Dynamics of natural temperate forests
- is there a universal model?

photo: Kateřina Slámová

Blue Cat research team

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What we are looking for?

1994

SALAJKA
(Beskydy)

2008

To understand the dynamics of tree layer in space and time and the spatial relations.

What we are looking for?

Disturbances - events making growing space available (Picket et White 1985; Oliver et Larson 1990).

1994

SALAJKA (Beskydy)

2008

Disturbances:

- frequency
- distribution/range
- severity/intensity
- endo- or exogenous

Hypothese: Natural (primeval) temperate forest dynamics is a cyclical process where the different patches with similar development are cyclically changed in the time. The patches have different ratio of living and dead wood and different developmental trends.

Questions (no hierarchic order):

- which features and variables should we measure?
- which scale of assessment should we use (how to assess endogenous and exogenous disturbances)?
- how to separate and classify the parts of cycle with similar processes (how to identify the patches of stages in the field/in the datasets)?

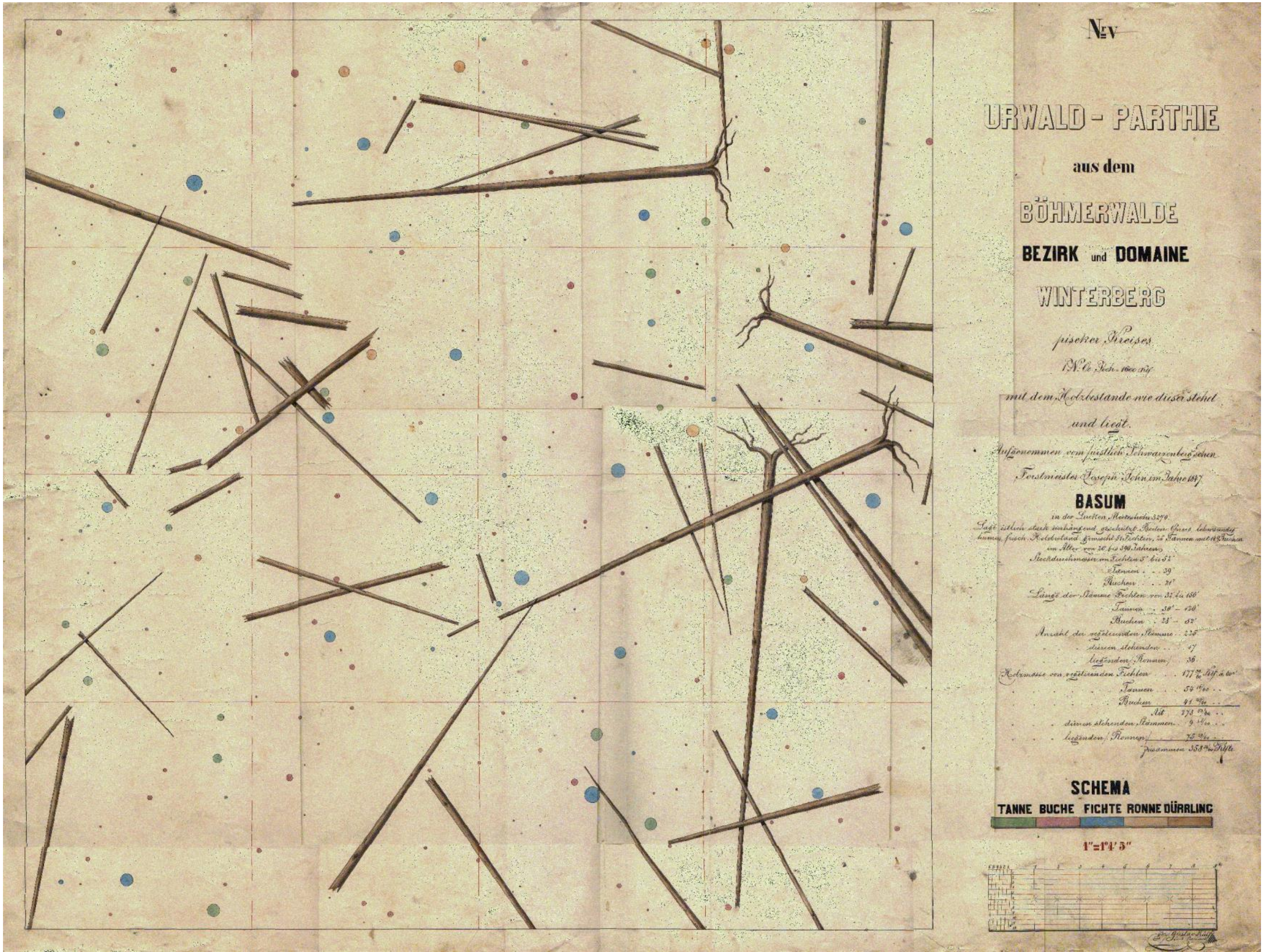
Three steps:

- Definition and classification of stages and phases – 2008-2010

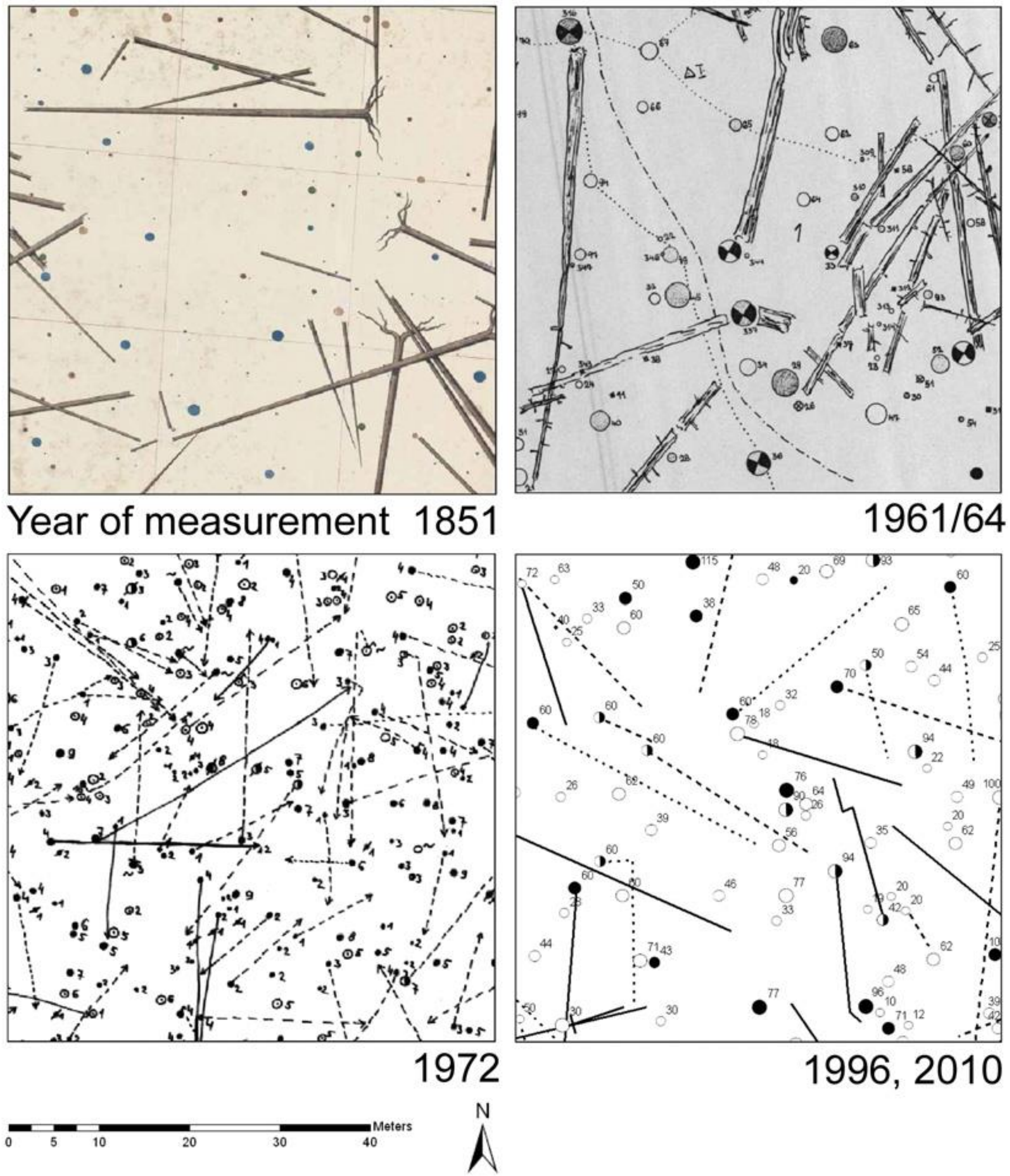
- Patch dynamics in the space and varibalitiy of patches on the altitudinal vegetation gradient – 2011-2014

- Spatio(multi)-temporal dynamics – transition between stages and phases – 2015-2017

Josef John – first idea how to described the dynamics of temperate forests - **1851**



Boubín - longest spatio-temporal dataset in the World



Šebková et al. 2011, Forest Ecology and Management

The Journal of Ecology, Vol. 35, No. 1/2. (Dec., 1947), pp. 1-22.

VOLUME 35, NOS. 1 AND 2 DECEMBER 1947

PATTERN AND PROCESS IN THE PLANT COMMUNITY*

BY ALEX. S. WATT, *Botany School, University of Cambridge*

(*With eleven Figures in the Text*)

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THE PLANT COMMUNITY AS A WORKING MECHANISM
THE EVIDENCE FROM SEVEN COMMUNITIES
The regeneration complex
Dwarf Callunetum
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Bracken
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SUPPLEMENTARY EVIDENCE
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REFERENCES

Beechwood

patch

phase

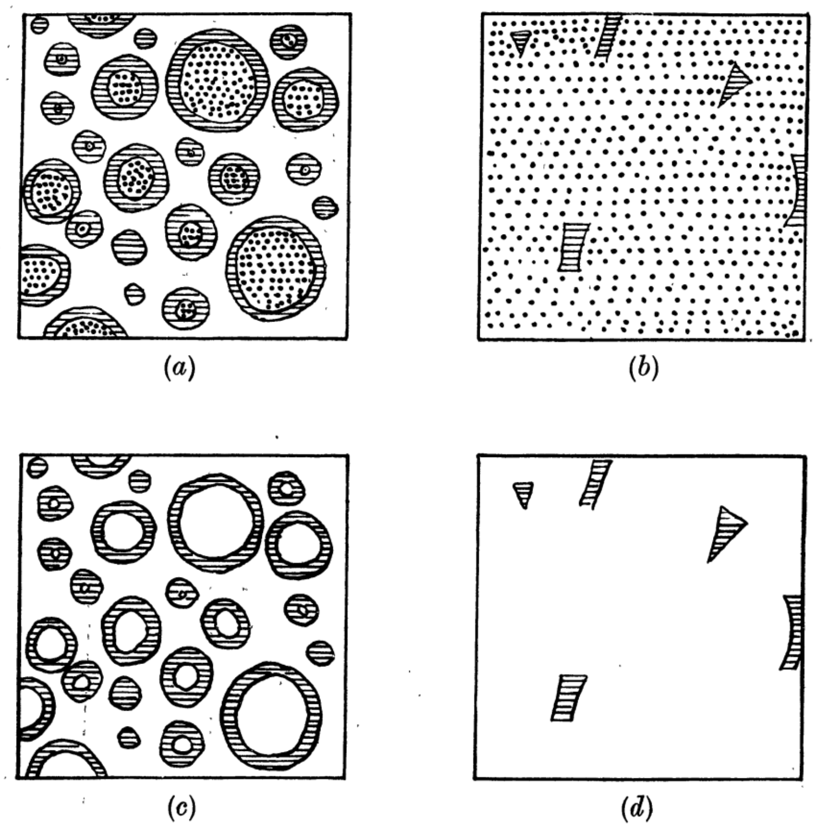
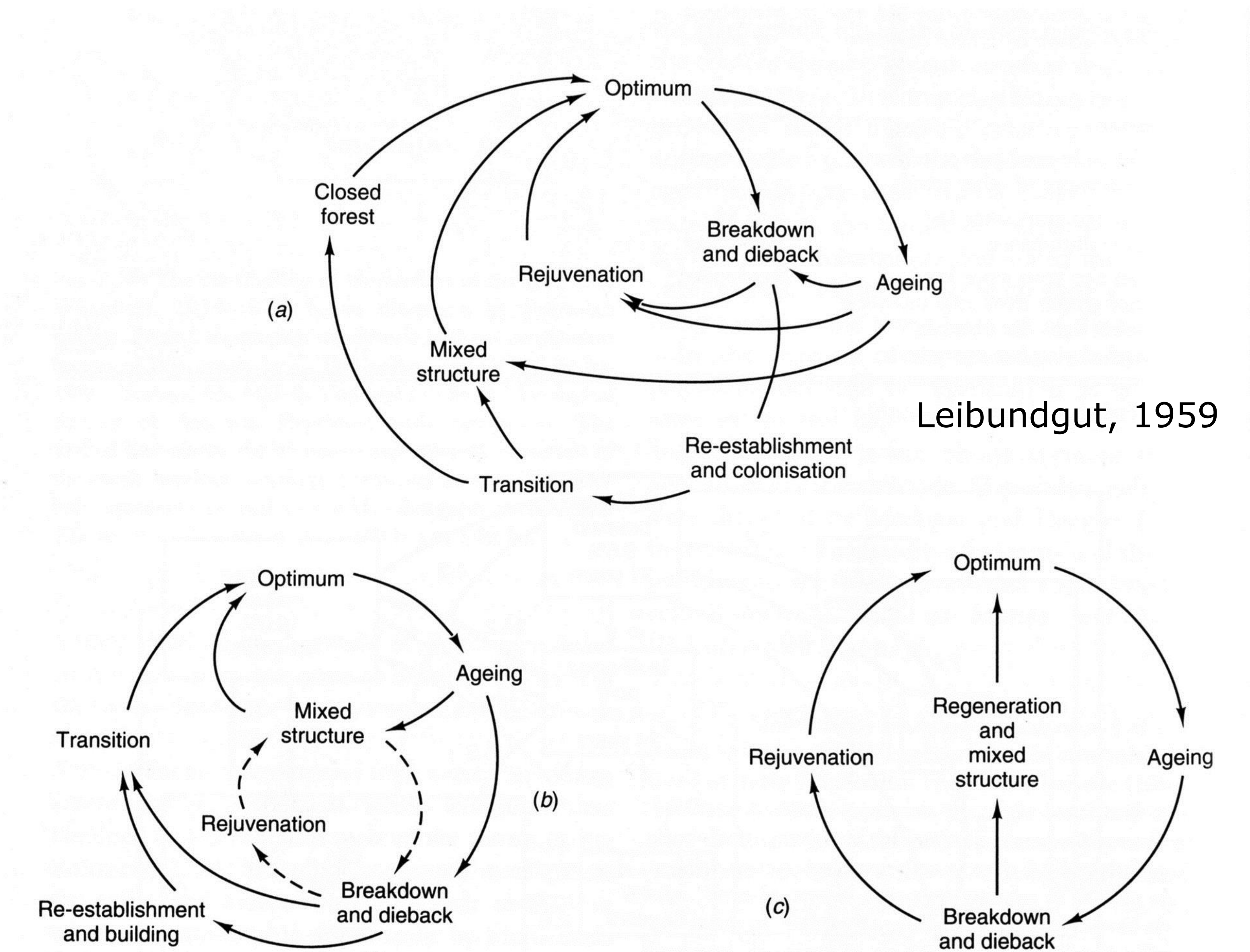


Fig. 9. Diagram to show the effect of drought on *Agrostis* in two areas of Festuco-Agrostidetum at differ stages of development. In (*a*) there are many small (young) patches of *Agrostis*; in (*b*) the patches ha grown and fused so that the bulk of the area is in the mature phase. In (*c*) and (*d*) drought has killed t *Agrostis* in the mature phase only of (*a*) and (*b*).

ukázky modelů vývojových cyklů temperátních lesů



Leibundgut, 1959

Zukrigl, 1963

Mueller-Dombois, 1987

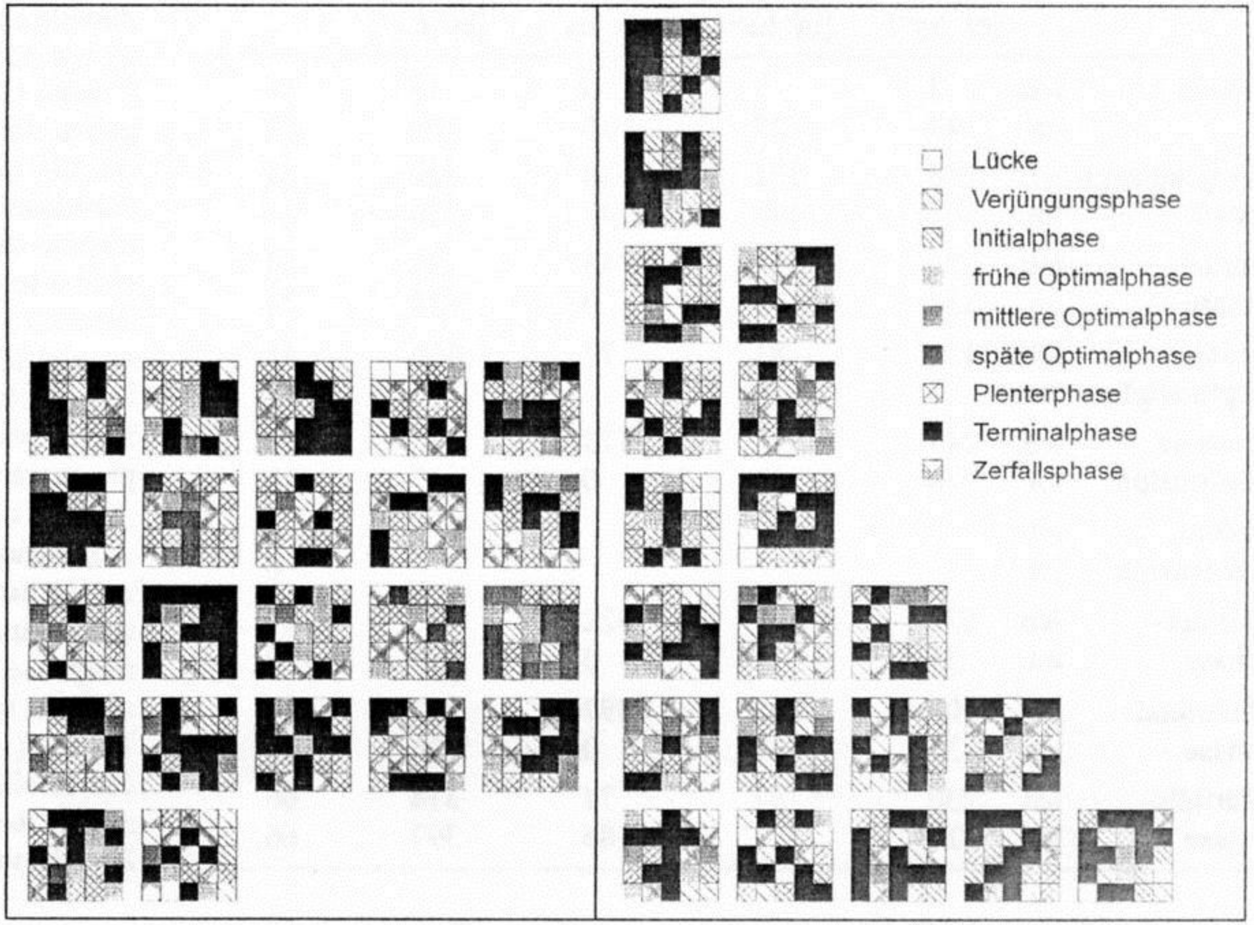
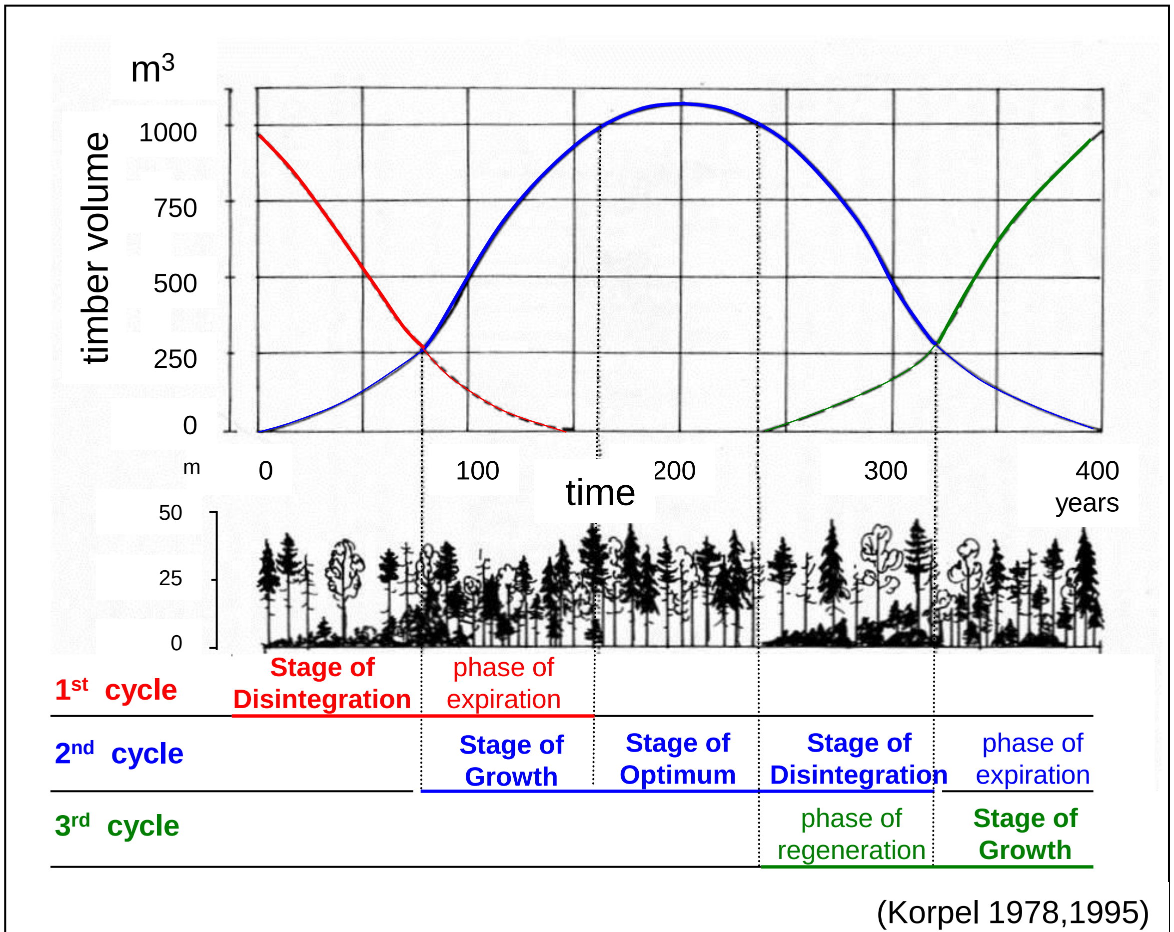


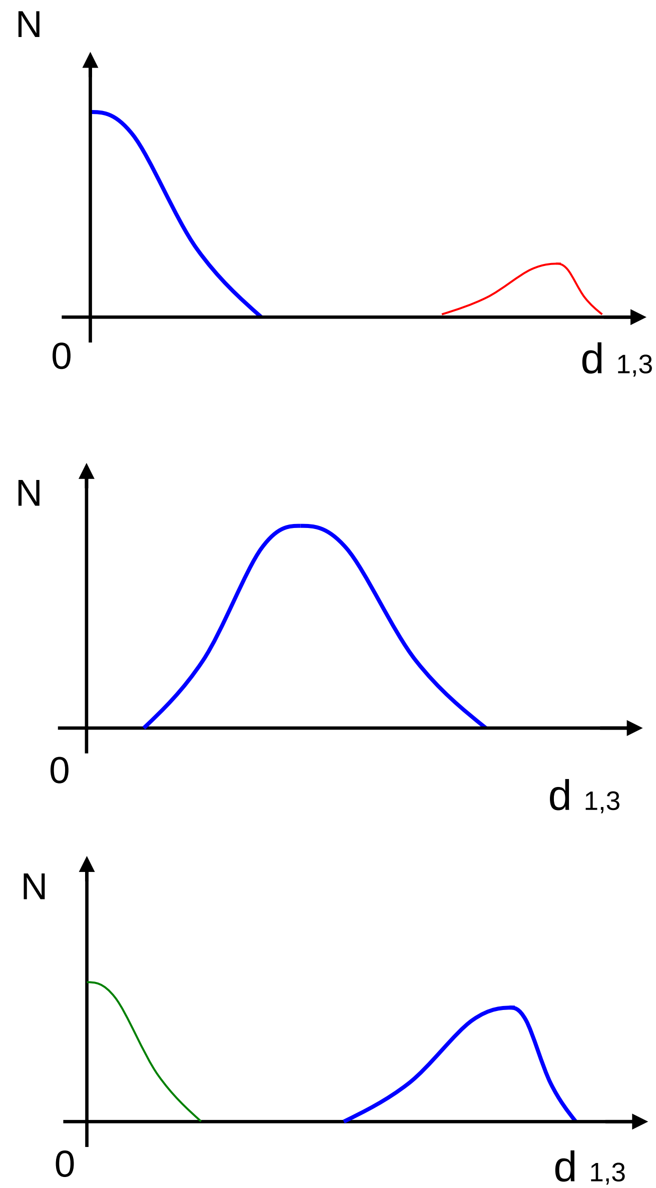
Abb. 3. Ausscheidung der Waldentwicklungsphasen auf 12,5 m x 12,5 m-Flächen für die Urwaldreservate Havešová (links) und Kyjov (rechts). Die einzelnen Probeflächen sind in Havešová 200 m und in Kyjov 20 m voneinander entfernt.
Forest development stages in Havešová (left) and Kyjov (right) determined on 12.5 m x 12.5 m squares. The distance between sample plots (62.5 m x 62.5 m) is 200 m in Havešová and 20 m in Kyjov.

Tabaku et al. 1999

Drössler et al. 2006

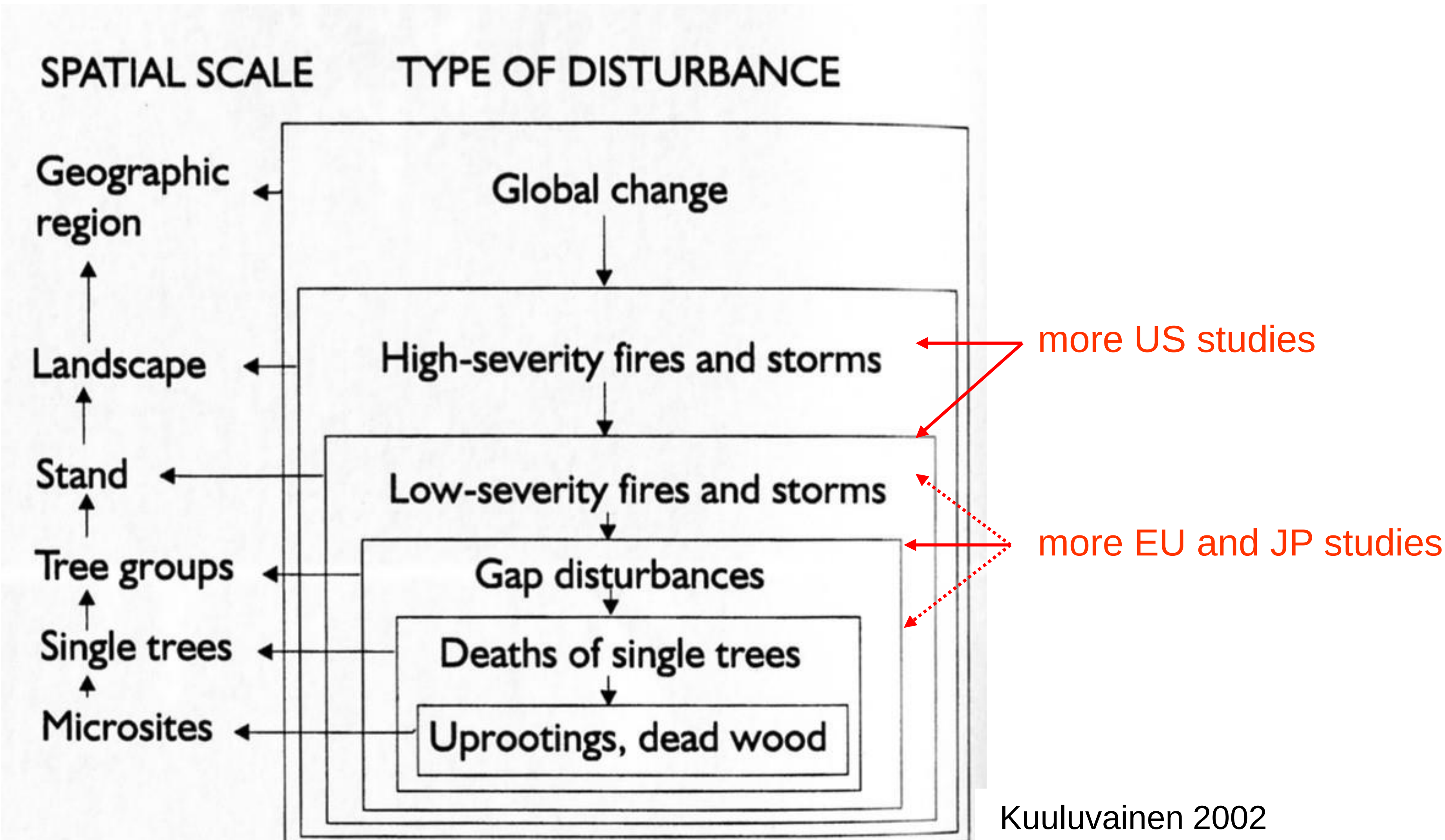
Developmental cycle model
(Korpel 1978, 1995)





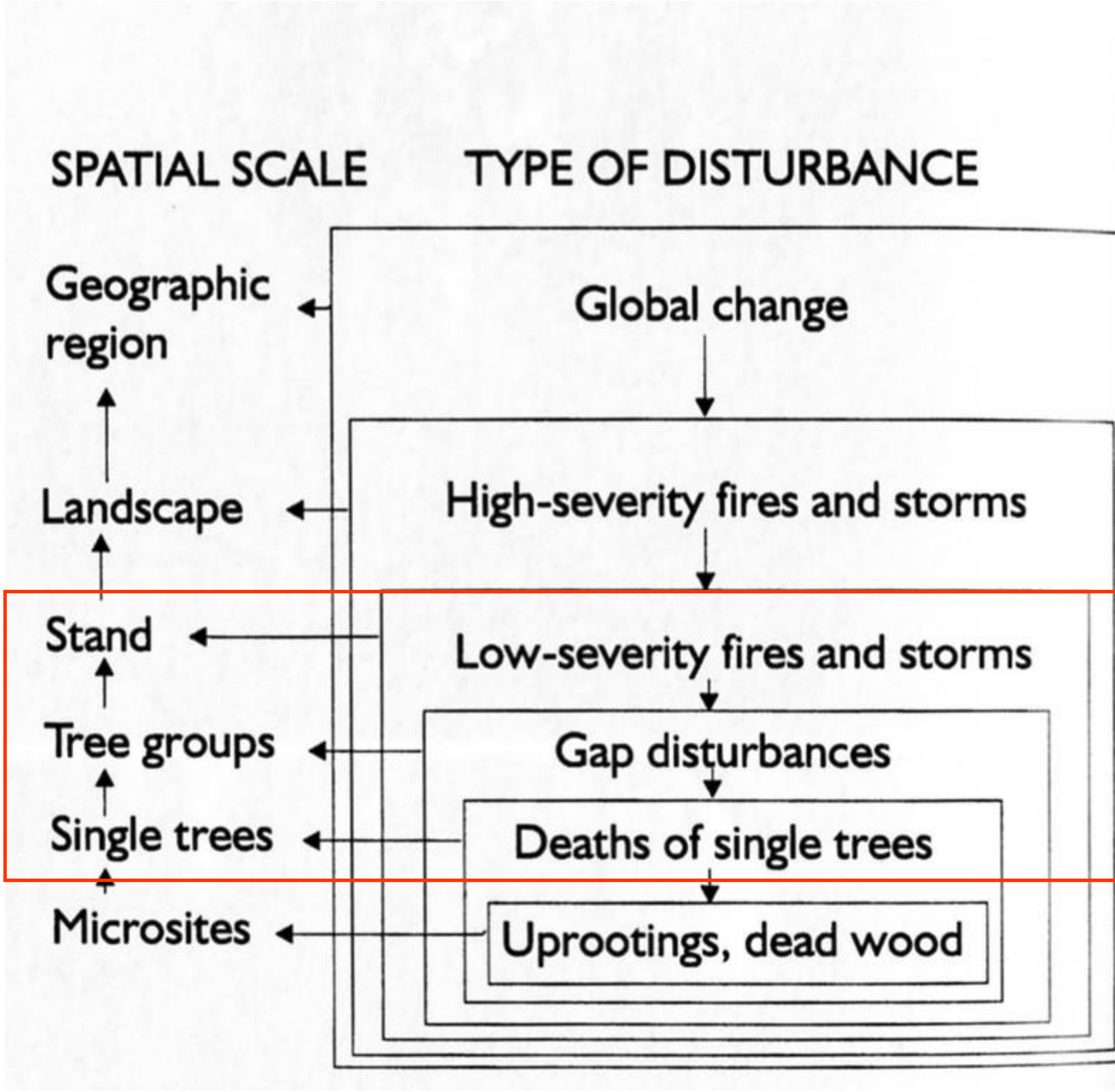
Which scale of assessment should we use?

Spatial scales and the often hierarchical nested occurence of different disturbance factors



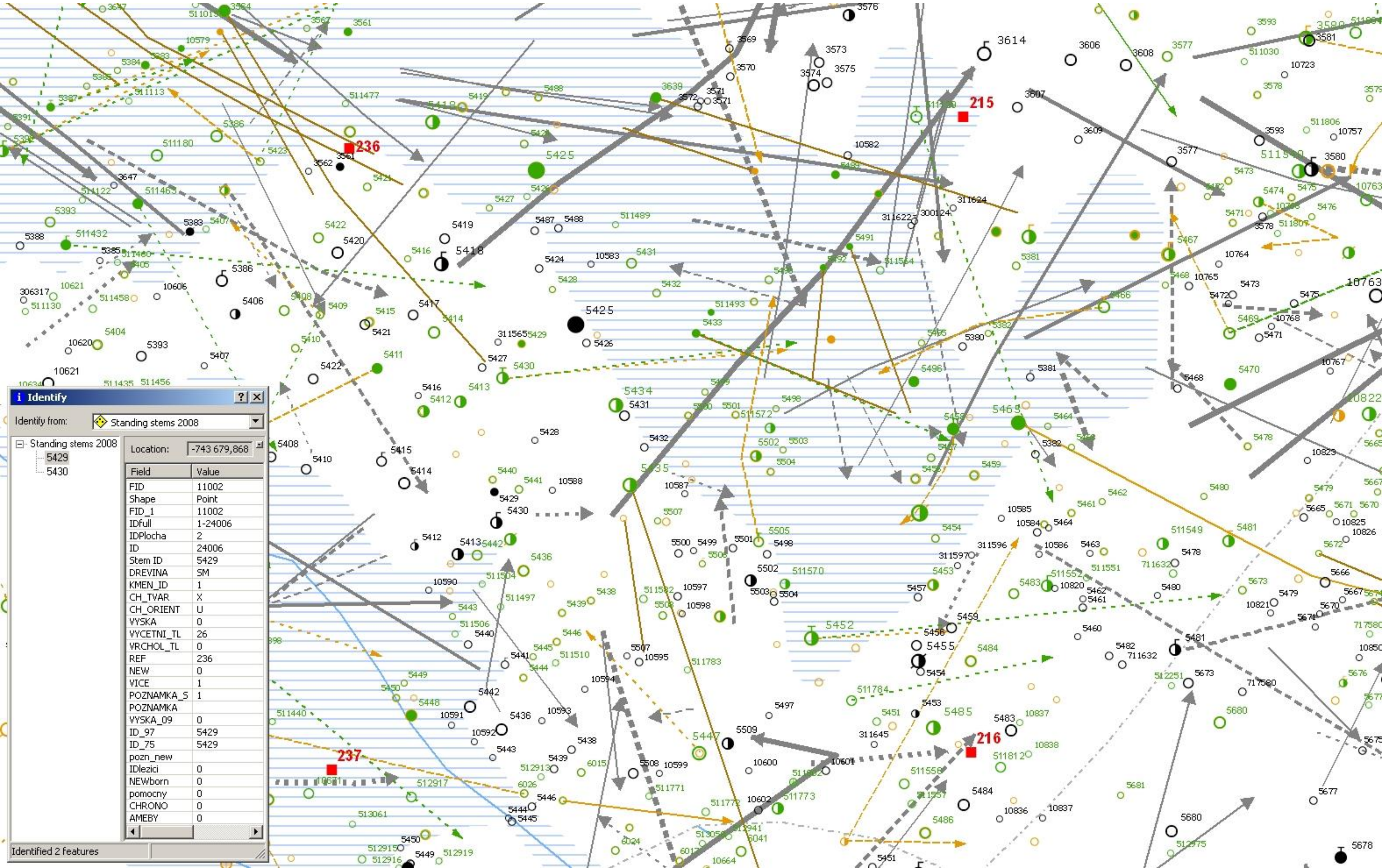
Kuuluvainen 2002

- limits of local and spatial variability
- intra- and interspecific competition
- single trees trajectory

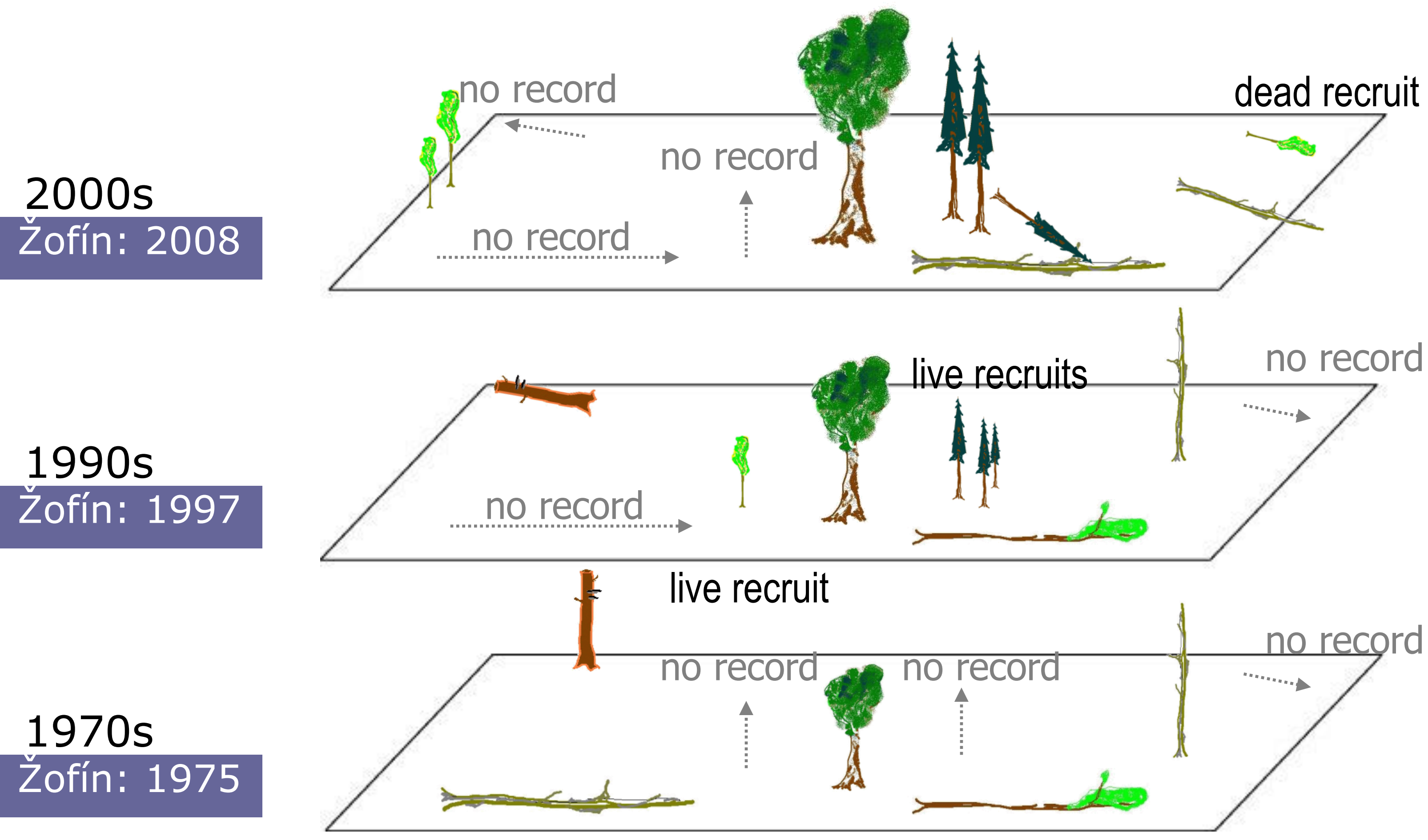


Kuuluvainen 2002

Žofín – stem position map (1975-1997-2008)

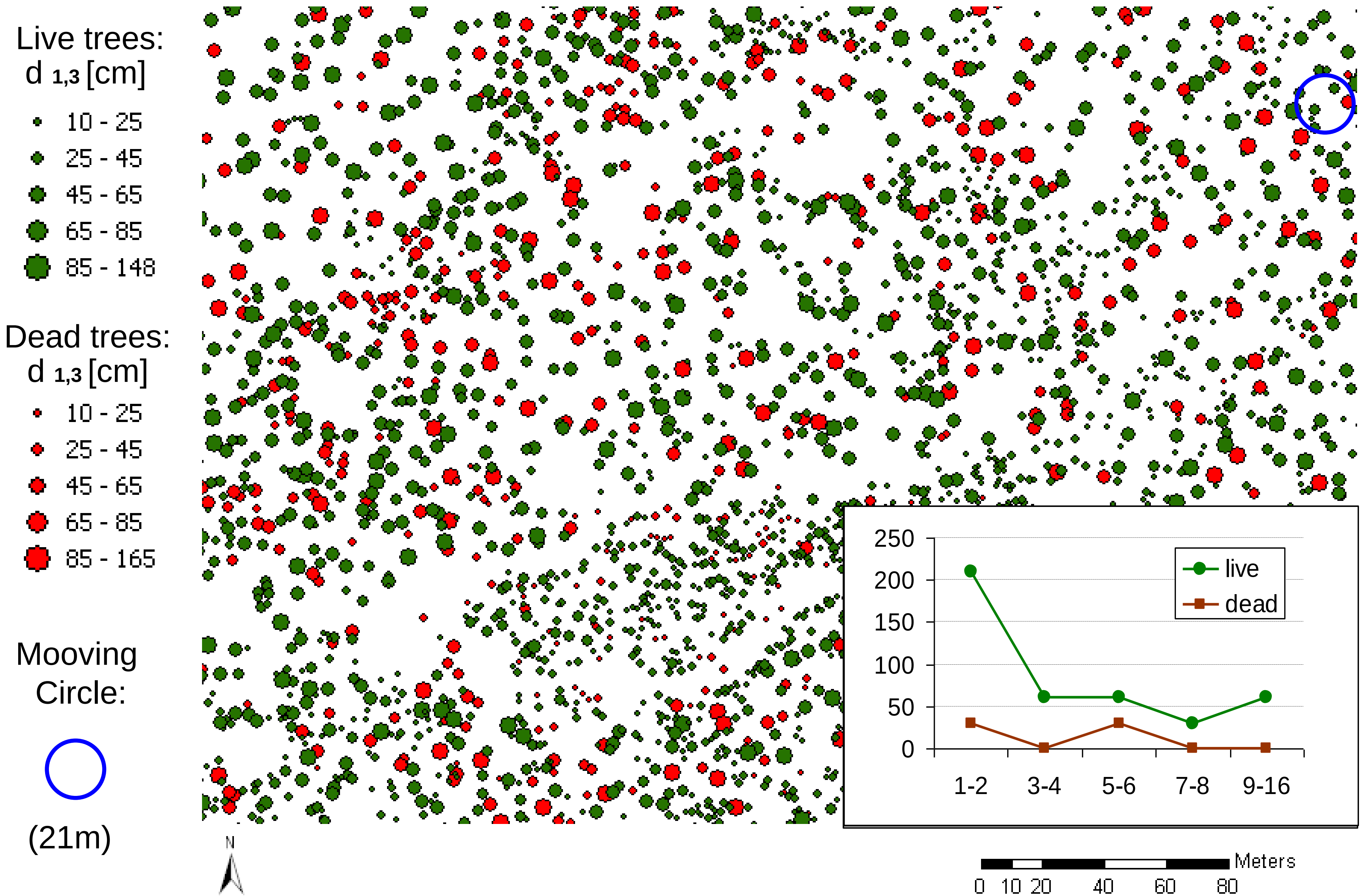


Different development in the time



no record – stem (still/already) doesn´t exist or doesn´t reach threshold d.b.h.

Method of the moving filter – focal filtering



Method of the moving filter – focal filtering

Live trees:
d 1,3 [cm]

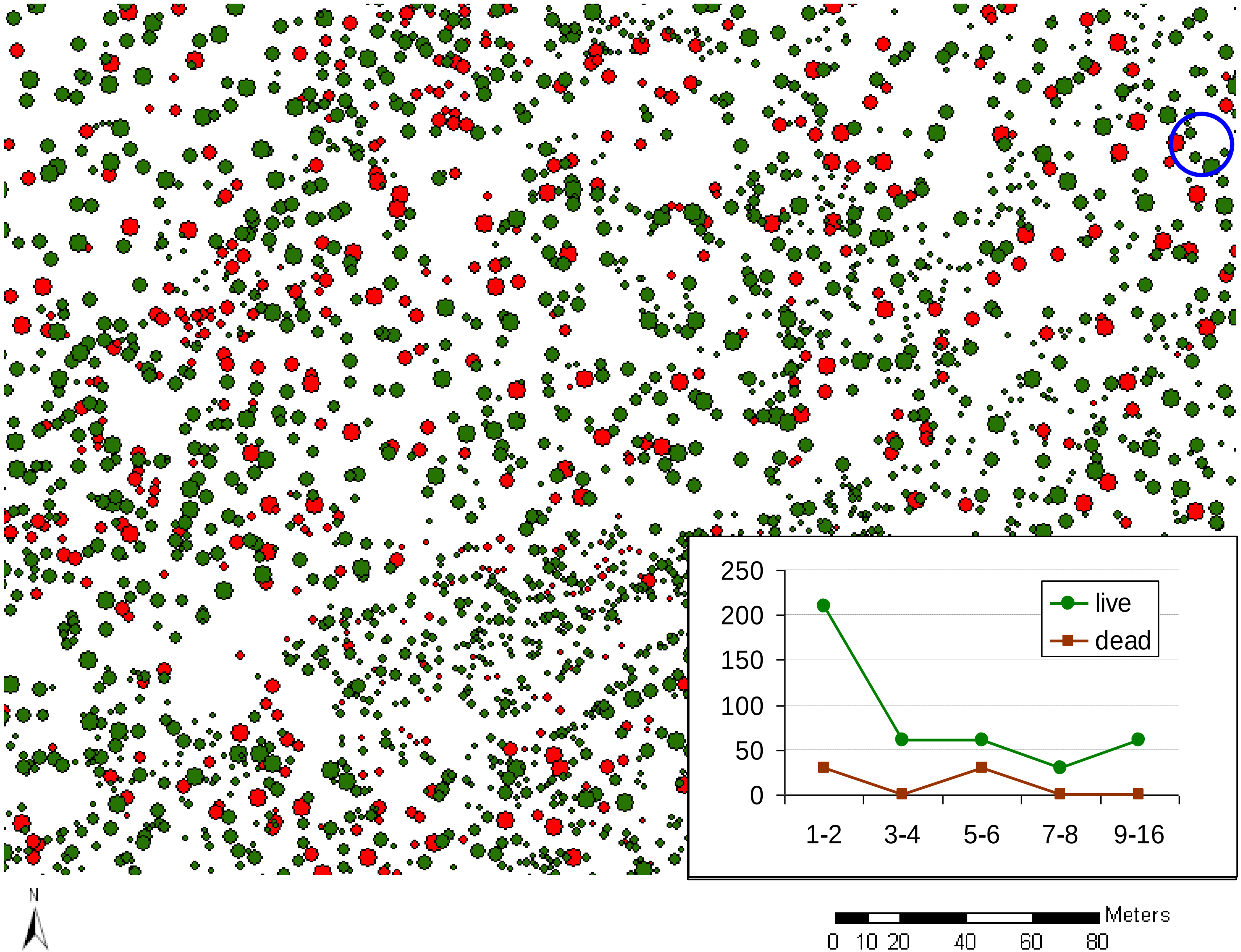
- 10 - 25
- 25 - 45
- 45 - 65
- 65 - 85
- 85 - 148

Dead trees:
d 1,3 [cm]

- 10 - 25
- 25 - 45
- 45 - 65
- 65 - 85
- 85 - 165

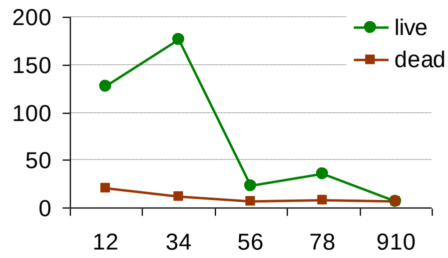
Mooving Circle:

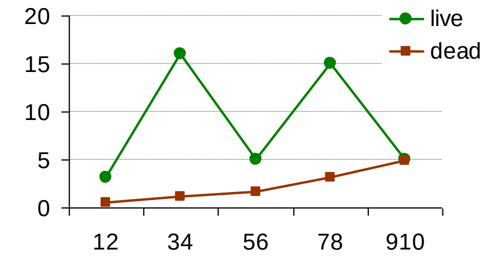
(21m)



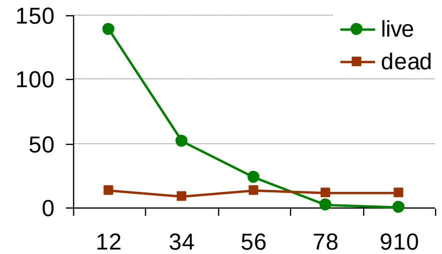
DBH distributions N BA

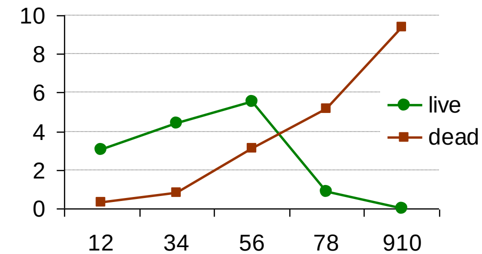
Growth / expiration



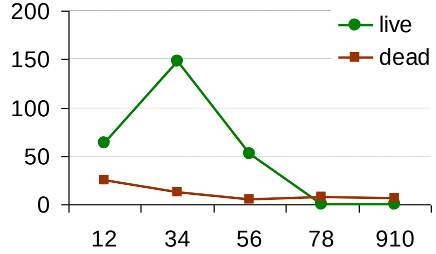


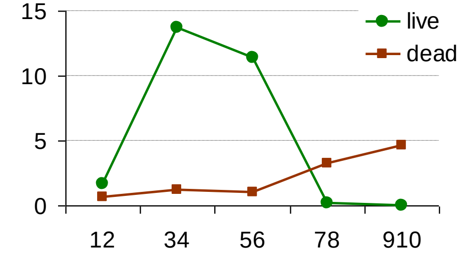
Growth, initial



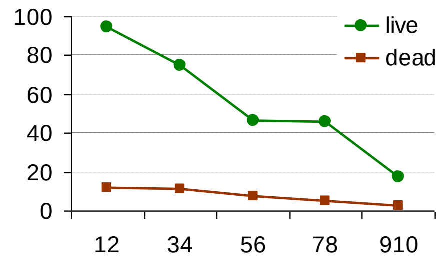


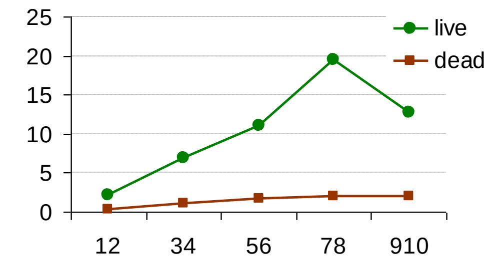
Growth, advanced





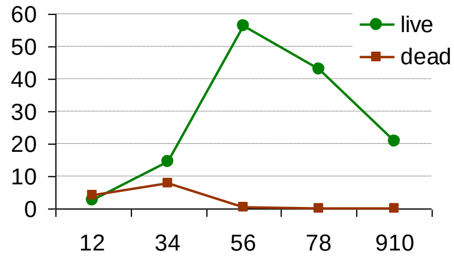
Steady State

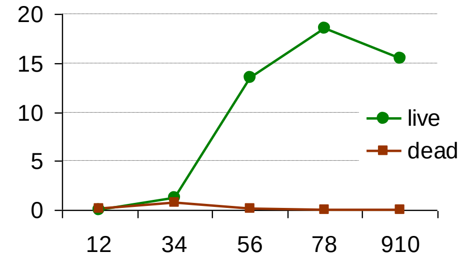




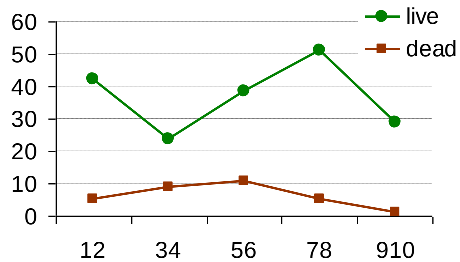
DBH distributions N BA

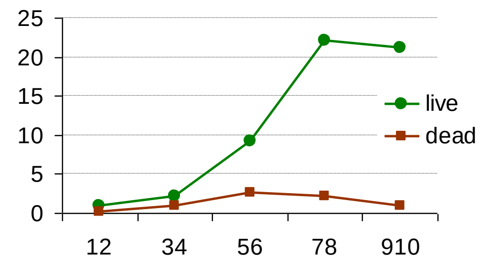
Optimum, typical



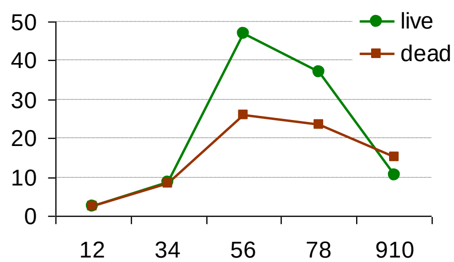


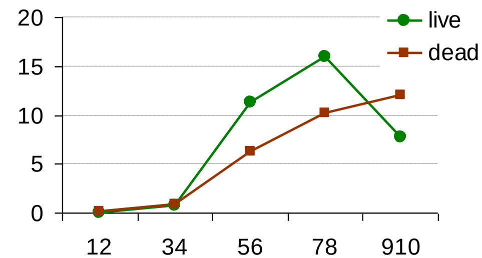
Optimum, ageing



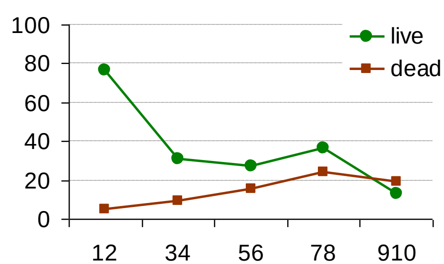


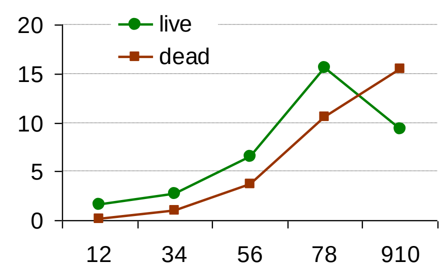
Breakdown, initial



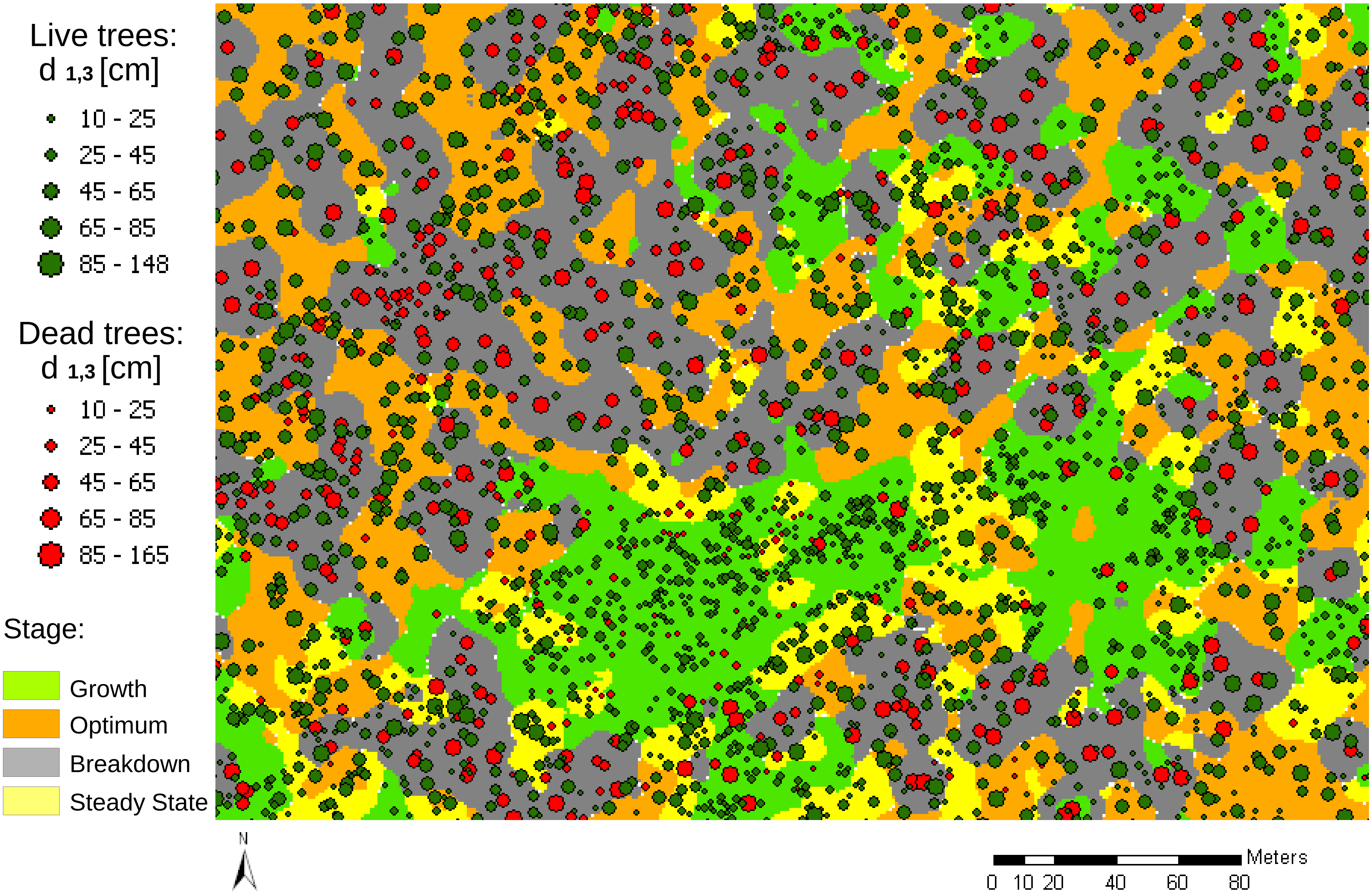


Breakdown / regeneration





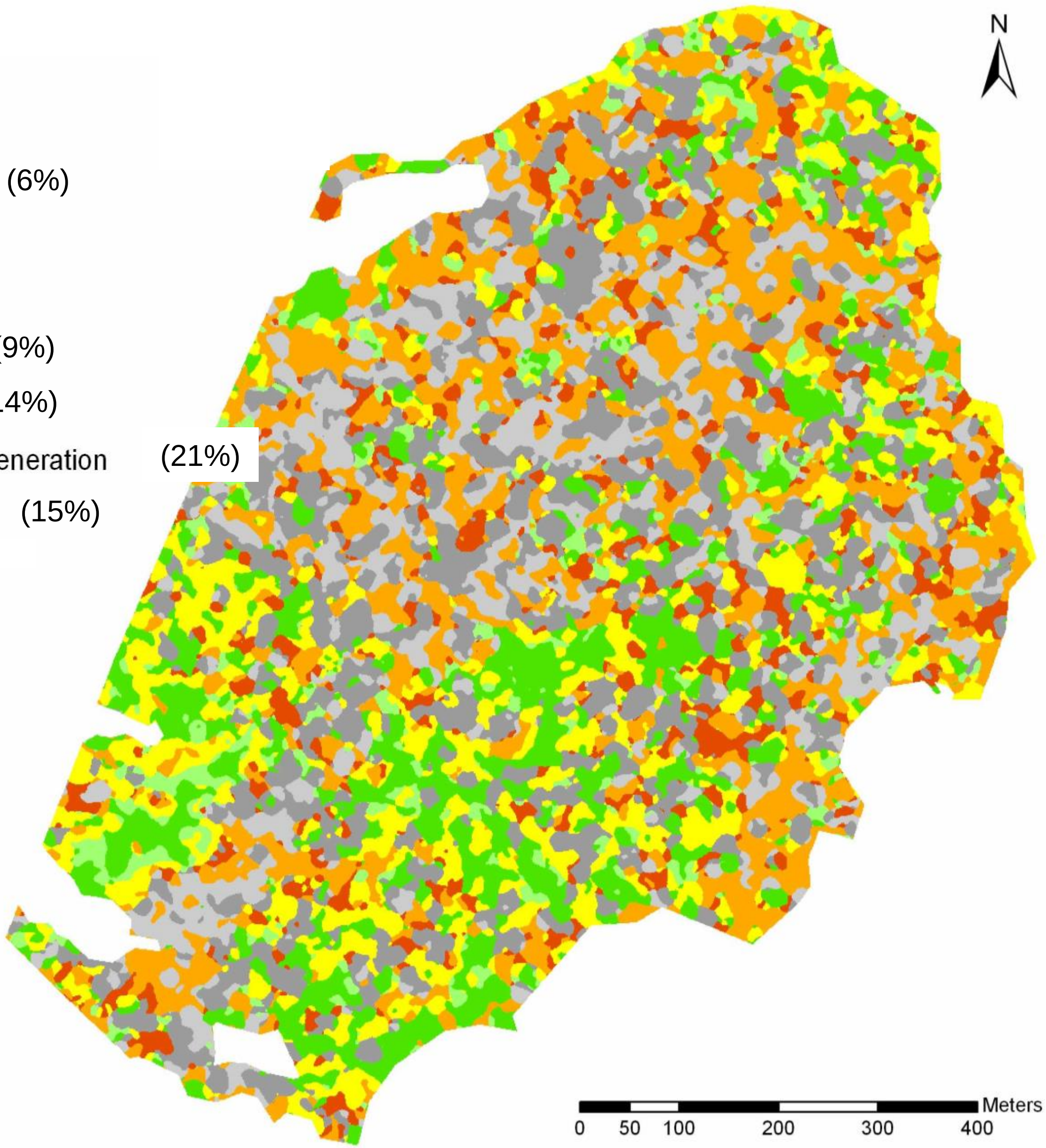
Classification using Artificial Neural Network



Resulting map of patches - developmental stages and phases

Legend:

- GROWTH; expiration (6%)
- GROWTH (16%)
- OPTIMUM (20%)
- OPTIMUM; terminal (9%)
- DISINTEGRATION (14%)
- DISINTEGRATION; regeneration (21%)
- **STEADY STATE** (15%)

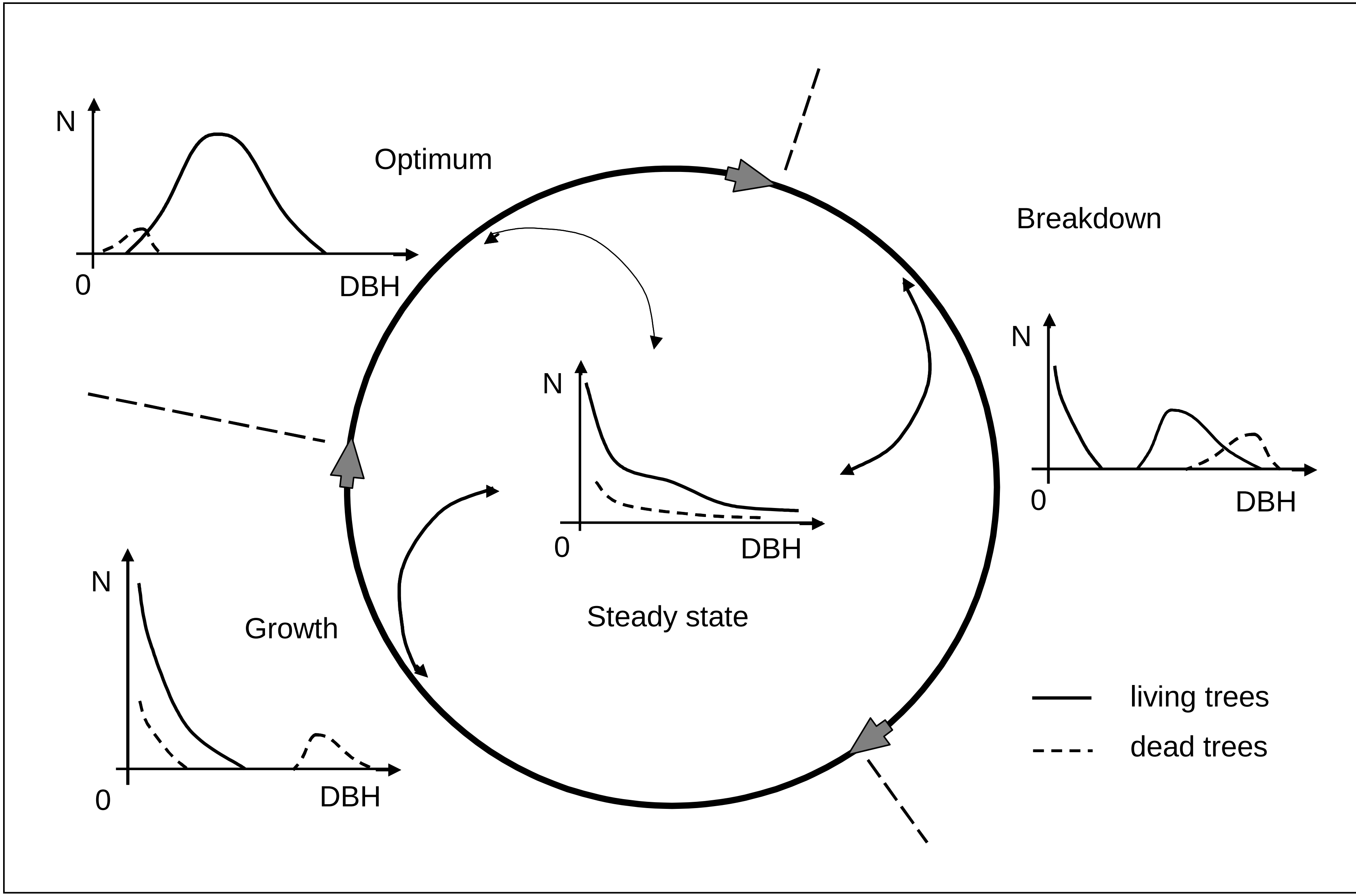


STAGE	Portion of Area
Growth	21%
Optimum	29%
Disintegration	35%
Steady state	15%
TOTAL	100%

Accuracy of Artificial Neural Network classification

PHASE	STAGE
Growth / expiration	Growth
Growth, initial	Growth
Growth, advanced	Growth
Optimum, typical	Optimum
Optimum, ageing	Optimum
Breakdown, initial	Breakdown
Breakdown / regeneration	Breakdown
Steady State	Steady State
86 %	**91 %**

Král,K., Vrška,T., Hort,L., Adam,D., Šamonil,P., 2010: Developmental phases in a temperate natural spruce-fir-beech forest: determination by a supervised classification method. European Journal of Forest Research 129, 339-351.



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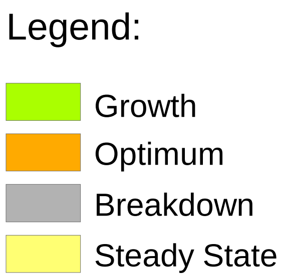
Three steps:

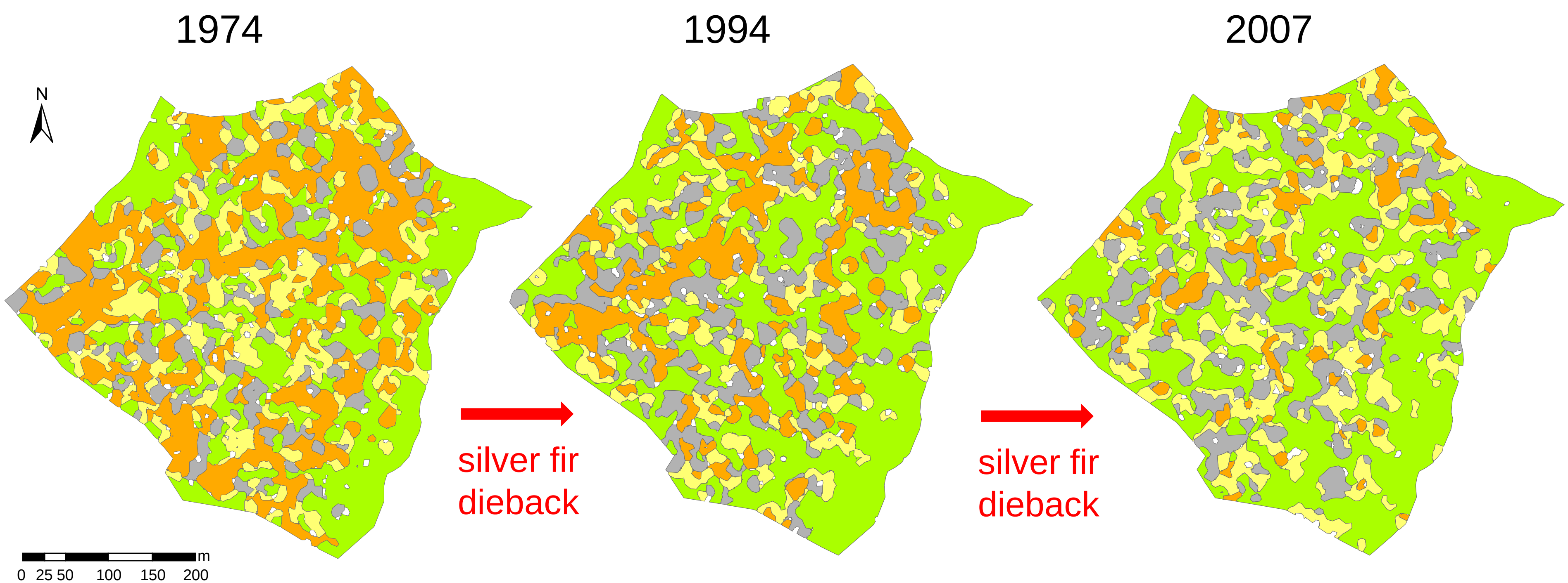
- Definition and classification of stages and phases – 2008-2010
- Patch dynamics in the space and varibalitiy of patches on the altitudinal vegetation gradient – 2011-2013
- Spatio(multi)-temporal dynamics – transition between stages and phases – 2014-2015

Study Site	Census area [ha]	Altitude min. [m a.s.l.]	Altitude max. [m a.s.l.]	Mean annual temp. [°C]	Mean annual prec. totals [mm]	Years of census
Cahnov	17.3	150	153	9.3	517	73', 94', 06'
Ranšpurk	22.3	152	155	9.3	517	73', 94', 06'
Salajka	19.0	715	815	5.4	1144	74', 94', 07'
Žofin	74.5	735	835	4.3	866	75', 97', 08'
Boubín	46.7	910	1110	4.0	867	72', 96', 10'

Salajka

- European beech > 80%
- Silver fir and Norway spruce < 10% each
- Altitude: 715 - 815 m a.s.l.
- Strictly protected since 1937; 19 ha



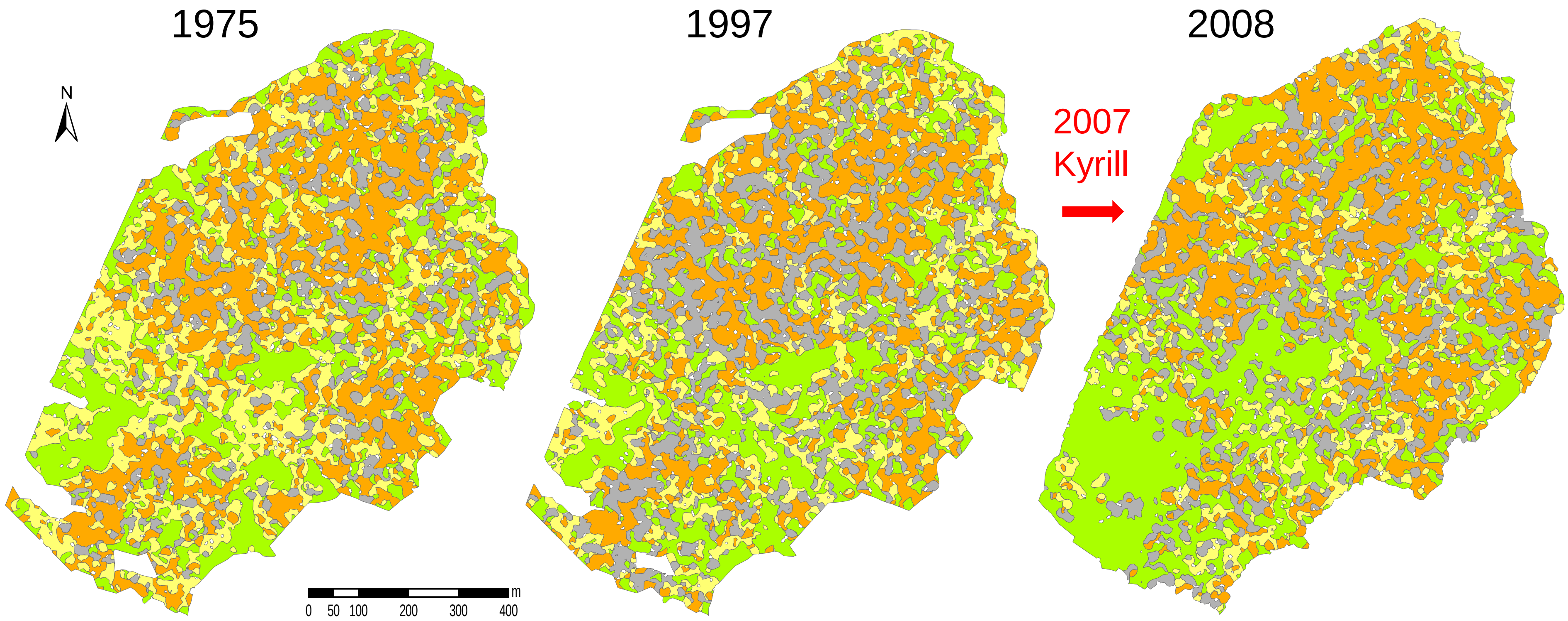


Žofín

- European beech 65%
- Norway spruce 33% and silver fir < 2%
- Altitude: 735 - 830 m a.s.l.
- Strictly protected since 1838; 72 ha !

Legend:

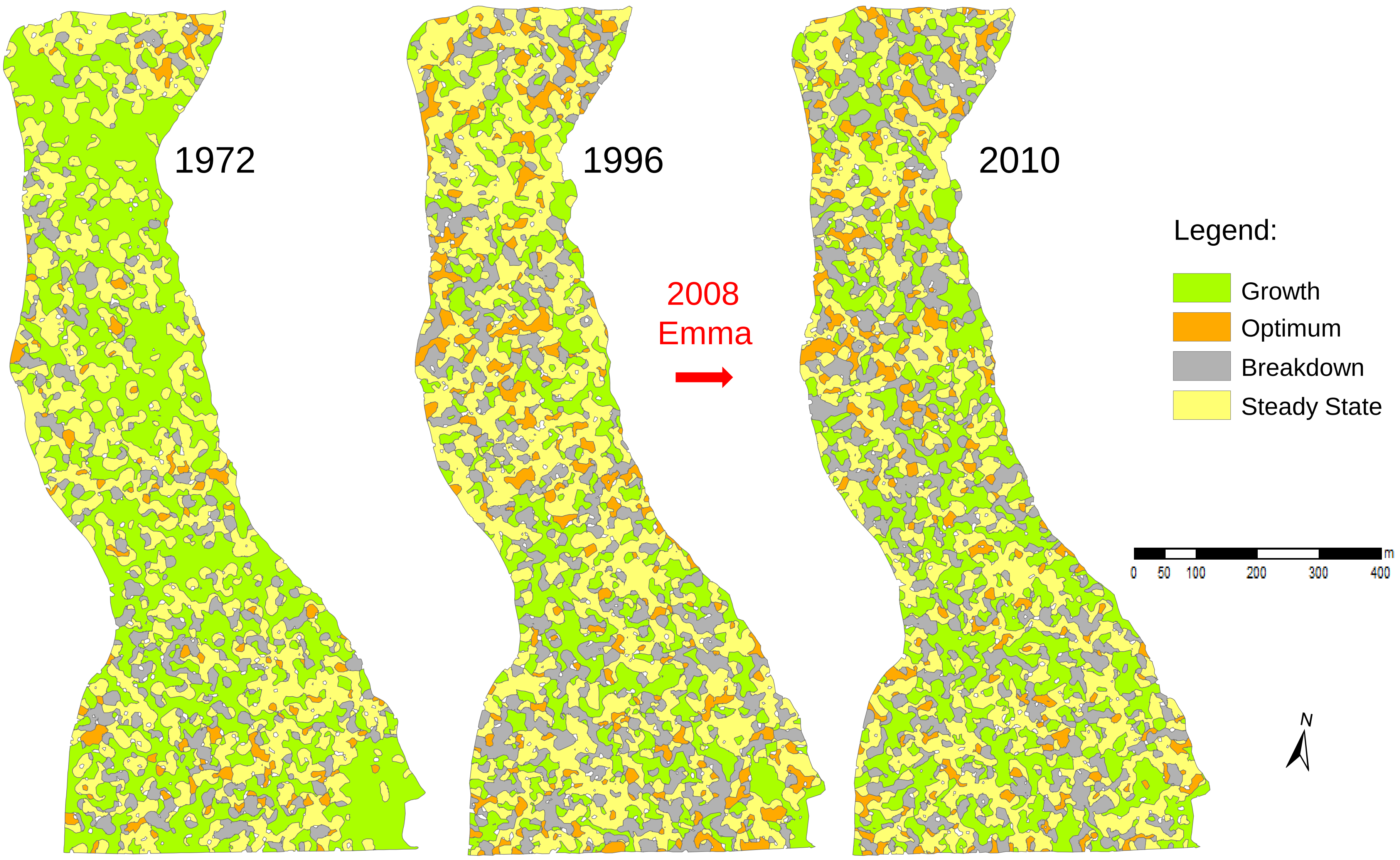
- Growth
- Optimum
- Breakdown
- Steady State



Boubín

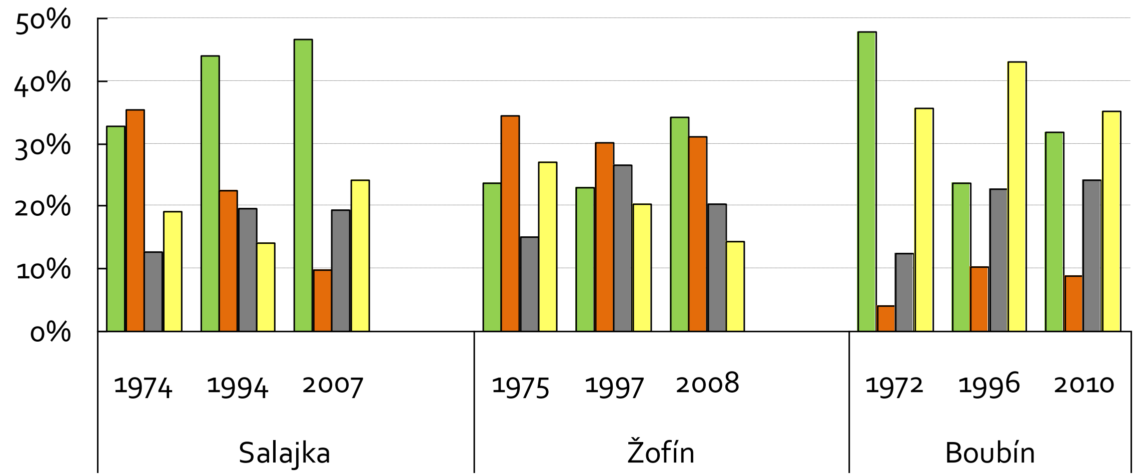
- European beech 54%
- Norway spruce 44% and silver fir < 2%
- Altitude: 930 - 1110 m a.s.l.

- Strictly protected since 1858
- 45 ha



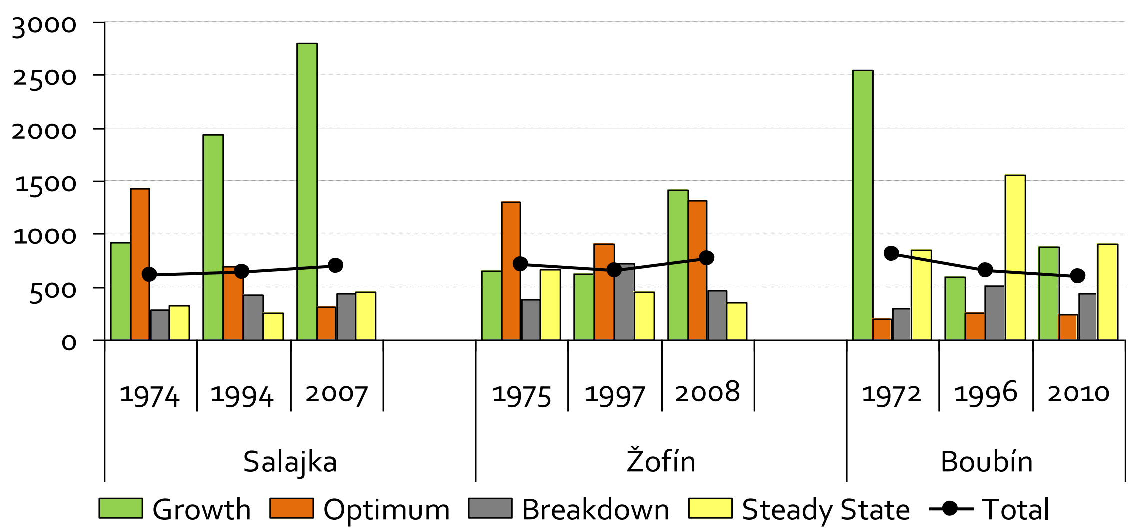
Patch Analyst 5.1

Stage Proportion [%]



- The proportion of stages varies among sites and also in time
- Growth stage cover usually 30 – 40 %
- Breakdown stage is usually 10-20 %
- Steady State seems to increase along altitude (18 -> 38 %)
- The MPS is usually higher than average for the Growth stage (in Boubin alternated by SS)
- MPS is always subnormal for Breakdown stage
- **Mean Patch Size is even at the level of the whole mosaic!**

Mean Patch Size [m]



KRÁL K., McMAHON S.M., JANIK D., ADAM D., VRŠKA T., 2014: Patch mosaic of developmental stages in central European natural forests along vegetation gradient. Forest Ecology and Management 330: 17–28.

In contrast to earlier hypotheses, it turns out the patch dynamics has the similar parameters in the N-E US forests:

KRÁL K., SHUE J., VRŠKA T., GONZALES-AKRE E.B., PARKER G.G., McSHEA W.J., McMAHON S.M., 2016. Fine-scale patch mosaic of developmental stages in Northeast American secondary temperate forests: the European perspective. European Journal of Forest Research 135 (5): 981-996.

Three steps:

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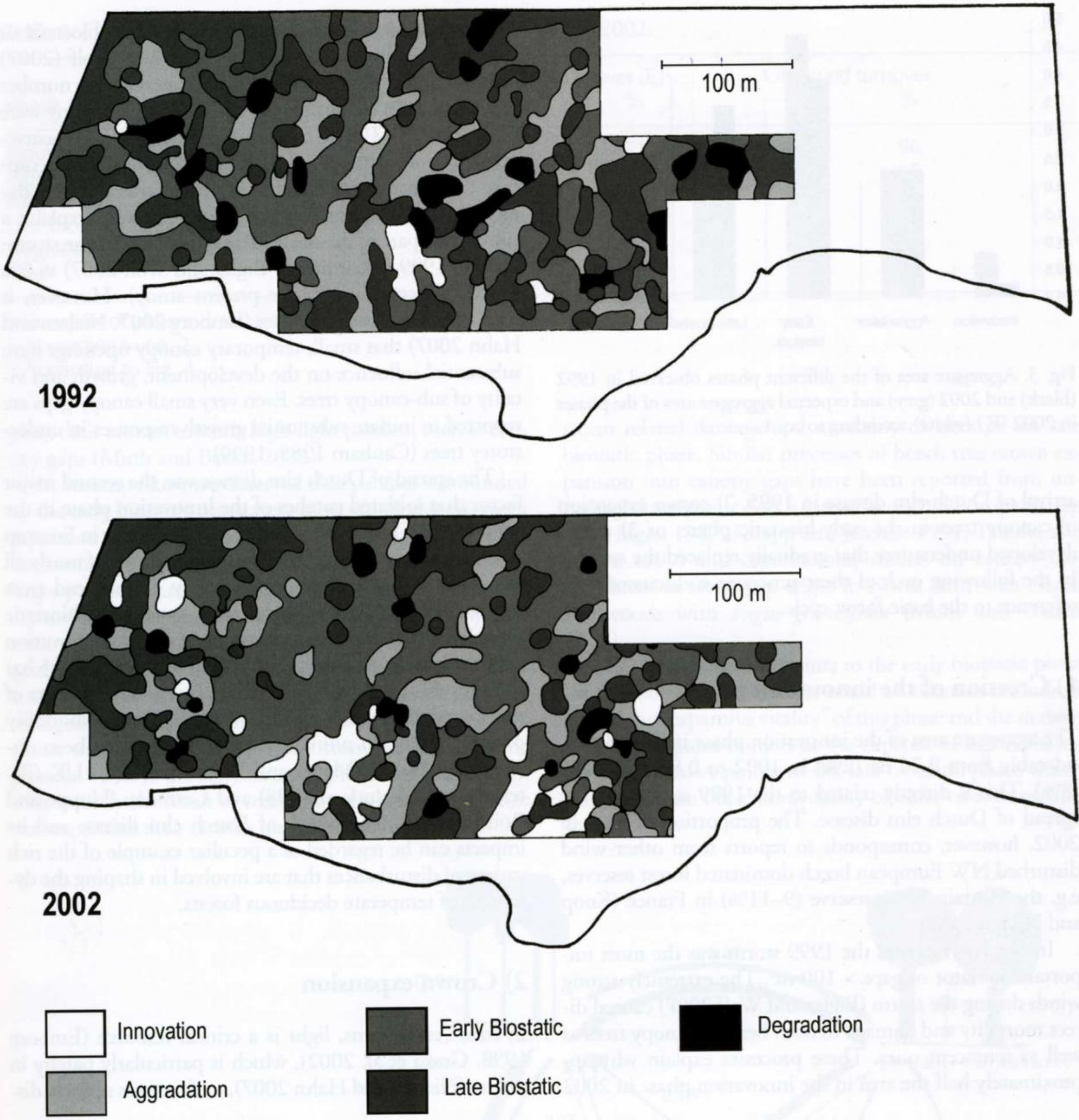


Fig. 2. Maps of the developmental phases in 1992 and 2002.

Christensen et al. 2007

Christensen et al. 2007

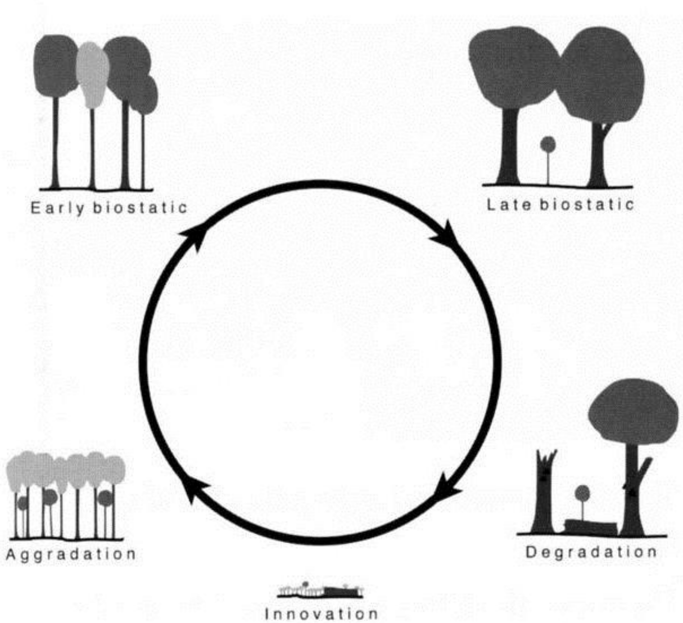


Fig. 1. Model of the basic forest cycle, including five developmental phases termed the innovation, the aggradation, the early biostatic, the late biostatic and the degradation phase, in accordance with Oldeman (1990). The definitions of the phases are described in Table 1.

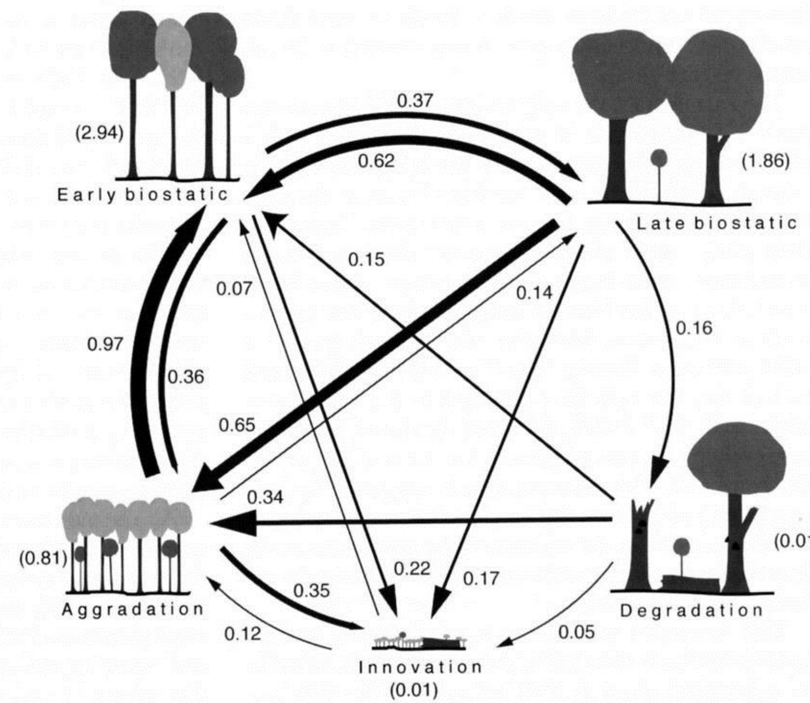


Fig. 4. Refined forest cycle model illustrating area of changes and non-changes (in ha) 1992–2002. The numbers written next to the illustrations of the phases are areas which not changed. The thickness of the arrows indicate the importance of different processes.

Multi-temporal comparisons – transitions between stages and phases

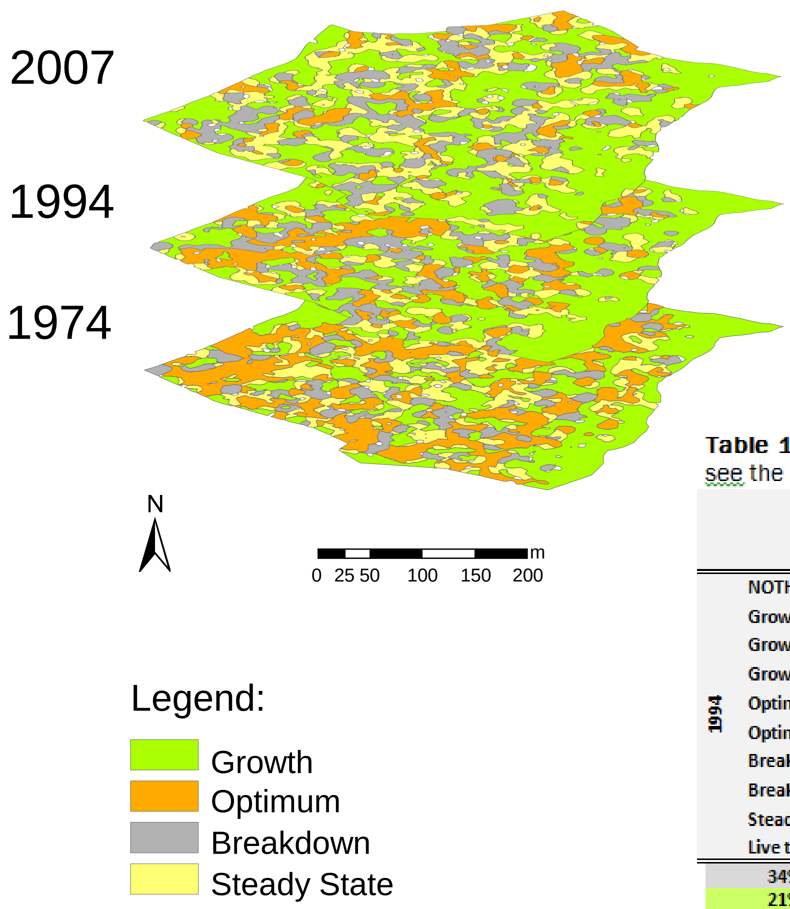


Table 1: Transitions (in ha) between developmental phases from 1973 to 1994 in Ranšpurk (21 years); see the summary and color key with explanation below the table.

	ha		1973 NO 0	G/ex. 1	G ini. 2	G adv. 3	O 4	O age. 5	B 6	B/reg. 7	SS 8	Gap 9
1994	NOTHING	0	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	Growth/expiration	1	0.00	0.08	0.00	0.46	0.07	0.21	0.01	0.07	0.09	0.00
	Growth initial	2	0.04	0.00	0.22	0.09	0.04	0.04	0.01	0.02	0.02	0.02
	Growth advanced	3	0.12	0.03	1.02	2.06	0.37	0.51	0.17	0.22	0.27	0.03
	Optimum typical	4	0.00	0.07	0.01	0.43	0.98	0.34	0.09	0.04	0.17	0.00
	Optimum ageing	5	0.00	0.09	0.01	0.42	1.50	1.18	0.19	0.14	0.49	0.00
	Breakdown initial	6	0.00	0.02	0.00	0.16	0.52	0.34	0.31	0.08	0.39	0.00
	Breakdown/regeneration	7	0.00	0.02	0.00	0.21	0.40	0.42	0.27	0.37	0.39	0.00
	Steady State	8	0.00	0.13	0.00	0.61	1.10	1.27	0.12	0.21	1.58	0.00
	Live tree GAP	9	0.00	0.00	0.00	0.01	0.05	0.02	0.01	0.00	0.00	0.01

34%	No change
21%	progressive development (one phase)
8%	strongly progressive development (two phases)
7.3%	regressive development (one phase)
0.4%	strongly regressive development (two phases)
3%	stochastic, yet possible development (e.g. disturbances)
1.0%	unlikely development (possible misclassification)
26%	possible development, no clear trend (progressive/regressive)

Rule-based classification of developmental stages and phases

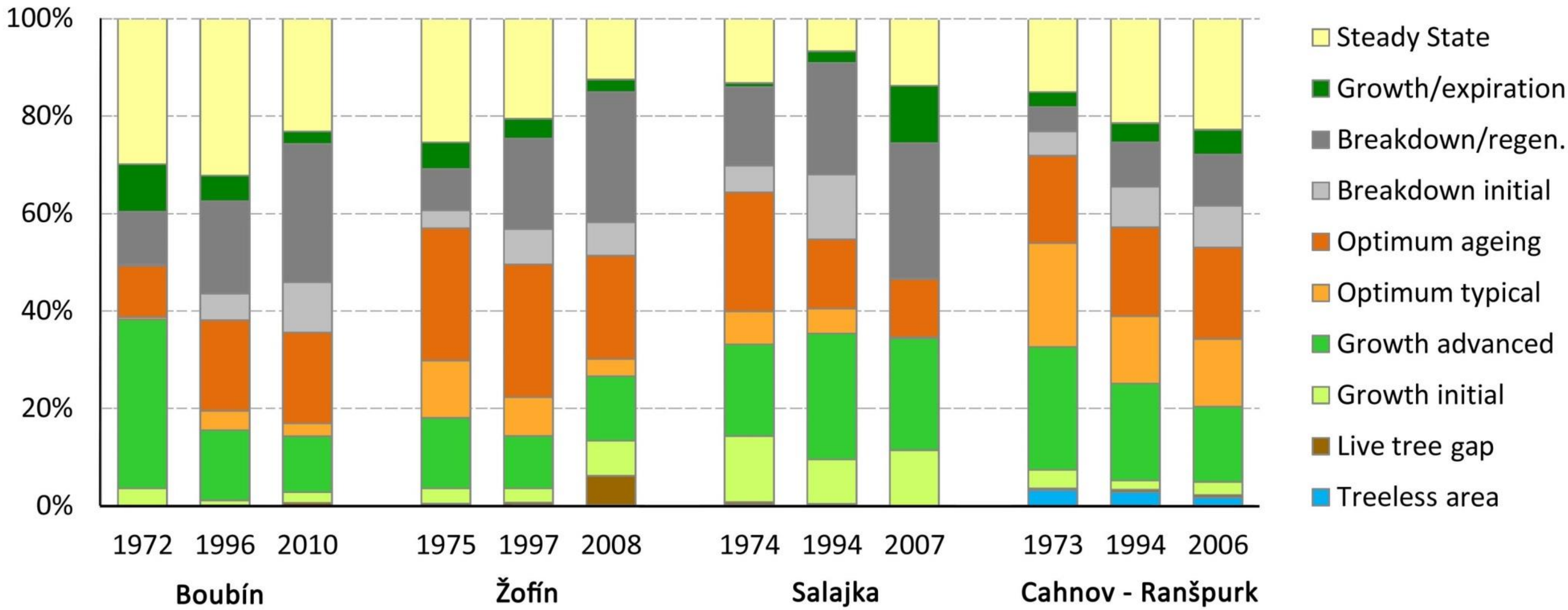
- ArcGIS Toolbox
- the DBH bins used in different forest types were defined and justified in Král et al. (2014a)
- 10 developmental phases described and portrayed by respective local DBH distributions characteristic for individual developmental phases

Empiric classification of transitions

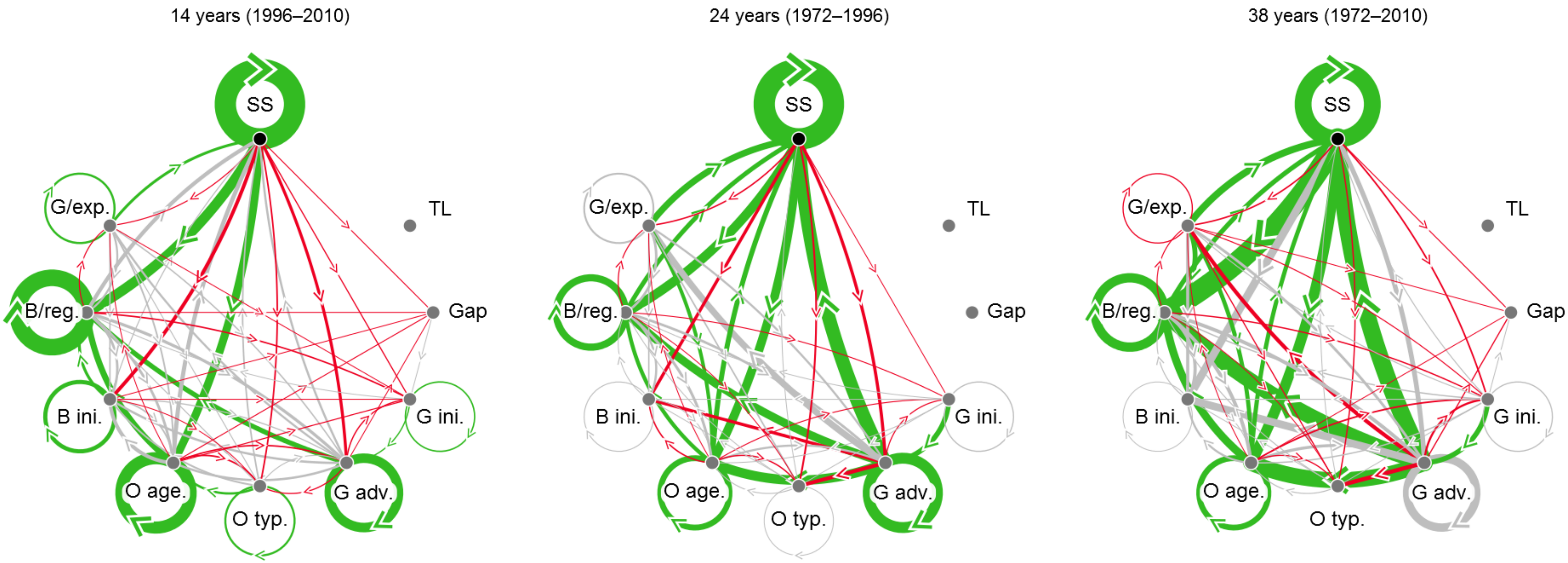
- all phase-to-phase transitions were quantified between the 70's and 90's, 90's and 00's and 70's and 00's.
- descriptive categories:
- Stable – the developmental phase remained unchanged between censuses
- Progressive – the phase was shifted forward in the cycle
- Regressive – the phase was shifted backward in the cycle
- Disturbance – a shortcut to early developmental phases likely caused by a disturbance
- No trend – development with no clear direction along the forest cycle
- Unlikely – unlikely development (a possible misclassification of the phase in either of the observations).

Quantitative evaluation of transitions

- 10,000 bootstrap samples we derived null distributions for all transition frequencies
- for each research plot we used a bootstrap sample size equal to the number of non-overlapping moving windows necessary to cover the whole area of the plot
- we used a sequential Bonferroni-type procedure (Benjamini & Hochberg 1995), which controls for a false discovery rate.


100%
80%
60%
40%
20%
0%
Steady State
Growth/expiration
Breakdown/regen.
Breakdown initial
Optimum ageing
Optimum typical
Growth advanced
Growth initial
Live tree gap
Treeless area
1972
1996
2010
1975
1997
2008
1974
1994
2007
1973
1994
2006
Boubín
Žofín
Salajka
Cahnov - Ranšpurk

example Boubín



Green – higher number of transitions than the null model
Red – lower number of transitions than the null model

The proportion of transitions following preferential, randomly frequent and uncommon pathways

	Research plots:	Boubín	Žofín	Salajka	Cahnov - Ranšpurk	Mean	SEM
90s - 00s	Period (years)	14	11	13	12	12.5	0.6
	Preferential pathways (%)	70.4%	66.1%	70.2%	63.0%	67.4	1.8
	Randomly frequent pathways (%)	21.1%	18.8%	27.8%	29.5%	24.3	2.6
	Uncommon pathways (%)	8.5%	15.1%	2.0%	7.5%	8.3	2.7
70s - 90s	Period (years)	24	22	20	21	21.8	0.9
	Preferential pathways (%)	76.5%	75.1%	49.6%	57.6%	64.7	6.6
	Randomly frequent pathways (%)	13.5%	12.5%	48.4%	37.7%	28.0	9.0
	Uncommon pathways (%)	10.0%	12.4%	2.0%	4.6%	7.2	2.4
70s - 00s	Period (years)	38	33	33	33	34.3	1.3
	Preferential pathways (%)	69.7%	61.8%	60.9%	59.7%	63.0	2.3
	Randomly frequent pathways (%)	23.0%	28.3%	38.3%	35.5%	31.3	3.5
	Uncommon pathways (%)	7.3%	9.8%	0.9%	4.8%	5.7	1.9

Table 4. Proportions (%) of transition types across the four study sites and three observation periods; SEM – standard error of the mean; ZF – Žofín plot, BB – Boubín plot, SL – Salajka plot, RN-CA – Ranšpurk–Cahnov bi-plot.

Period	**90s – 00s (ca. 12 years)**						**70s – 90s (ca. 22 years)**						**70s – 00s (ca. 34 years)**					
Transition types	ZF	BB	SL	RN-CA	**Mean**	SEM	ZF	BB	SL	RN-CA	**Mean**	SEM	**ZF**	**BB**	**SL**	RN-CA	**Mean**	SEM
stable	45	47	46	52	**47.4**	1.5	37	30	26	34	**31.9**	2.5	23	19	21	22	**21.1**	0.8
progressive	22	15	27	16	**20.0**	3.0	23	17	37	28	**26.2**	4.3	31	20	41	35	**31.7**	4.4
regressive	4	5	2	8	**4.8**	1.1	5	4	7	6	**5.5**	0.6	4	5	2	6	**4.4**	0.8
no trend	20	30	20	22	**23.0**	2.4	31	46	24	29	**32.6**	4.8	32	49	32	33	**36.5**	4.1
disturbance	8	3	3	2	**3.9**	1.5	2	2	6	2	**3.1**	0.8	9	5	2	2	**4.7**	1.7
unlikely	1	1	1	1	**0.9**	0.1	0	1	1	1	**0.6**	0.1	1	2	2	1	**1.6**	0.3

The six transition types were consequently regrouped into three summary categories evaluating the nature of transitions from the viewpoint of the functionality of the model forest cycle as follows: No transition (stable), Cyclic transition (progressive), Acyclic transition (all other types). These were further used and analyzed in the paper.

The proportion of the three major transition categories in all observations

	Research plots:	Boubín	Žofín	Salajka	Cahnov - Ranšpurk	Mean	SEM
90s - 00s	Period (years)	14	11	13	12	12.5	0.6
	No transitions (%)	46.6%	45.0%	46.0%	51.7%	47.4	1.5
	Cyclic transitions (%)	14.7%	22.0%	27.4%	15.7%	20.0	3.0
	Acyclic transitions (%)	38.6%	33.0%	26.5%	32.5%	32.7	2.5
70s - 90s	Period (years)	24	22	20	21	21.8	0.9
	No transitions (%)	30.0%	37.4%	26.2%	34.2%	31.9	2.5
	Cyclic transitions (%)	16.7%	23.4%	37.0%	27.8%	26.2	4.3
	Acyclic transitions (%)	53.4%	39.2%	36.8%	38.0%	41.8	3.9
70s - 00s	Period (years)	38	33	33	33	34.3	1.3
	No transitions (%)	19.2%	22.5%	20.5%	22.2%	21.1	0.8
	Cyclic transitions (%)	20.1%	31.0%	40.8%	34.8%	31.7	4.4
	Acyclic transitions (%)	60.8%	46.4%	38.6%	43.0%	47.2	4.8

Three main outputs

- in total about 65% of all observed phase-to-phase transitions were significantly more frequent than random switches between phases
- about 28% of observed transitions proceeded along pathways of random frequency
- only about 7% of observed transitions were realized through pathways significantly less frequent than random switches between phases

- the mean ratio of cyclic/acyclic transitions (2:3) was more or less stable throughout time

- in average only less than 40% of transitions between different developmental phases were classified as cyclic (following the model cycle), the majority of these transitions were realized through significantly frequent preferential pathways

Král K., Daněk P., Janík D., Krůček M. & Vrška T., 2017. **How cyclical and predictable are central European temperate forest dynamics in terms of developmental phases?** Journal of Vegetation Science – online first

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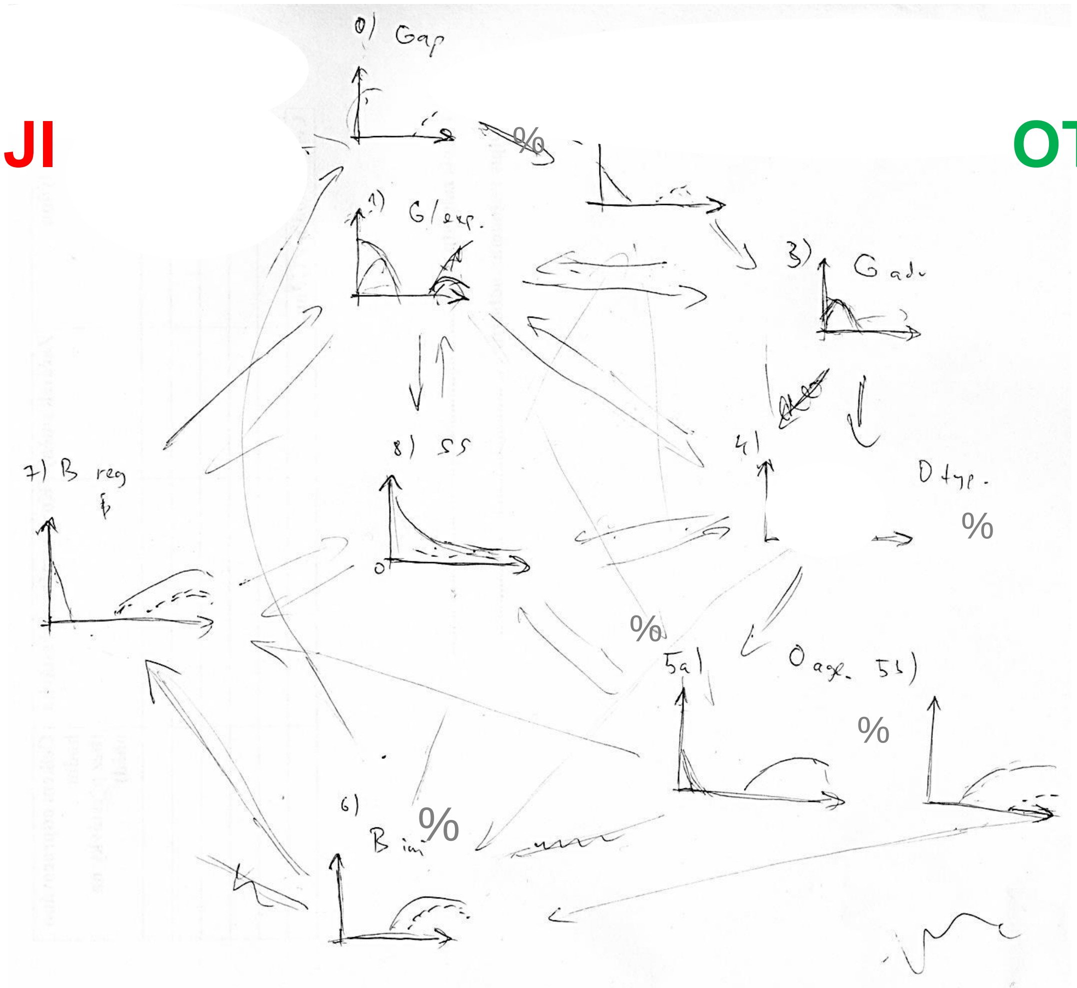

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