



Modeling for Adaptive Forest Management

Evaluating and Selecting Good Adaptive Strategies

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Adaptation to Climate Change

Problem:

Climate Change Uncertainty (e.g. IPCC scenario A1, A1B2)

Solution:

Probability assignments (e.g. Belief mass to CC-Scenarios)

Regarding:

Decision-maker's behavior (i.e. Perception of CC)

Forest response to CC (e.g. $\uparrow \downarrow$ Productivity/Mortality)

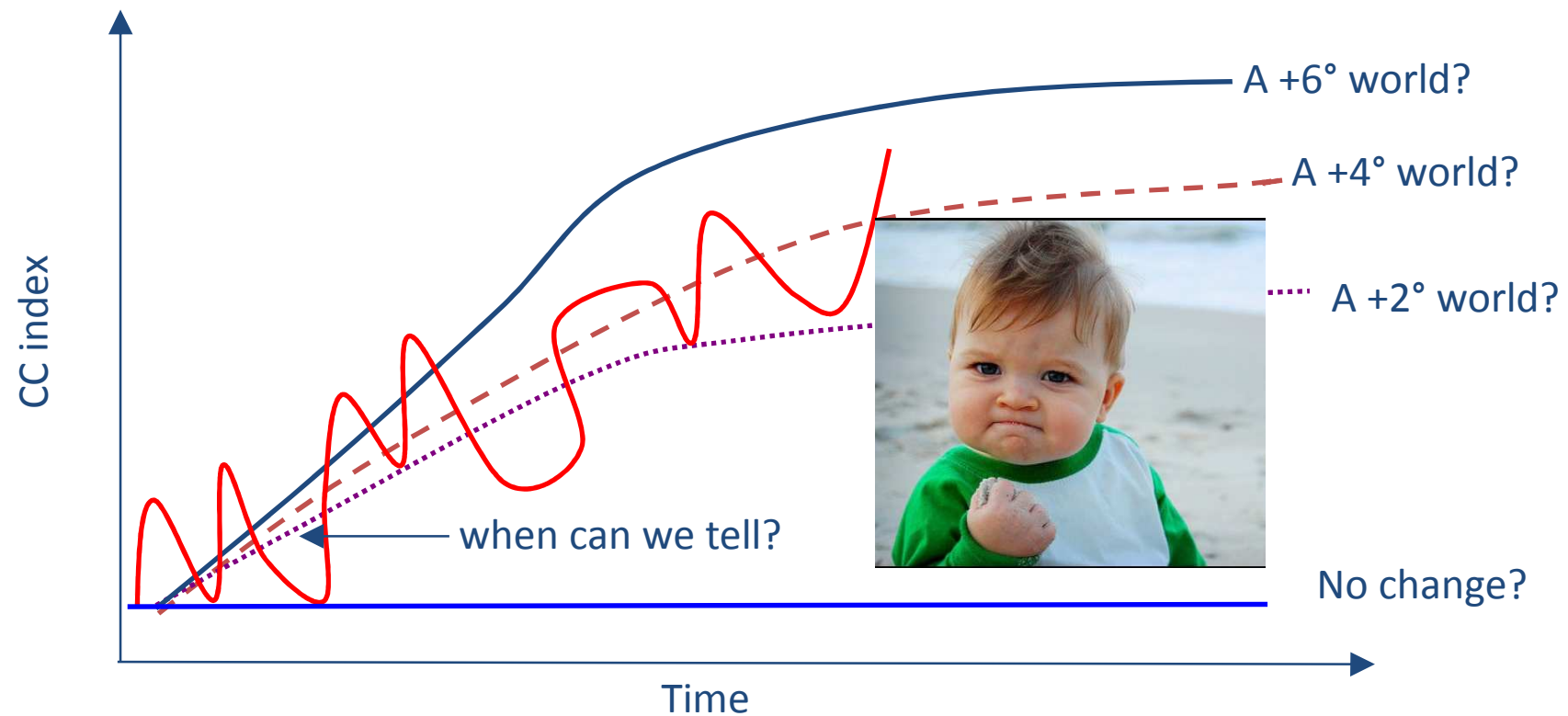
Actions' performance*CC (i.e. Finding optimal decision)

Scale of adaptation (i.e. Local owner, Forest structure)

Objective of adaptation (e.g. min. Δ productivity)



Assumption 1: **Uncertain about the actual climate NOW,
Explore it some time in the FUTURE**





Observations:



2007



2006



2008



2011



2009



2010



No/Low Change



50%

Moderate Change



30%

High Change



20%





Update with Bayes' theorem

$$w_{it+1}(\hat{\lambda}_{R_t})$$

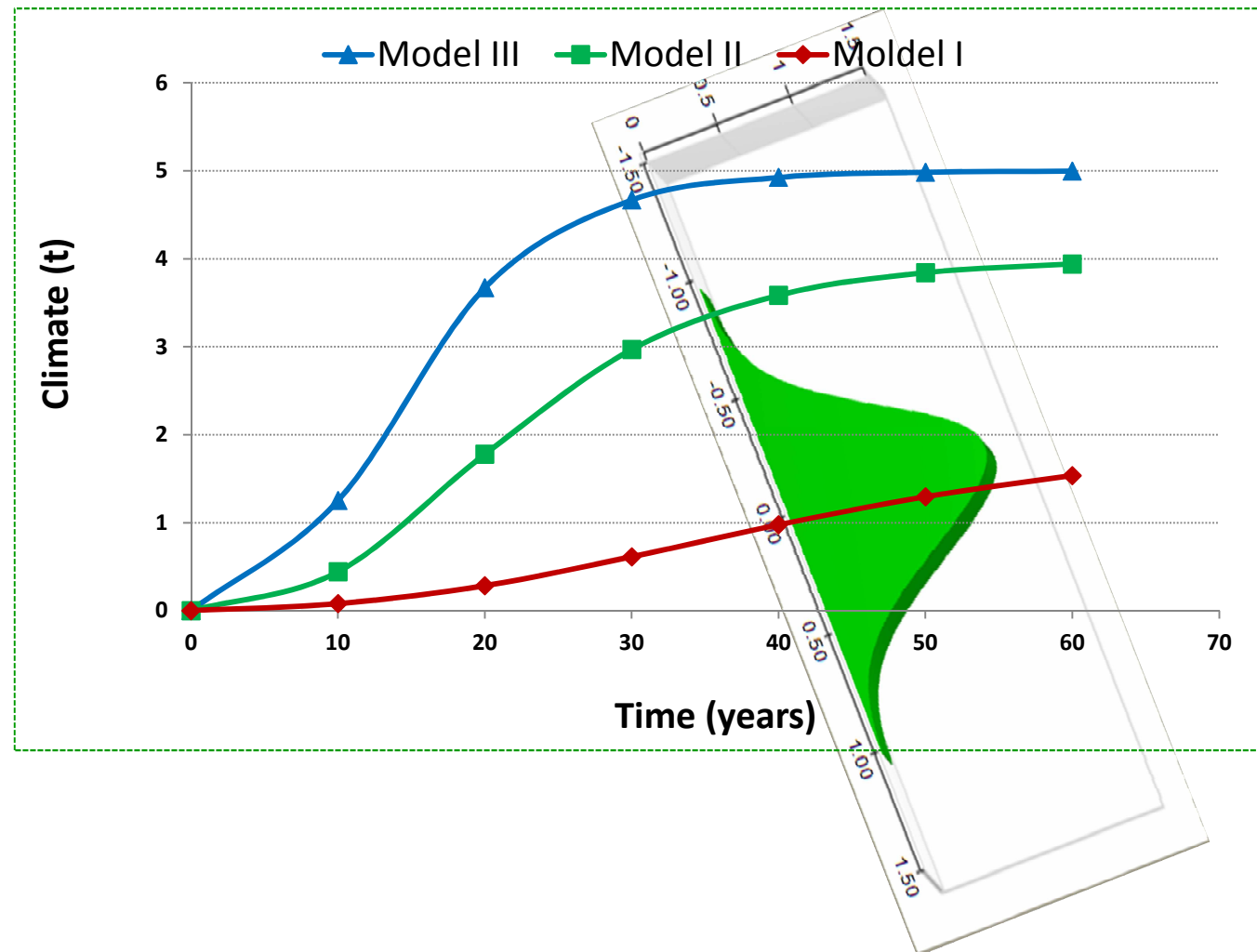
$$= \Pr(\text{model}_i | \hat{\lambda}_{R_t})$$

$$= \frac{\Pr(\hat{\lambda}_{R_t} | \text{model}_i) \Pr(\text{model}_i)}{\sum_{i=1}^I \Pr(\hat{\lambda}_{R_t} | \text{model}_i) \Pr(\text{model}_i)}$$

$$\& \quad \Pr(\text{model}_i) = w_{it}$$

Draws for the realization of climate's future state (*Monte Carlo*):

$$\hat{\lambda}_t(\text{model}_i, t) = x_{it}(\text{model}_i, t) + \varepsilon_{it}$$





Decision on action

to be made in each decision point:

$$\max_{a_{tj}} v(W_t, t) = \sum_{i=1}^I w_{it} OBJ_{it}(a_{tj})$$

$$\sum_{i=1}^I w_{it} = 100\%, \quad w_{it} \geq 0$$

OBJ_{it} = action's output (e.g. goal = min. ΔTBP)

a_j = action_{j=1,...J}

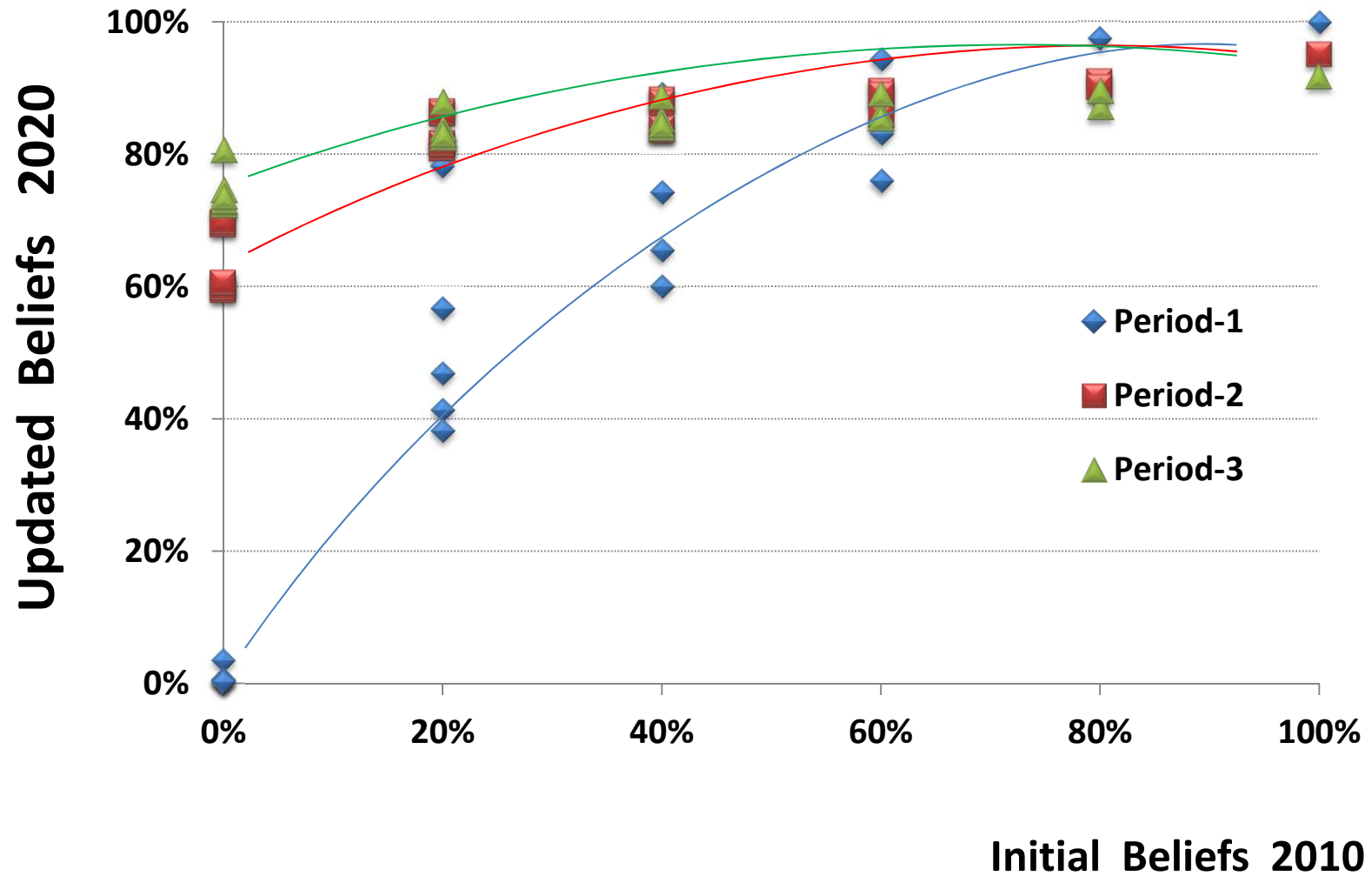


Simulation of Management actions by LandClim for Veluwe:

	Management scenarios			
	M1: Multifunctional forestry	M2: Multifunctional forestry with a focus on production	M3: No intervention	M4: No intervention with removing non-native tree species
<i>Category</i>	<i>adaptive</i>	<i>adaptive & productive</i>	<i>protective & adaptive</i>	<i>forest conservation</i>
Management overview	Diversification of forest structure	Focus on timber harvesting	Natural regeneration	Convert to near natural forest



Change of beliefs in time (true climate = medium change)



Decision-maker's behaviour:

Active-adaptive: constantly observes the state of the climate and update the knowledge and beliefs towards the actual climate realization

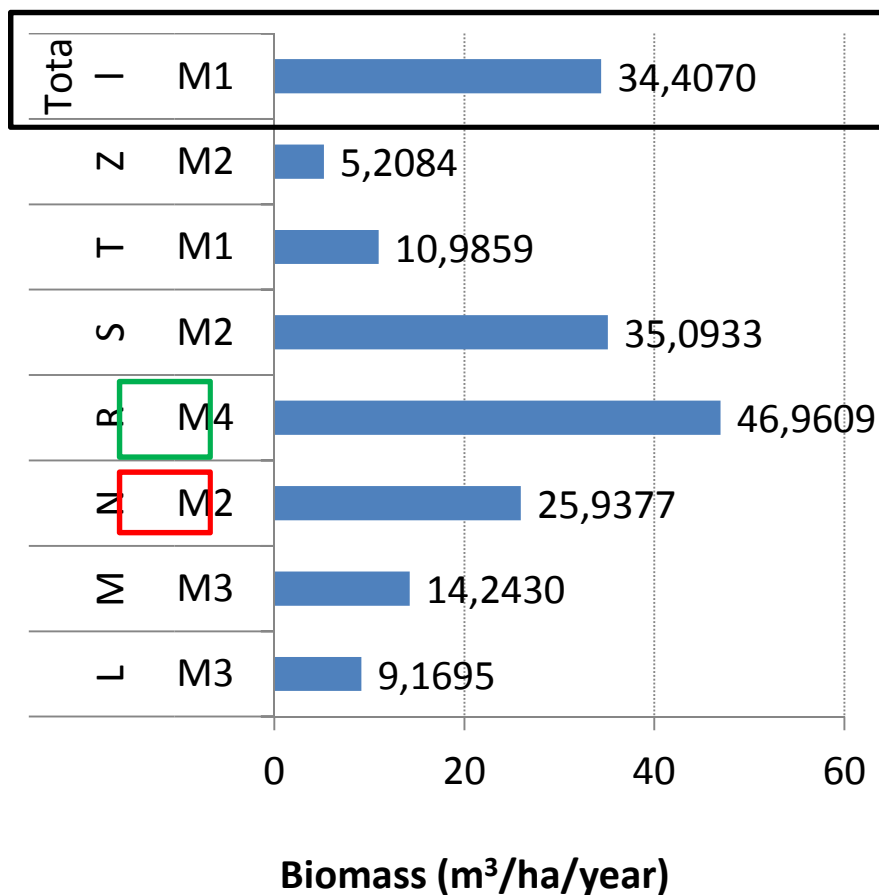


Determinist: no way believes in climate change and stick to the absolute belief in no-change unless very convincing evidence are experienced

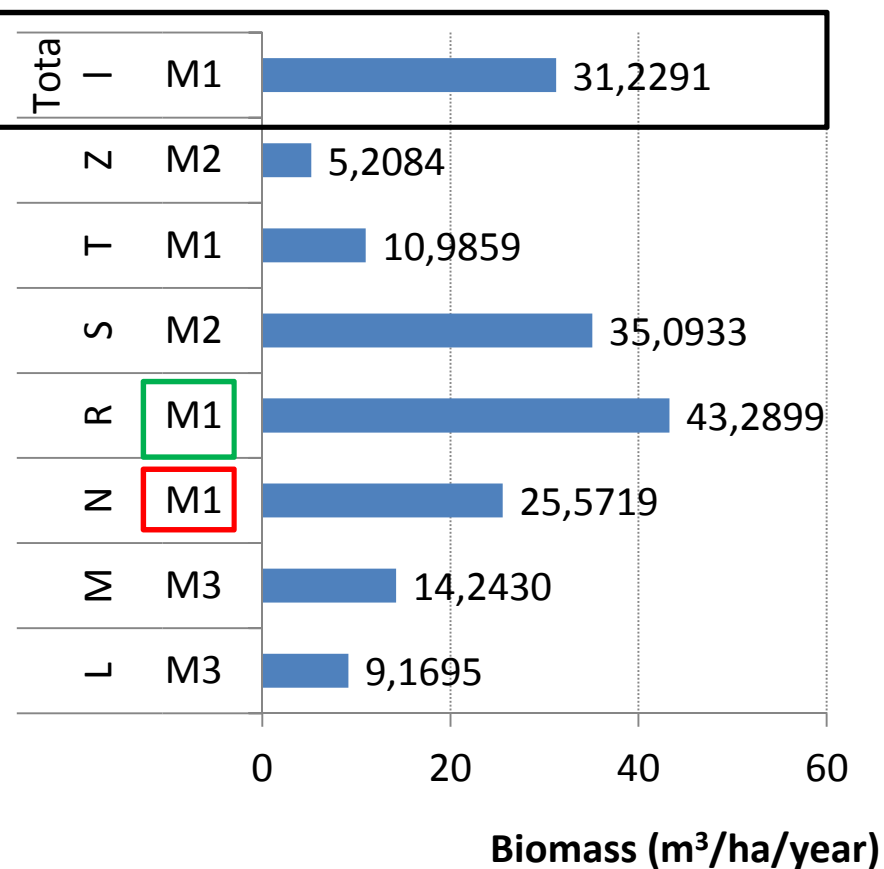




Determinist

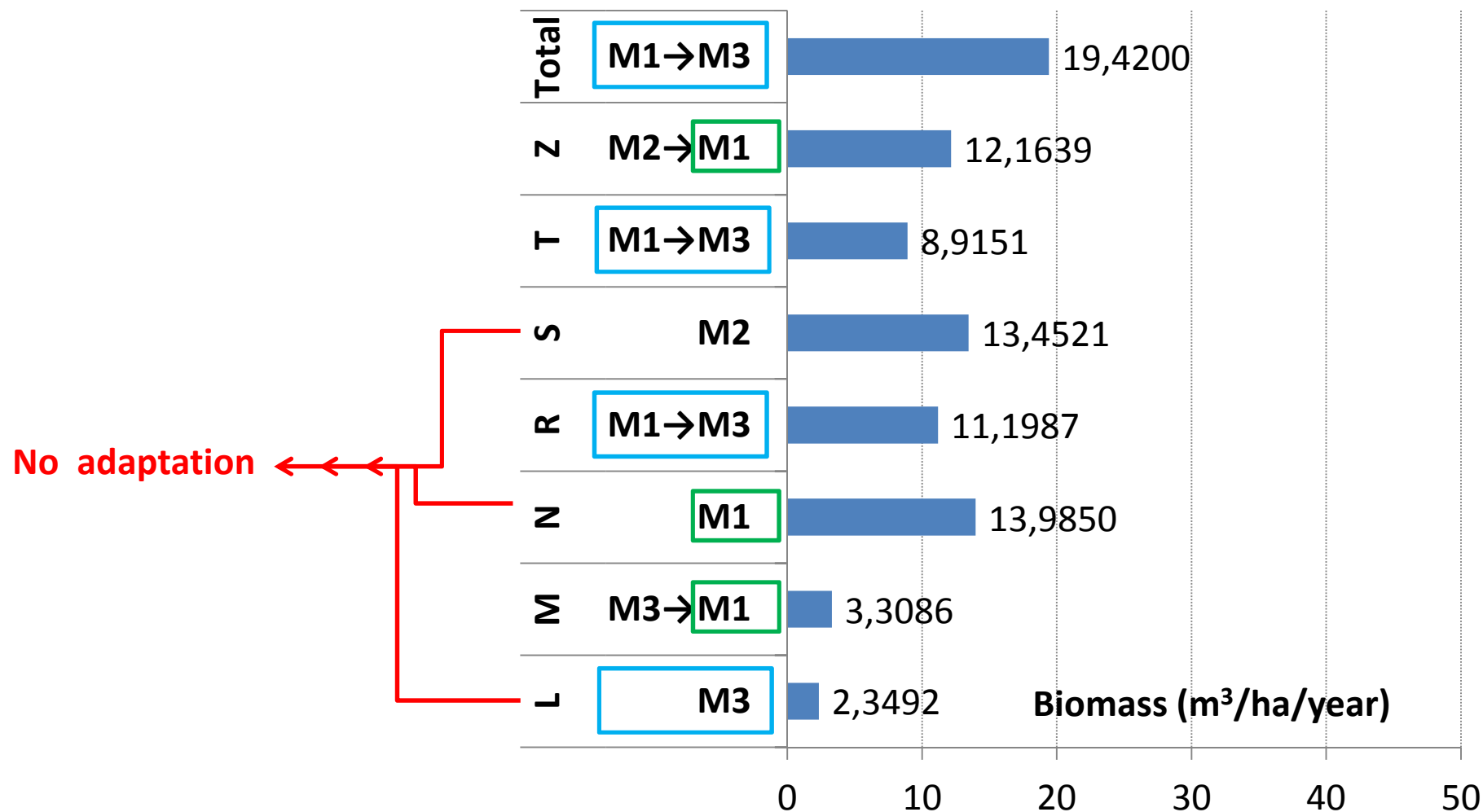


Active-adaptive





Results for Veluwe (adaptation at 2020):





w_1 , (% initial belief)

Windthrow↓ *decisions at 2010*

Historic	SMHI	HCCPR	Historic	Obj	SMHI	Obj	HCCPR	Obj
0	0	100	M4	0.19	M4	0.19	M4	0.19
0	20	80	M4	0.19	M4	0.19	M4	0.19
0	40	60	M4	0.19	M4	0.19	M4	0.19
0	60	40	M4	0.19	M4	0.19	M4	0.19
0	80	20	M4	0.19	M4	0.19	M4	0.19
0	100	0	M4	0.19	M4	0.19	M4	0.19
20	0	80	M4	0.29	M4	0.22	M4	0.17
20	20	60	M4	0.29	M4	0.22	M4	0.17
20	40	40	M4	0.29	M4	0.22	M4	0.17
20	60	20	M4	0.29	M4	0.22	M4	0.17
20	80	0	M4	0.29	M4	0.22	M4	0.17
40	0	60	M4	0.40	M4	0.25	M4	0.15
40	20	40	M4	0.40	M4	0.25	M4	0.15
40	40	20	M4	0.40	M4	0.25	M4	0.15
40	60	0	M4	0.40	M4	0.25	M4	0.15
60	0	40	M2	0.45	M3	0.27	M4	0.13
60	20	20	M2	0.45	M3	0.27	M4	0.13
60	40	0	M2	0.45	M3	0.27	M4	0.13
80	0	20	M2	0.46	M3	0.25	M4	0.12
80	20	0	M2	0.46	M3	0.25	M4	0.12
100	0	0	M2	0.47	M3	0.23	M4	0.10



Actual scenario	Variable	w ₅ (% belief at 2050)			Windthrow↓ decisions at 2050	
		Historic	SMHI	HCCPR		
Historic	Temperature	100	0	0	Switch to M3	0.21
	Precipitation	100	0	0	Switch to M3	0.16
	ADI	35	33	32	Switch to M3	0.27
	TBP	100	0	0	Switch to M3	0.16
	Biodiversity	100	0	0	Switch to M3	0.16
	Windthrow	84	6	10	Switch to M3	0.19
SMHI	Temperature	0	65	35	Continue with/Switch to M3	0.32
	Precipitation	0	100	0	Continue with/Switch to M3	0.32
	ADI	32	34	34	Continue with/Switch to M3	0.29
	TBP	0	100	0	Continue with/Switch to M3	0.32
	Biodiversity	0	90	10	Continue with/Switch to M3	0.32
	Windthrow	7	91	2	Continue with/Switch to M3	0.31
HCCPR	Temperature	0	35	65	Switch to M3	0.32
	Precipitation	0	0	100	Switch to M3	0.32
	ADI	32	34	34	Switch to M3	0.29
	TBP	0	0	100	Switch to M3	0.32
	Biodiversity	0	10	90	Switch to M3	0.32
	Windthrow	11	3	87	Switch to M3	0.31



Conclusion:

- Climate change realizations should be developed and selected carefully, i.e. Numerous, extremes, divergence
- Management decisions are sensitive to the initial state of the forest state, the objective of adaptive management and the beliefs mass about the climate change.
- Decision points create the opportunity to adapt/switch the actions and make use of novel information, update the beliefs and optimize decisions
- Sometimes, adaptation leads to a change in management now, sometimes, it is better to wait for more certainty of the climate development and then change
- Scale of adaptive actions on climate change matters because of differences in natural state of forest management units



Thank you!