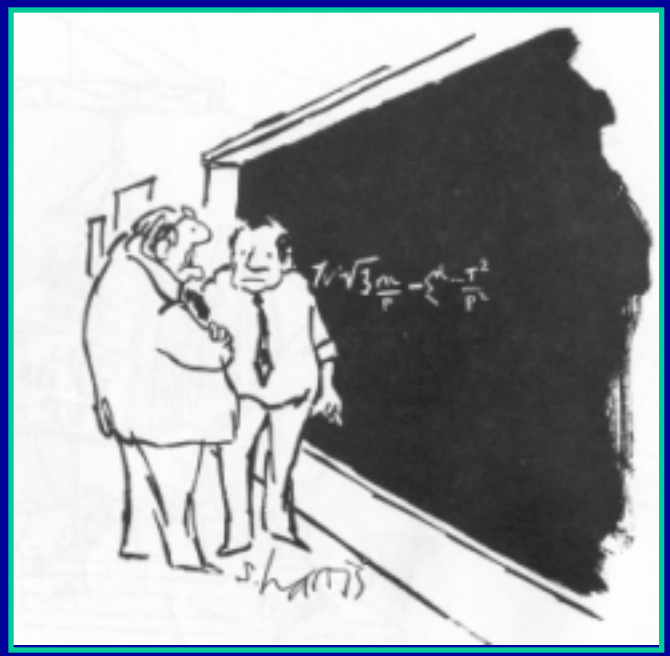
A Spatial Statistical Model for the spread of dwarf mistletoe within and between stands

Donald Robinson, ESSA Technologies
Brian Geils, USDA Forest Service
John Muir, BC Ministry of Forests

and 20 others

A Spatial Statistical Model for the spread of dwarf mistletoe within and between stands



"In effect what you're doing is you're taking a big lead off third…"

Dwarf Mistletoe - *Arceuthobium*

- widely-occurring severe pathogen of conifers
- ecological effects on forest community and habitat structure, composition & dynamics
- implications for fuels management

Dwarf Mistletoe - *Arceuthobium*

- damage can include reduced growth, reproduction & survival, stem/crown deformity (cankers and brooms)

Dwarf Mistletoe - Life History

- dispersal mainly ballistic
- immediate or delayed development - role of light
- multi-year vegetative development before reproduction
- fruit maturation requires 1+ years
- individuals produce multiple flower crops

Population Dynamics & Effects

- dispersal up to 14 m
- infections have **cumulative** impacts
- individual-tree infections increase slowly
- stand infestations develop over decades
- persistent expanding mistletoe centres

DM Rating System

- **DMR** - a relative index of mistletoe abundance and disease severity: the Hawksworth 6-class system
- individual tree rating is the **sum** of ratings for each crown third:

0 = none 1 = light 2 = heavy

- stand rating is the average of the host trees

Model History

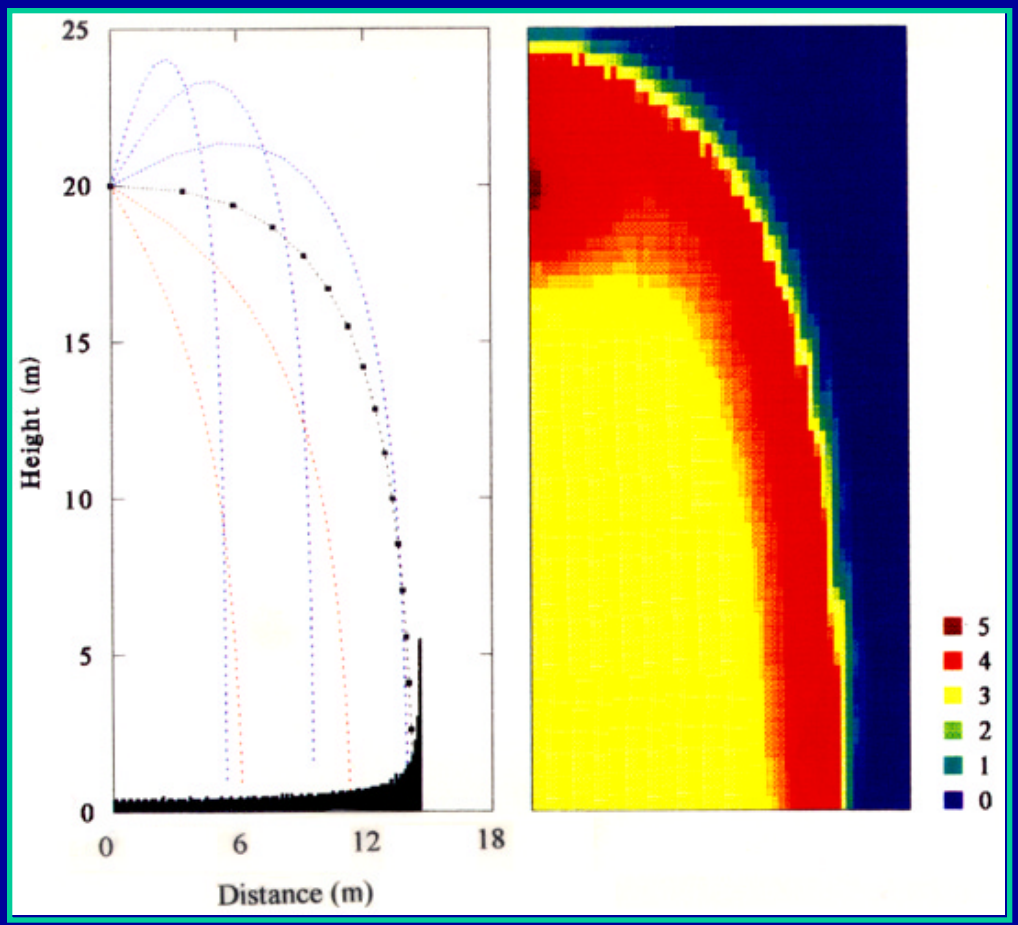
A nine-year collaborative effort involving

- **USDA Forest Service, Forest Health Technology Enterprise Team** Fort Collins, CO
- **Rocky Mountain Research Station** Flagstaff, AZ
- **ESSA Technologies Ltd.** Vancouver, BC
- **BC Ministry of Forests & Forest Renewal BC** Victoria, BC

Model Features

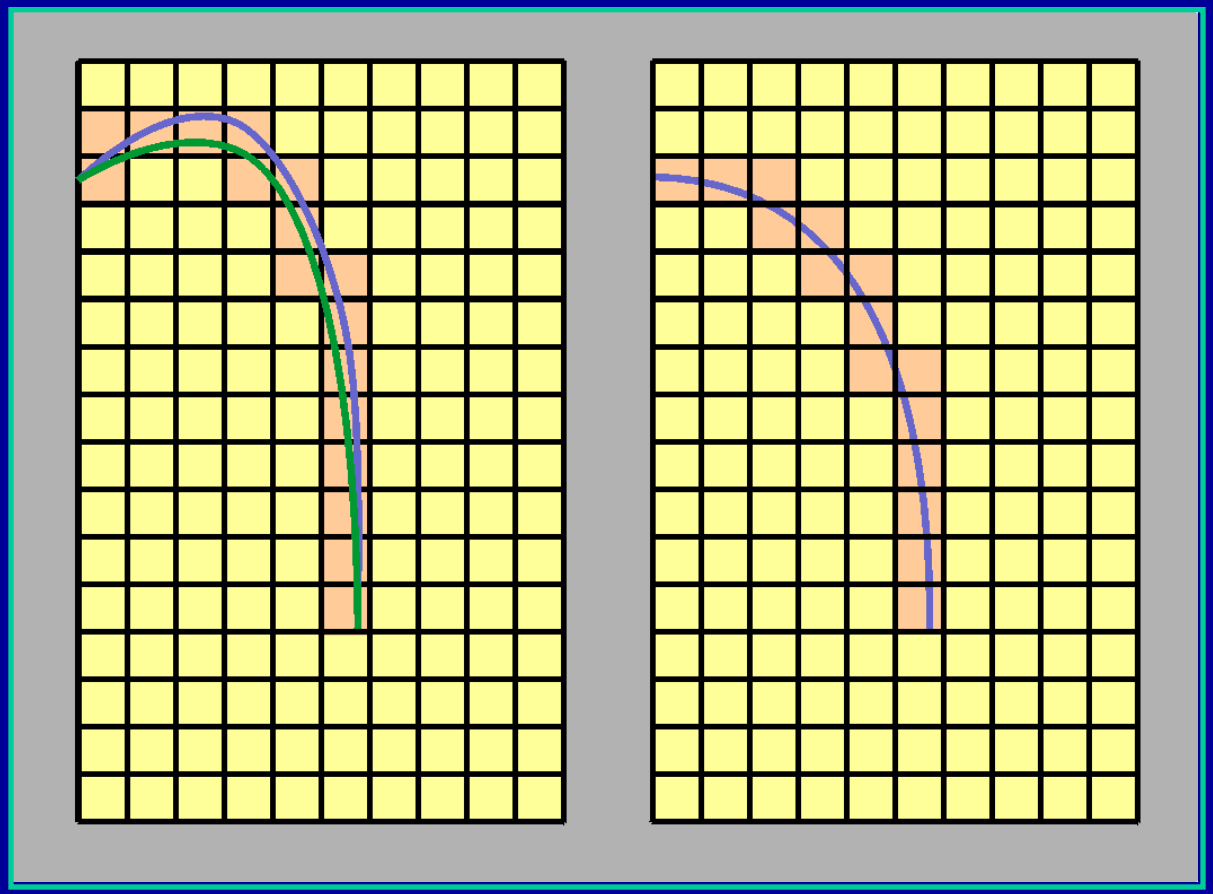
- propagation by **ballistic spread** with interception
- species, height and density - **crown structure & opacity**
- tree clumping - **stem map simulation**
- DMR patches - **spatial autocorrelation**
- role of light - **life history**
- complex management - **spread between stands**

Ballistic Spread



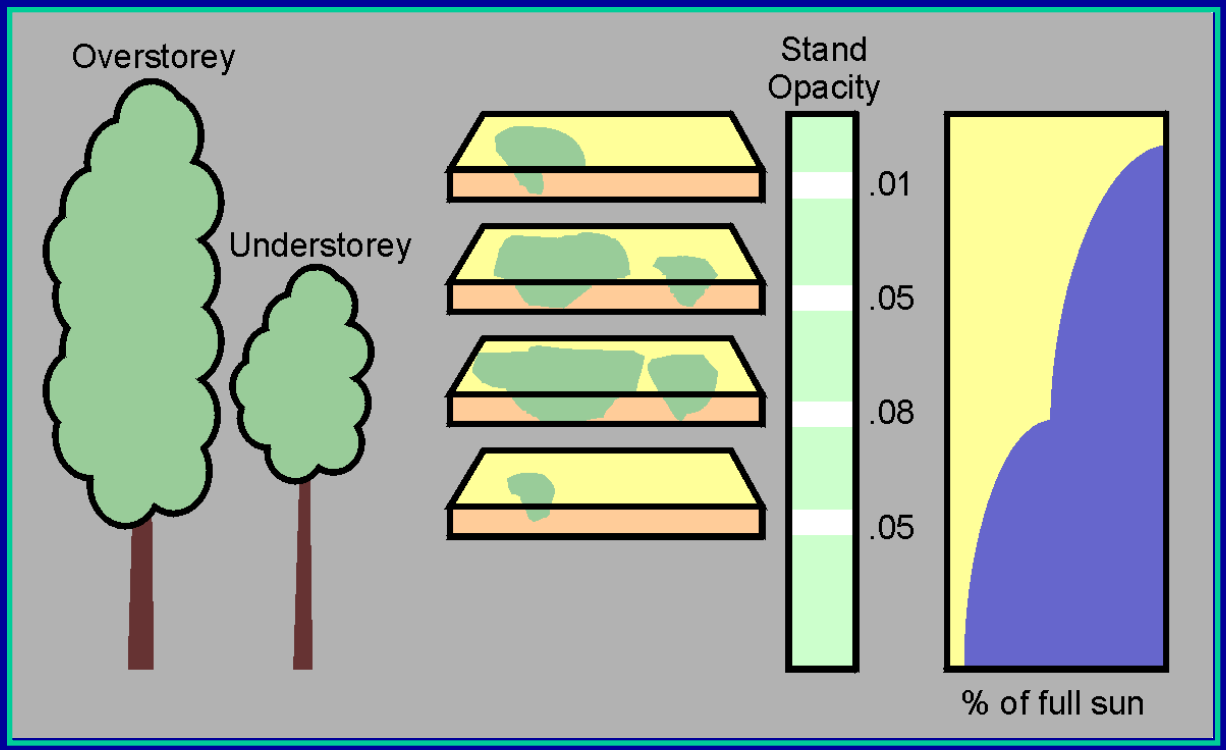
- random discharge angle
- precomputed trajectories
- spread ‘template’

Ballistic Spread



- 2 m grid resolution
- all paths counted
- different routes, frequencies & outcomes
- same start points
- same end points

Crown Structure & Opacity

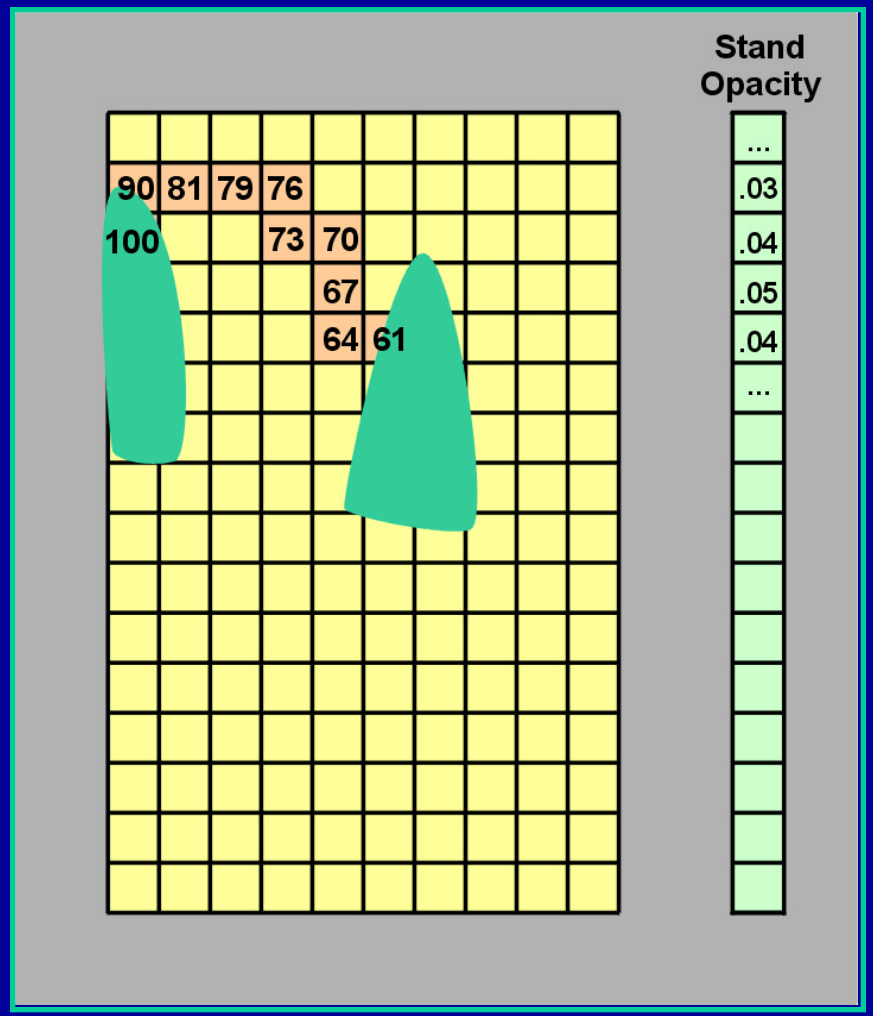


Impact:

- spread to neighbors
- light-driven DM maturation

- crown model & current inventory
- canopy space occupied at each height
- **stand average (open air) opacity**
- depends on stand composition & vertical structure

Crown Structure & Opacity



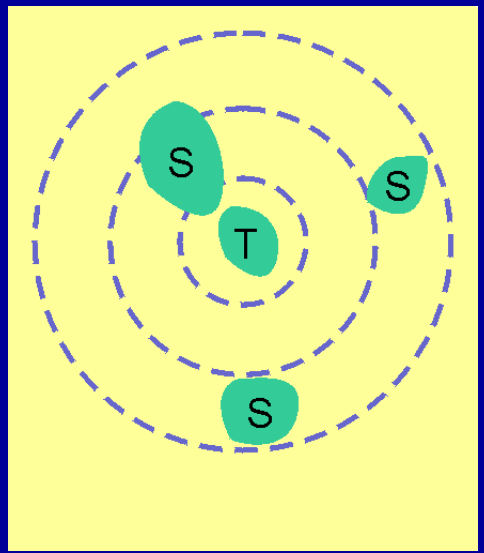
- crown shape and height
- within-source & within-target foliage opacity
- stand average (open air) opacity

- opacity depends on species
- stand average opacity depends on stand composition & structure

Interception:

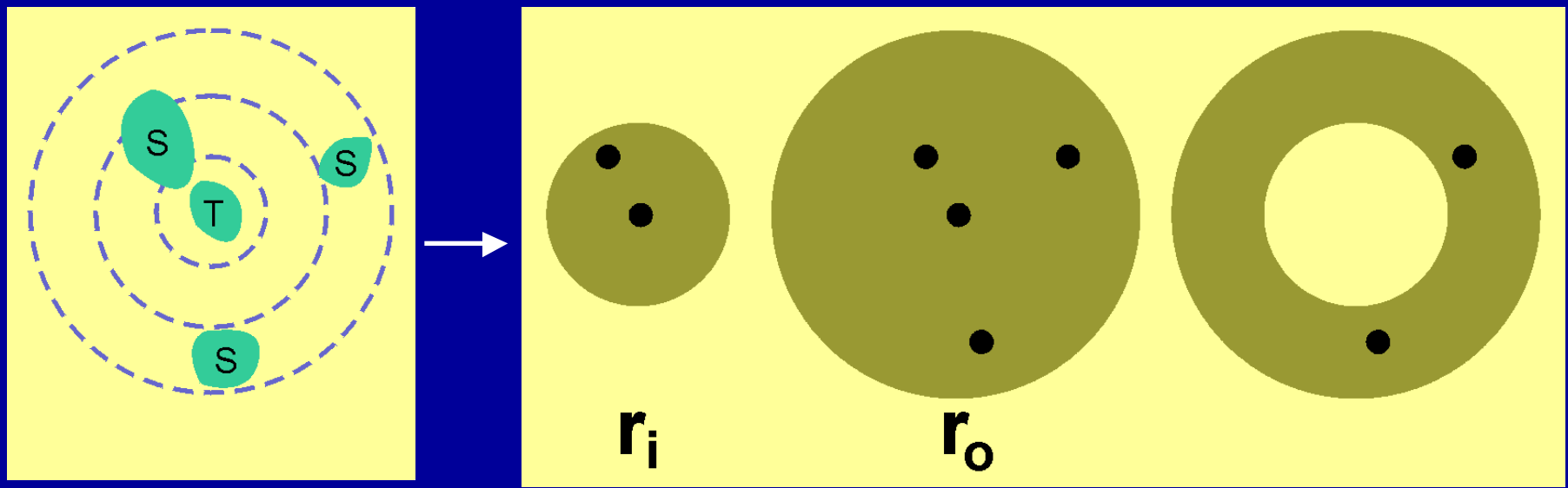
- **within-source = intensification**
- **within-target = spread**

Stem Map Simulation



- statistically representative **neighborhood**
- each tree a target at each timestep
- target tree at center
- surrounding source trees in 2 m rings
- stem distribution may be B() - P() - NB() = **clumping patterns**
- neighbors depend on stand composition and stem clumping

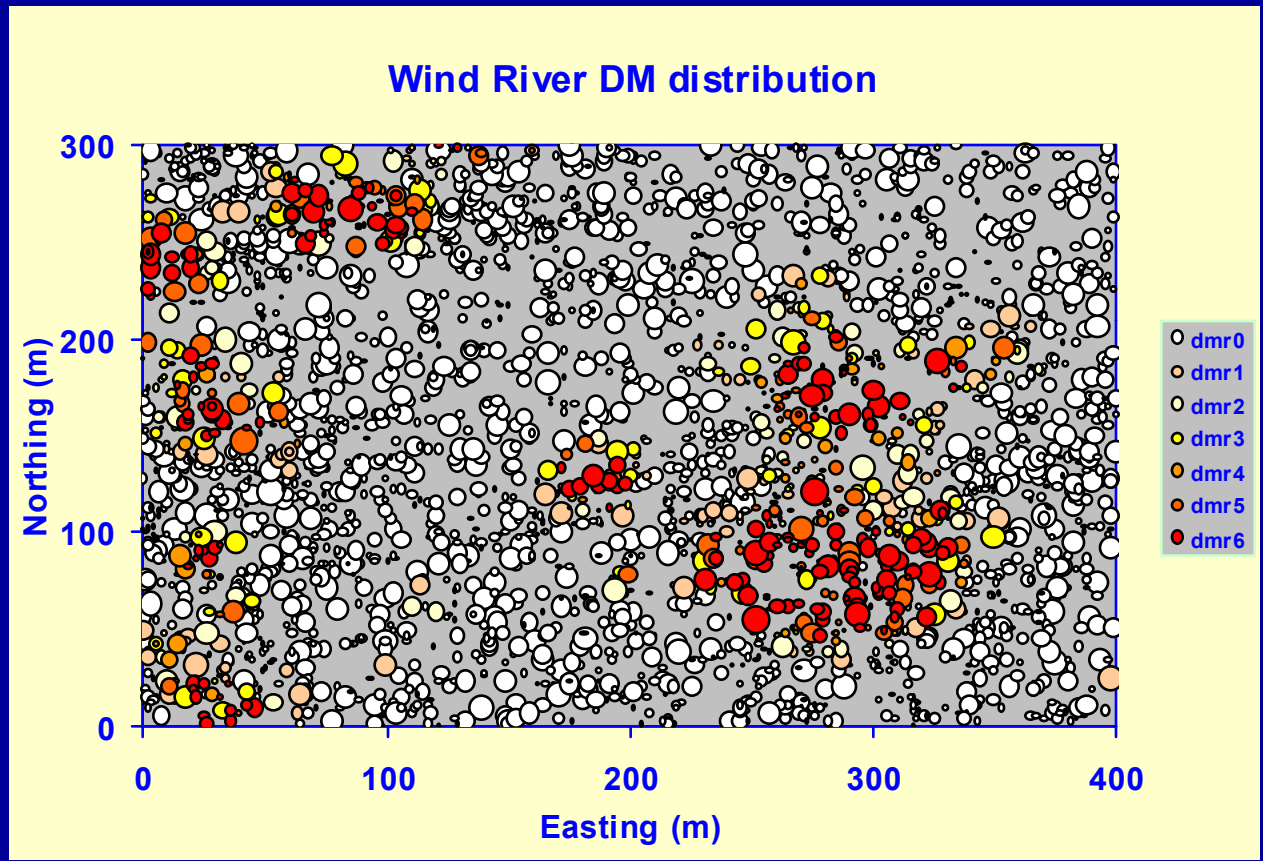
Stem Map Simulation



- 2 m rings consistent with 2 m height-resolution
- 14 m disc sampling scale
- number of trees in rings sensitive to numbers in adjacent rings

Spatial Autocorrelation

- DMR *similarities* between near neighbors greater than expected = **patchiness**



Spatial Autocorrelation

- a relationship that gives locally-appropriate neighbors
- a result of the dynamics of spread, intensification & mortality

$$\rho_i' = \rho_i \, e^{\alpha |t-i|} \frac{\sum_{j=0}^{6} \rho_j}{\sum_{j=0}^{6} \rho_j \, e^{\alpha |t-j|}}$$

- α changes ρ_i the density of trees of DMR i in the neighborhood of a target tree of DMR t

Spatial Autocorrelation

- DMR *similarities* between near neighbors greater than expected = **patchiness**
- locally-appropriate neighbors with overall stand statistics unchanged

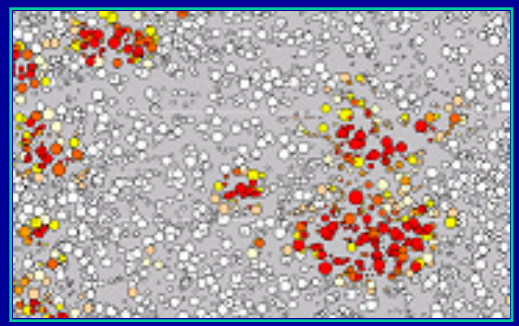
DMR	Average stand density
0	45
1	25
2	32
3	17
4	12
5	3
6	5
Total	139

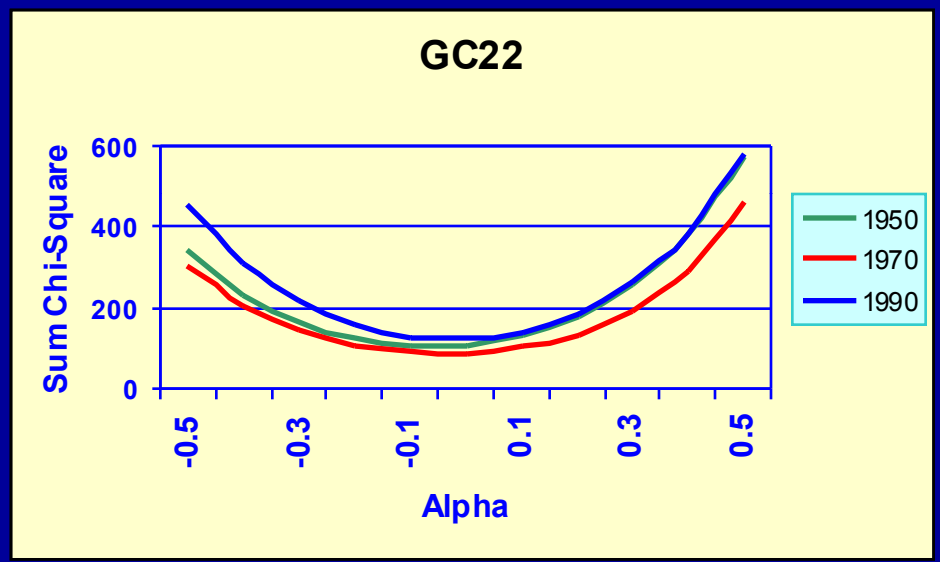
Source DMR	Target DMR 0	1	2	3	4	5	6
0	80	47	29	21	17	15	13
1	27	43	26	20	16	14	12
2	21	33	56	41	33	29	25
3	7	11	18	36	29	26	22
4	3	5	8	16	34	30	26
5	0	1	1	2	5	12	11
6	0	1	1	2	5	12	29
Total	139	139	139	139	139	139	139

Weighted density
45
25
32
17
12
3
5

Spatial Autocorrelation

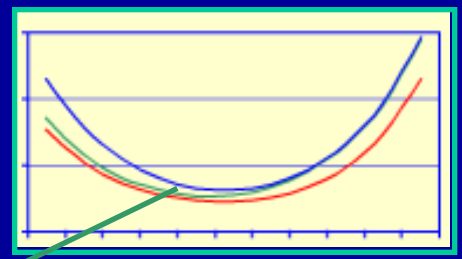
- α can be estimated from a stem mapped plot by minimizing χ^2





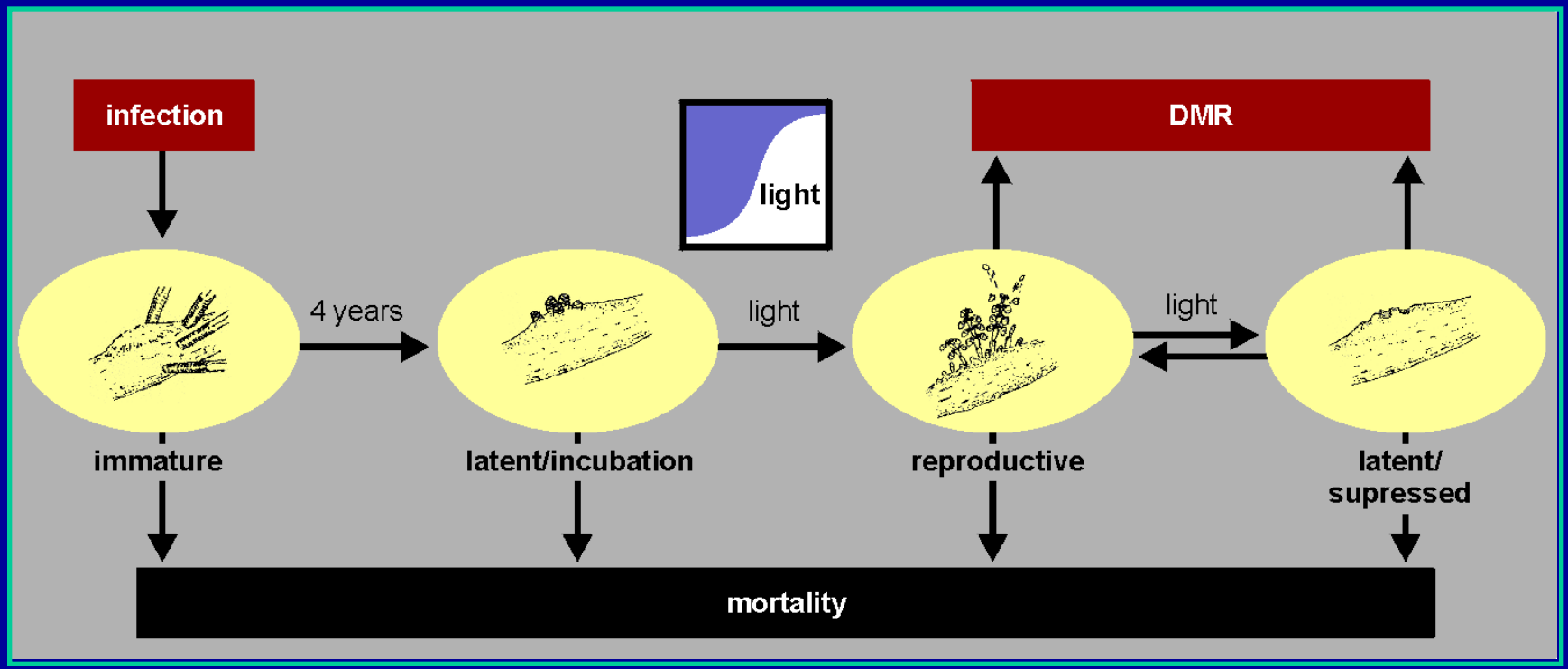
Spatial Autocorrelation

- empirical distribution of α
- 6 locations, 3 with repeated measures
- site or temporal trends not yet compelling
- mean: -0.103, SD: 0.075



Year	GC11	GC12	GC22	GC06	Ft Valley	Hemlock
1950		– 0.13	– 0.07			
1952				0.06		
1955		– 0.12	– 0.06	0.00		
1961		– 0.15	– 0.08	– 0.01		
1966		– 0.14	– 0.07	– 0.03		
1970		– 0.15	– 0.03	– 0.04		
1979		– 0.16				
1982		– 0.20	– 0.07	– 0.10		
1986		– 0.25				
1988				– 0.13		
1990		– 0.27	– 0.02	– 0.14		
1997	– 0.07	– 0.18			– 0.12	– 0.15

Life History



- 4 stages - driven by time and light
- crown opening induces resurgence of DM
- latent-suppressed & mortality simulate **biological control**

Single Stand: Results

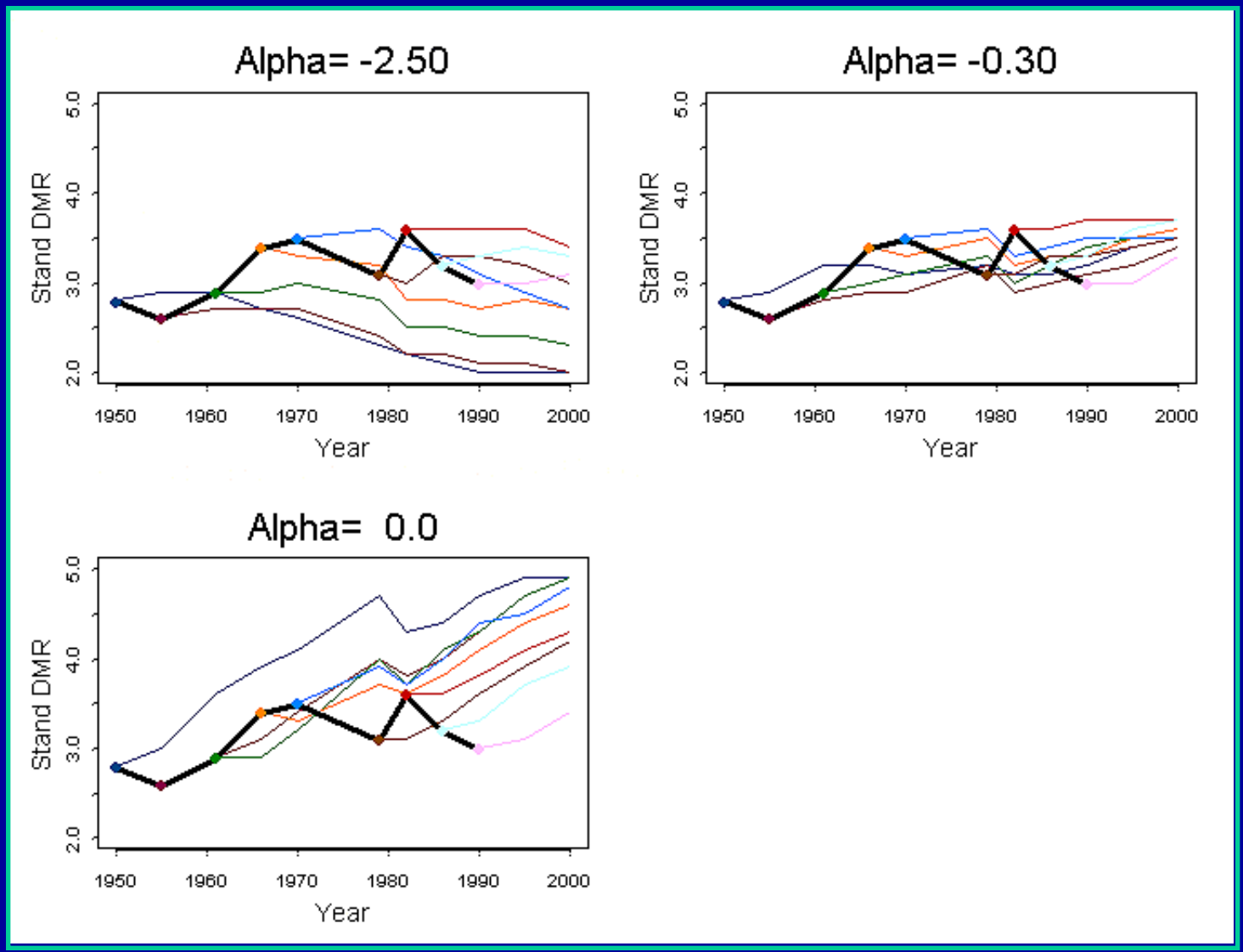
1 unmanaged **moisture-limited** ponderosa pine stand - Grand Canyon, AZ (CR variant)

2 managed **light-limited** western hemlock stand - Vancouver Island, BC (PN variant)

Grand Canyon: stand summary

- 10 acre open pure ponderosa pine stand (GC12)
- 9 inventories: 1950 to 1990 (+ 2000)
- all trees recorded in each inventory
- stand basal area 50 ft^2 ac^{-1} in 1950, declining to 23 ft^2 ac^{-1} in the 1990 inventory
- oldest trees are about 250 years old

Grand Canyon: stand DMR and DM patchiness



Single Stand: Results

1 unmanaged **moisture-limited** ponderosa pine stand - Grand Canyon, AZ (CR variant)

2 managed **light-limited** western hemlock stand - Vancouver Island, BC (PN variant)

Vancouver Island: stand summary

- predominantly western hemlock
- all trees recorded in 1 ha inventory

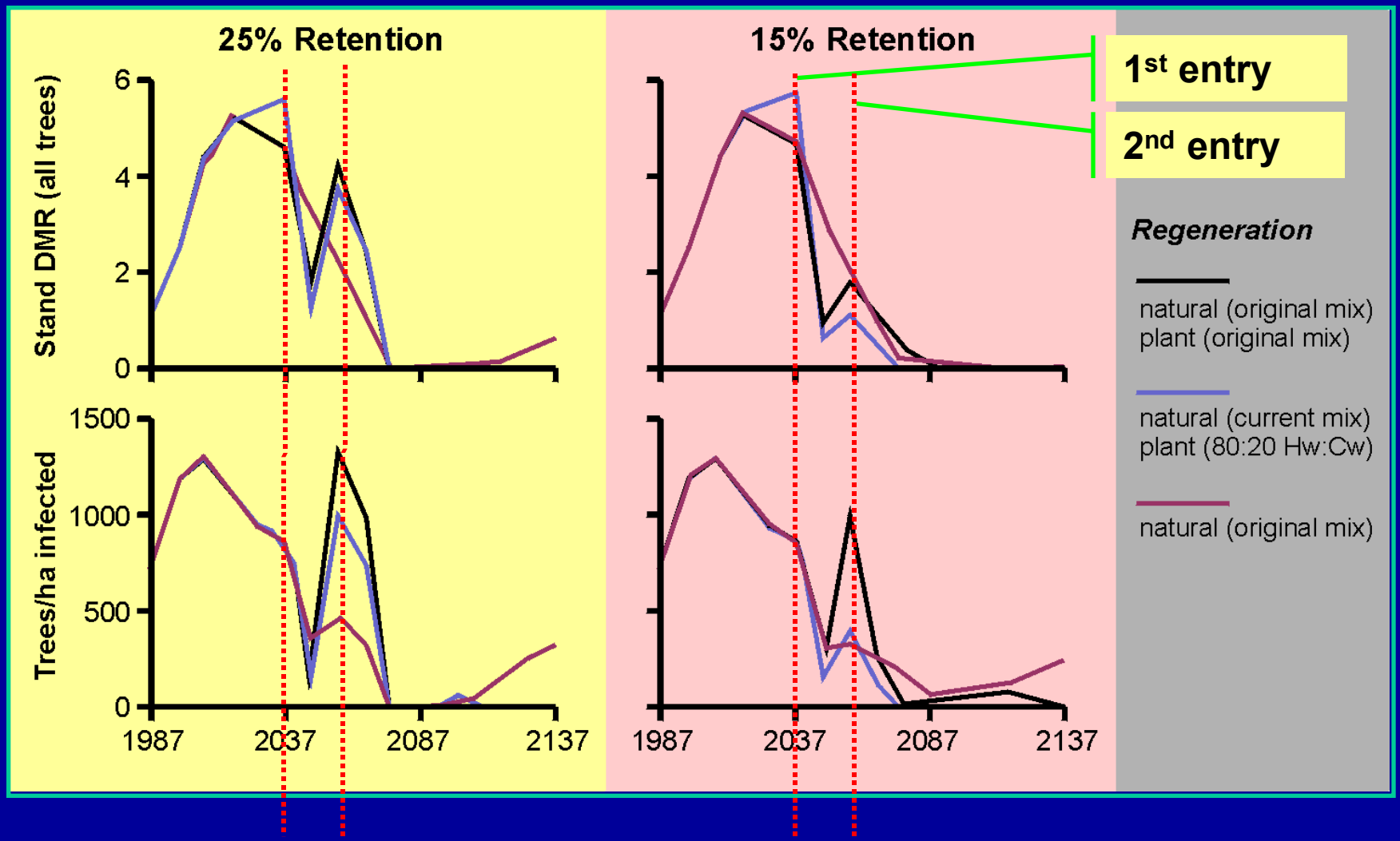
- SI - 24.3 m
- 380 m elevation, near-flat aspect
- age - 53 yrs (1987)
- QMD - 15 cm
- basal area - 44 m^2 ha^{-1}

- light mistletoe infestation
- DMR - 1.2 (1987)
- infected - 710 ha^{-1}

Vancouver Island: management summary

- entry at age 100 (Year 2037)
- target stocking 1200 ha^{-1}
- 25% & 15% evenly-spaced retention (shelterwood)
- 3 regeneration options
  - natural (original mix)
  - natural (current mix) + planted (80:20 Hw:Cw)
  - natural (original mix) + planted (original mix)
- residual overstorey removal 20 yr after entry
- 15% mortality to advanced regeneration at entry
- no natural regeneration in planted stands for 20 years after entry

Vancouver Island: 2 retention systems



Vancouver Island: 2 retention systems

Summary

1 DMR and infected trees decline after first entry

2 fast-growing young stands (initially) outgrow DM

3 Shelterwood Harvest

- 25% retention: more DM, more subsequent impact

4 Regeneration Options

- less DMR decline in natural mix: no ‘dilution’ effect from planting
- planting with cedar reduces DM transmission

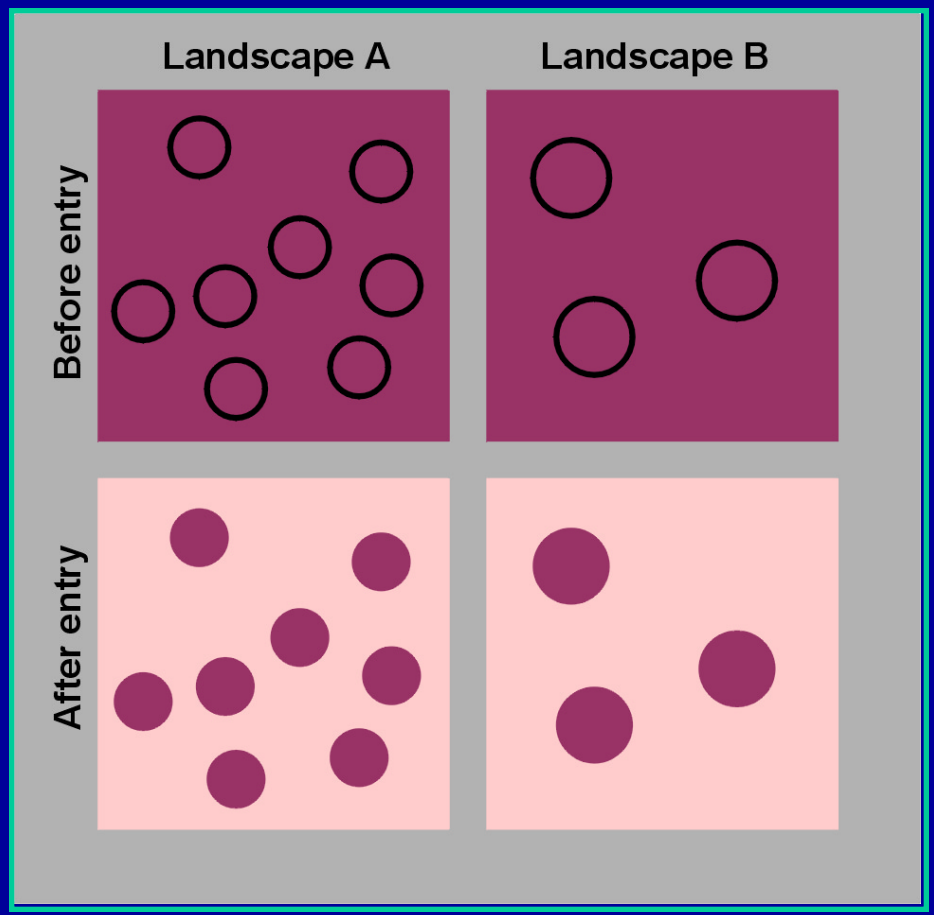
Single Stand: Conclusions

The Spatial Statistical DM model responds to

- spatial arrangement - clumping and patchiness
- over and understorey structure and species mixtures
- management and regeneration

Spread Across Boundaries

Spread Across Boundaries



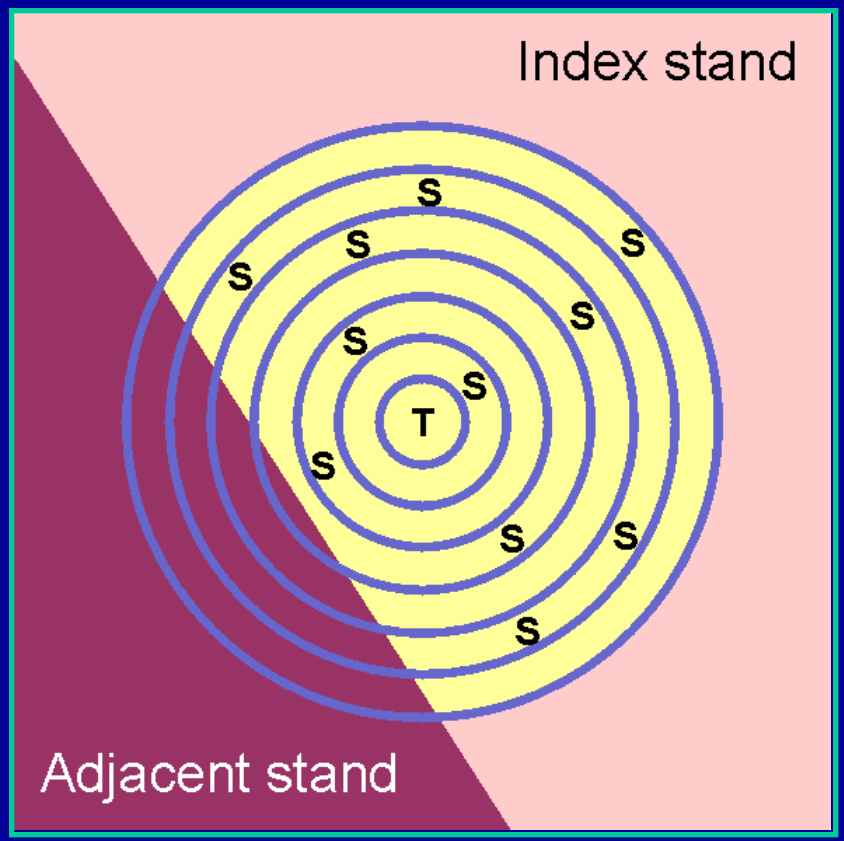
15% Group Retention Harvest

- 2 group retention sizes:

  8 x 0.375 ha
  3 x 1.00 ha

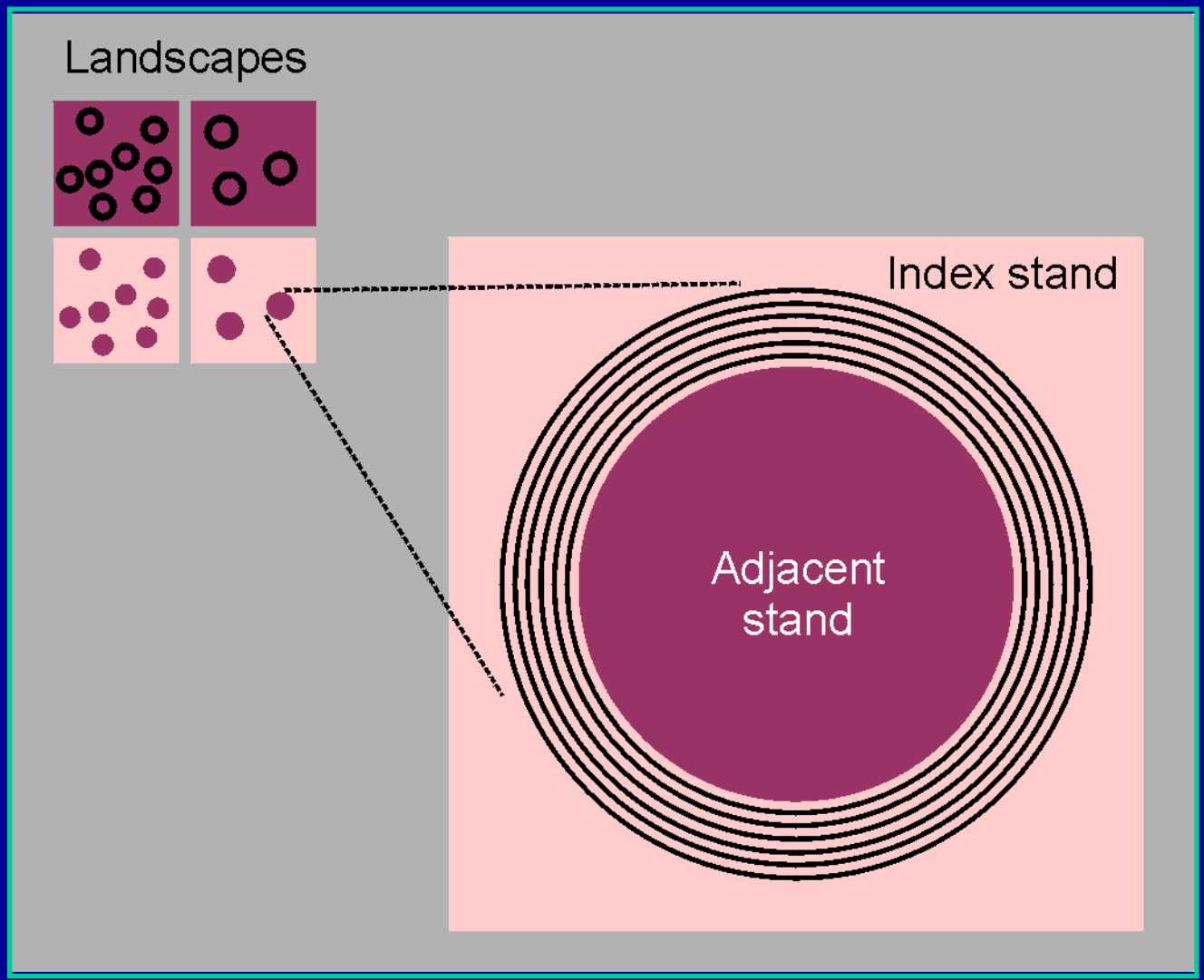
- larger groups have less relative area near edges

Spread Across Boundaries

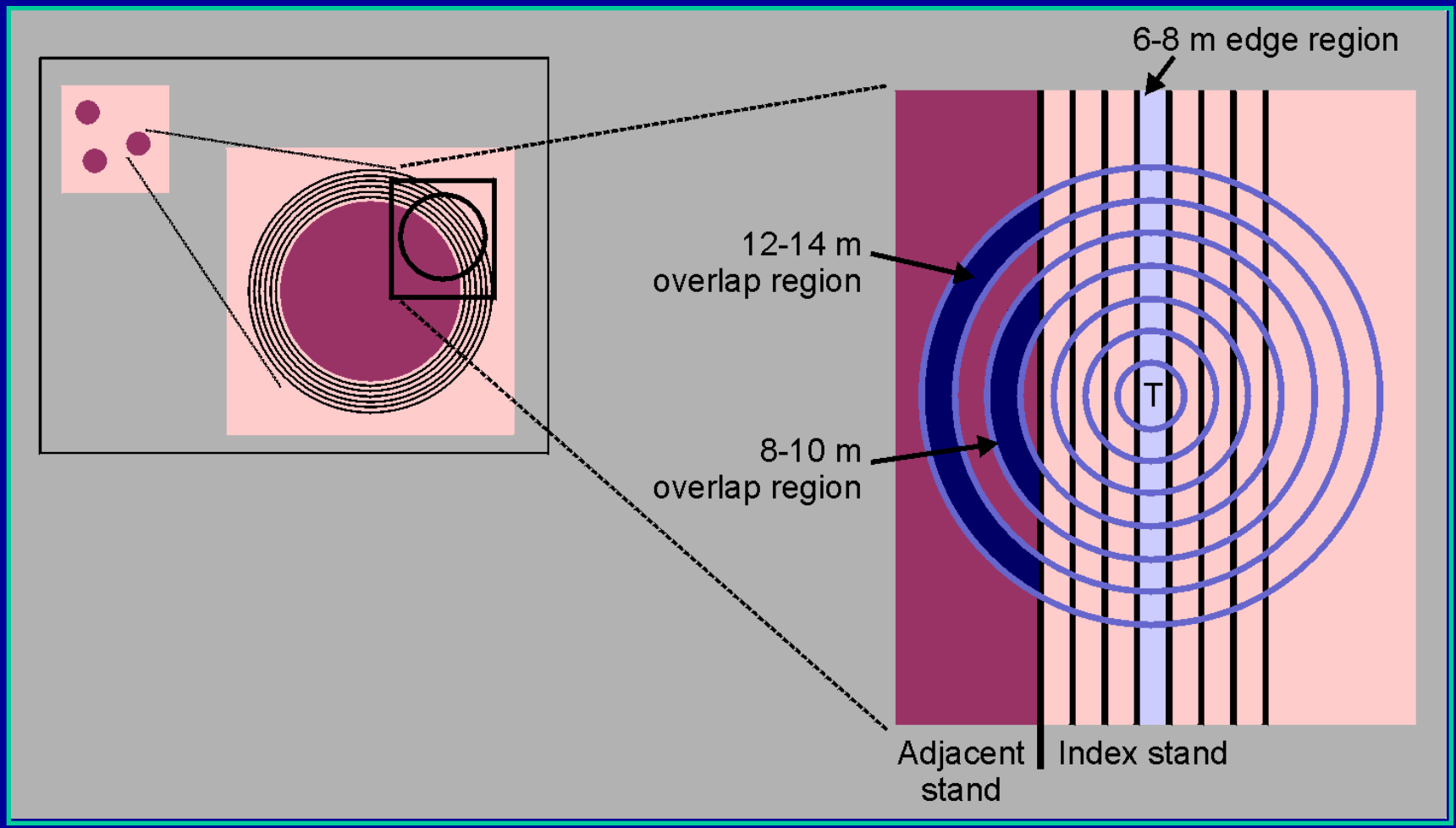


- a proportion of trees lie near stand boundaries
- DM can spread across these boundaries in either direction

Spread Across Boundaries



Spread Across Boundaries



Spread Across Boundaries

Edge Region	Overlapping Ring Area (m^2)						
	0-2	2-4	4-6	6-8	8-10	10-12	12-14
0-2	2.46	14.76	27.39	39.97	52.54	65.11	77.68
2-4		3.63	18.48	31.57	44.31	56.96	69.57
4-6			4.50	21.60	35.32	48.34	61.15
6-8				5.23	24.32	38.73	52.10
8-10					5.87	26.77	41.87
10-12						6.45	29.01
12-14							6.98

	Overlapping Ring Proportion						
0-2	0.1955	0.3915	0.4359	0.4544	0.4646	0.4710	0.4755
2-4		0.0962	0.2942	0.3589	0.3918	0.4121	0.4259
4-6			0.0716	0.2455	0.3123	0.3497	0.3743
6-8				0.0595	0.2150	0.2802	0.3189
8-10					0.0519	0.1936	0.2563
10-12						0.0467	0.1776
12-14							0.0427

General Conclusions

The Spatial Statistical DM model responds to

- spatial arrangement - clumping and patchiness
- over and understorey structure and species mixtures
- management and regeneration

The Multistand DM model

- uses an identical spatial representation to model between-stand interactions

Ongoing Work: Single- and Multi-stand Model

- linkage to TASS individual tree model: *complete*
- coding of multi-stand model (PPE+PN+DM): *nearly complete*
- parameter estimation from stem-mapped stands, life history & light extinction studies: *ongoing*
- validation with long-term monitoring plots: *ongoing*

Contacts

More information on this model
and on mistletoes is available at:

www.essa.com/forestry/mistletoe
www.rmrs.nau.edu/mistletoe

Donald Robinson drobinson@essa.com
Brian Geils bgeils@fs.fed.us
John Muir john.muir@gems1.gov.bc.ca