates of mosquitoes searching oviposition sites	per time