

Dealing with uncertainty in forest management under climate change

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“Managers must embrace uncertainty in the New Year

Why? First, because uncertainty will not dissipate soon, so businesses might as well try to make the best of what little they do know. Second, because an excess of certainty got us into this predicament. “

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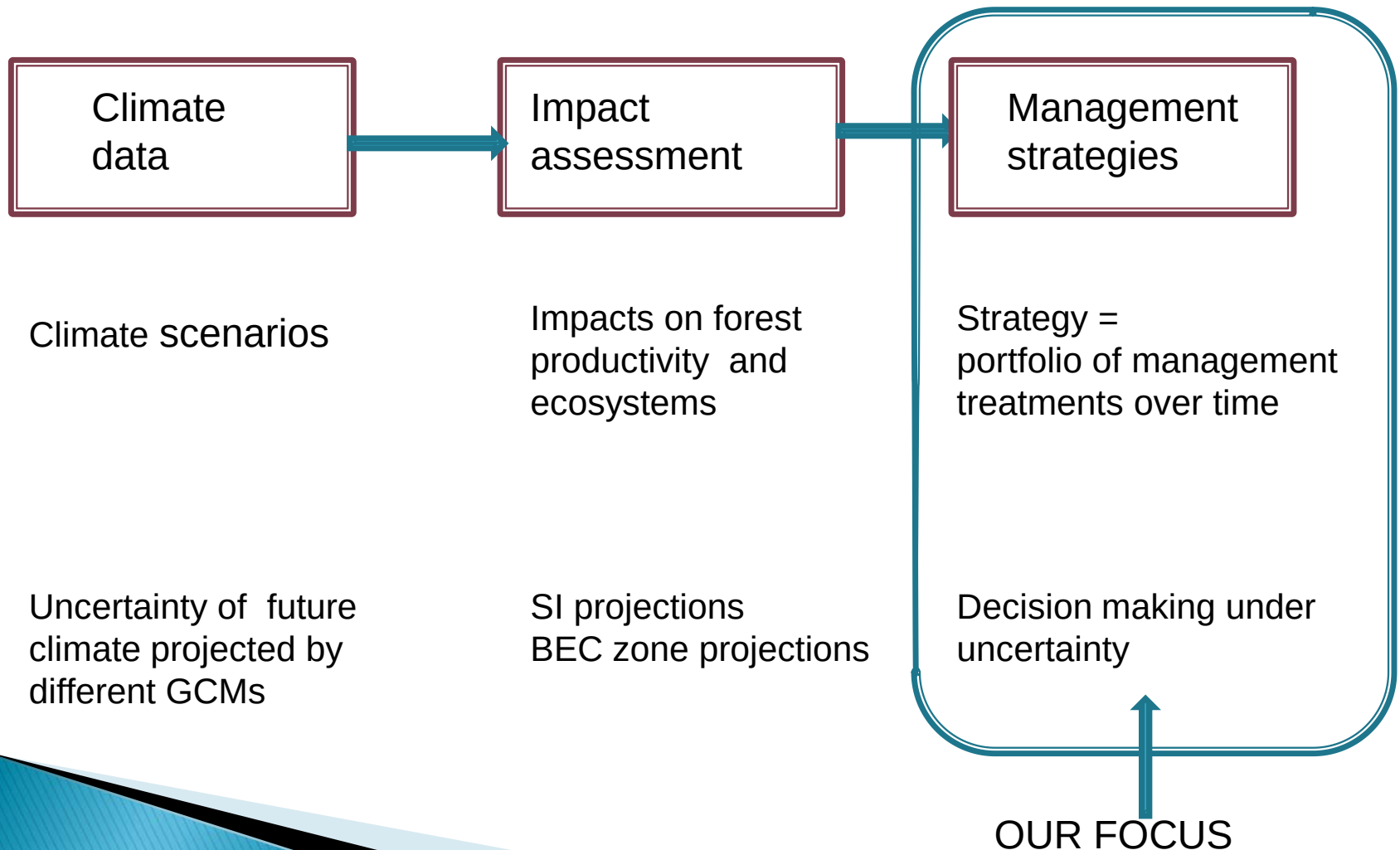
A. Hill, Financial Times, Jan. 03, 2012

Management decisions

Financial vs. Forest

- ▶ Time horizon: short , long
- ▶ Impact of current decisions on future performance
- ▶ Task: find a portfolio of investments/treatments over time to meet multiple objectives
- ▶ Attitude toward risk
- ▶ Uncertainty

A framework for forest management under climate change



Dealing with uncertainty

- ▶ Forest management decisions under climate change are decisions under uncertainty
- ▶ What kind of uncertainty?
- ▶ “Deep” uncertainty (Schneider 2003, Dessai and Hulme 2007)

Deep uncertainty

“... the climate change debate is characterized by deep uncertainty, which results from factors such as lack of information, disagreement about what is known or even knowable, linguistic imprecision, statistical variation, measurement error, approximation, subjective judgment, and disagreement about structural models, among others. [...] Moreover, climate change is not just a scientific topic but also a matter of public and political debate, and degrees of uncertainty may be played up or down (and further confused, whatever the case) by stakeholders in that debate.”

Schneider (2003)

Robust decisions under deep uncertainty

- ▶ Robust decision making is not a technique but an iterative and interactive framework to help identify and evaluate potential robust decisions
- ▶ Robust approaches search for “good-enough” or satisficing (Simon 1957) strategies under a range of unknown future conditions
- ▶ Robust decisions reflect some degree of pessimism resulting in reduced objective levels

Forest management under climate change for the Quesnel study area

- ▶ *Goal:* timber supply formulated as even flow of harvest volume over time or sustained yield management (SYM)
- ▶ *Assumptions:*
 - timber harvesting land base (THLB) divided into strata according to BEC zones, tree species, site productivity and age classes
 - focus on three species: interior Douglas–fir, interior spruce, lodgepole pine
 - “status quo” management scenario: regenerate naturally or by planting while maintaining pre-harvest species composition

Sustained Yield Management (SYM)

Objectives:

- Period harvest as high as possible
- Even harvest flow

SYM problem is formulated as:

$$\begin{aligned} & \text{Max } Vol(x, c) \\ & \text{subject to} \\ & \quad FlowD(x, c) = 0 \end{aligned}$$

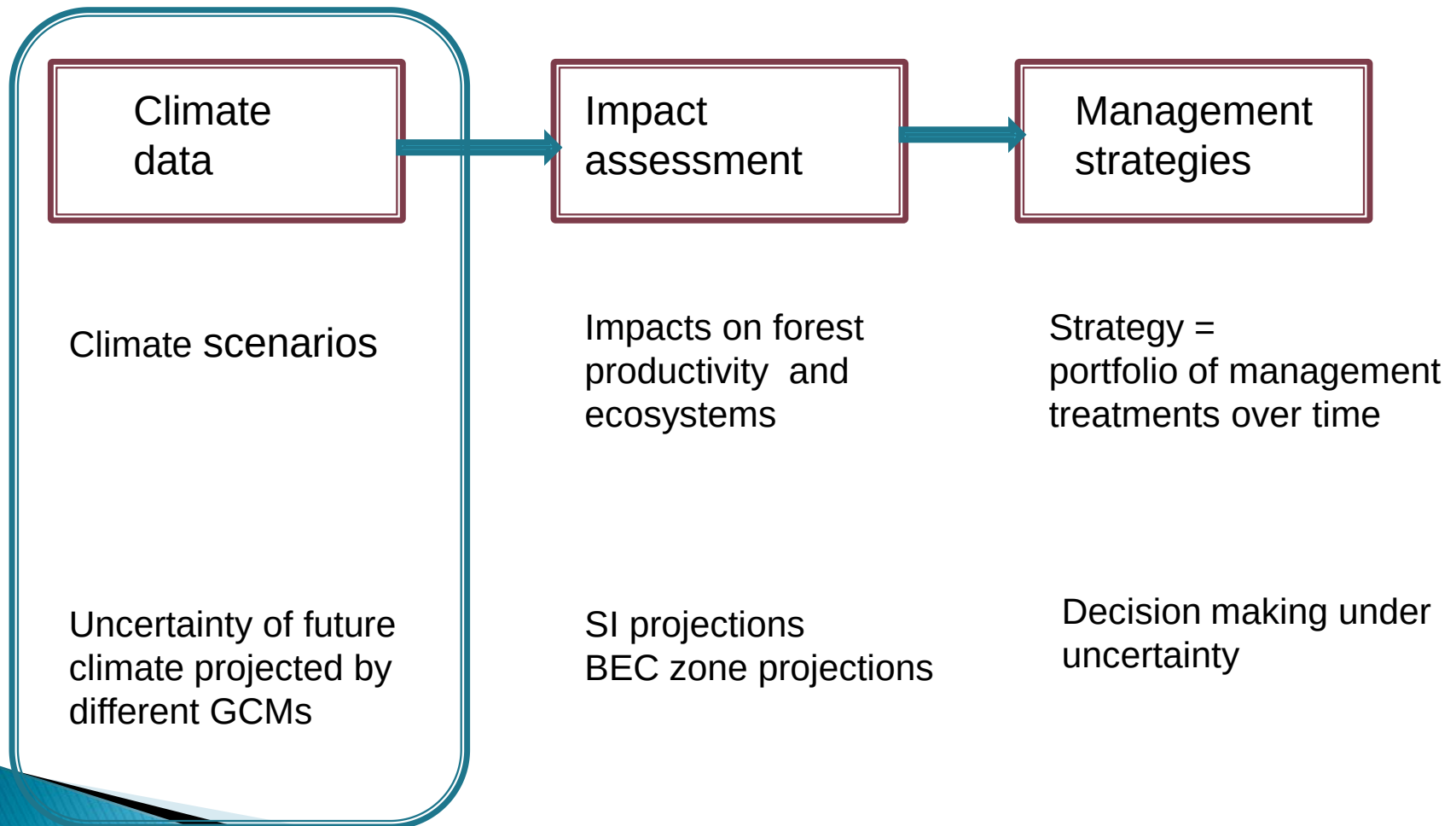
where

$Vol(x, c)$ = cumulative volume over the horizon

$FlowD(x, c)$ = flow deviation or max difference between period harvests

x = management strategy, c = climate scenario

A framework for forest management under climate change

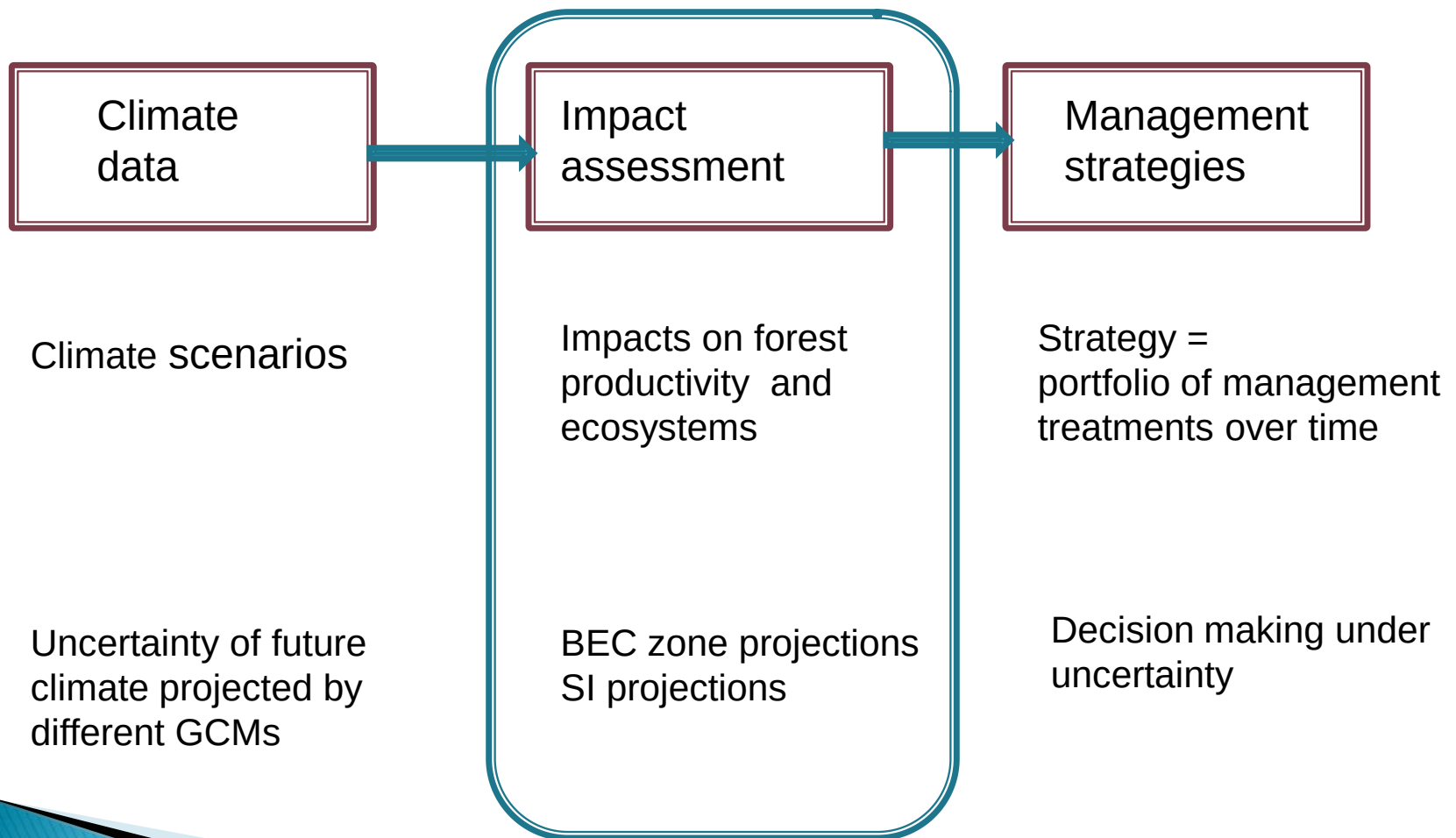


Climate scenarios

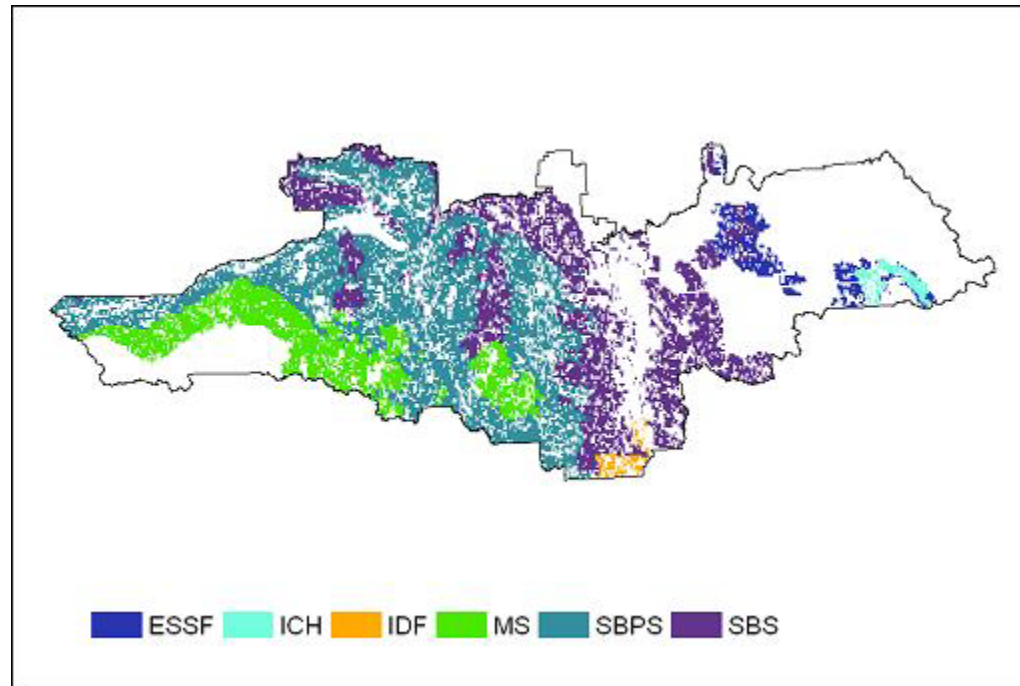
C	Model	Emissions	Run	Description
0				No change
1	CGCM3	A2	4	Warm and wet
2	HadCM3	B1	1	Cool and moist
3	HadGEM	A1B	1	Hot and dry
4	GFDLCM21	A2	1	
5	CSIROMK30	B1	1	
6	NCARCSM30	A1B	5	
7	GISS-EH	A1B	3	
8	CGCM3	A2	5	
9	ECHAM5	B1	1	
10	MRICGCM232A	B1	5	

climate scenarios are equally likely (Spittlehouse and Murdock 2010)

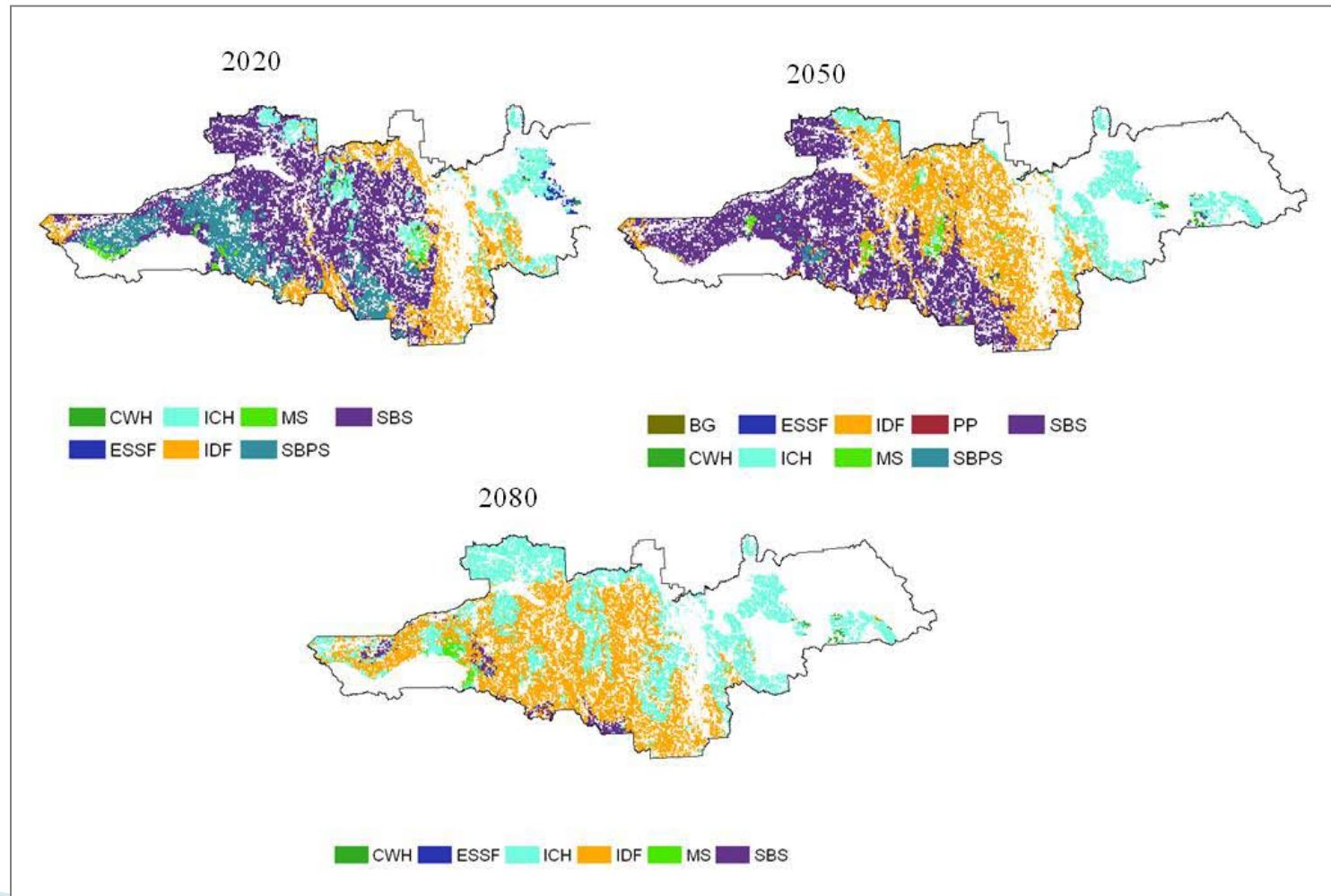
A framework for forest management under climate change



Current distribution of BEC zones in Quesnel THLB



Projected distributions of BEC zones, C#1



Future climate: Warm and wet

Projections generated by Climate BC/WNA (Wang 2011)

Site index (SI)

values are projected by equations:

Lodgepole pine:

$$SI = 2.514 + 0.06615 \times NFFD - 0.07939 \times \text{RATIOA} + 0.4060 \times \text{CONT}$$

Interior spruce: $SI = 6.424 + 0.9918 \times \text{MTWM}$

Interior Douglas-fir:

$$SI = -4.586 + 1.577 \times \text{MAT} - 0.3787 \times \text{RATIOA} + 1.168 \times \text{CONT}$$

where CONT, MAT, MTWM, NFFD, RATIOA are climate variables
(Night et al 2004)

Projected changes of SI

	2020			2050			2080		
C	<i>Pine</i>	<i>Fir</i>	<i>Spruce</i>	<i>Pine</i>	<i>Fir</i>	<i>Spruce</i>	<i>Pine</i>	<i>Fir</i>	<i>Spruce</i>
1	1	2	2	2	2	3	4	4	4
2	2	3	2	3	5	3	4	7	4
3	2	3	2	4	5	5	5	8	7
4	1	1	2	3	4	3	3	5	3
5	1	1	1	2	3	2	2	3	2
6	2	1	2	3	3	4	3	5	4
7	2	3	1	2	3	2	3	5	3
8	1	1	2	2	2	2	3	4	4
9	0	1	1	1	2	2	2	4	3
10	1	1	1	1	2	1	1	2	2

Implementation

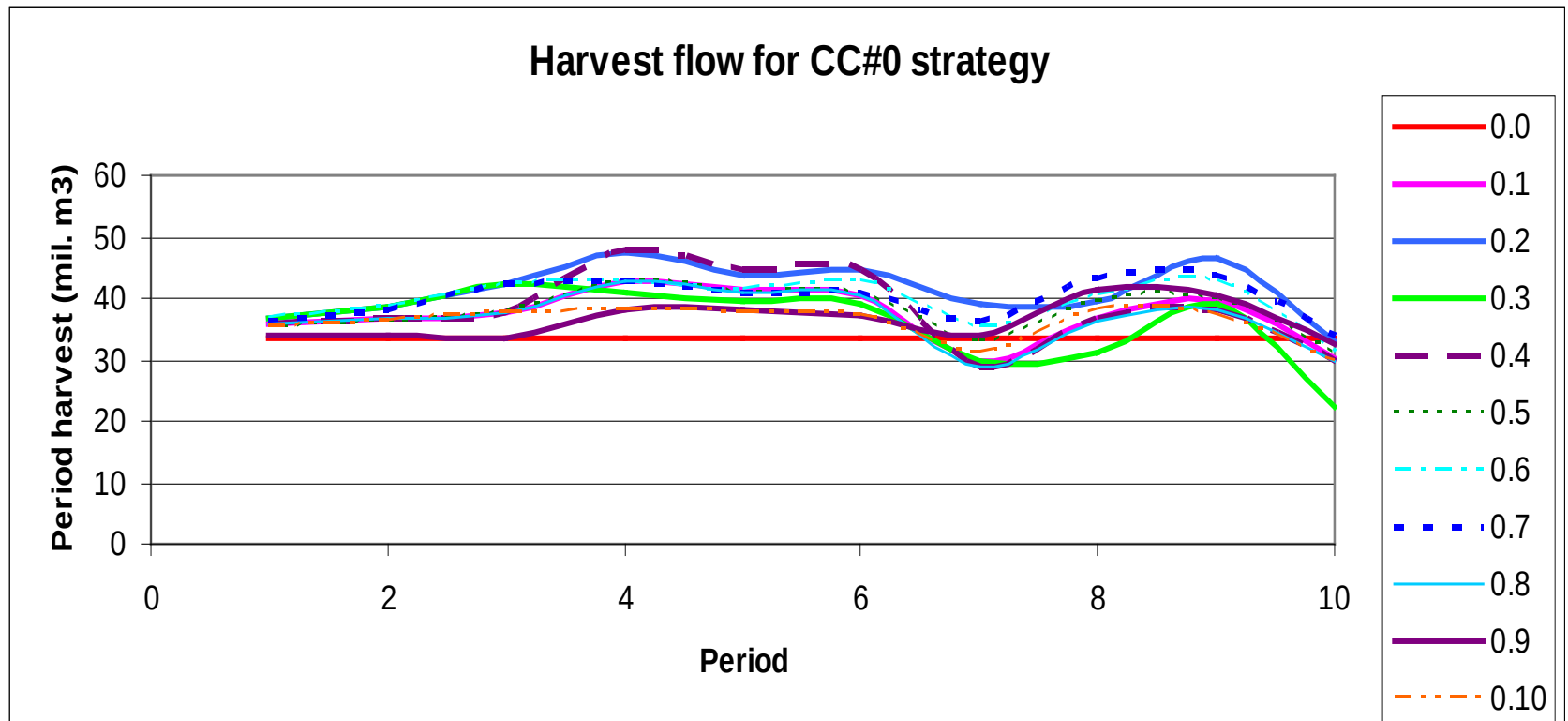
of climate impact projections into SYM model

- ▶ BEC zones projections: an average of the 2020, 2050 and 2080 projections is used over the horizon
- ▶ Suitability of species to BECs projections: a binary indicator is assigned according to the current distribution of species across BEC zones in BC Interior
- ▶ SI projections: if species is suitable for BEC, SI is estimated using equations on slide 16 ; otherwise, SI under 'no CC' is used & yield reduced by 10% (O'Neill and Nigh 2011)

Results

- ▶ SYM model for the Quesnel area is an LP solved by CPLEX on GAMS platform
- ▶ SYM model is solved for each climate scenario producing eleven individual sustained yield strategies
- ▶ For each sustained yield strategy, period harvests and flow deviations were determined assuming that several different climate scenarios may occur in the future
- ▶ This approach generates 121 ($=11 \times 11$) projected values for the period harvests and flow deviations

Projected harvest flow for 'no CC' strategy



Analysis of the 'no CC' SYM strategy

using SYM model outcomes calculated for the 'no CC' SYM strategy and different climate scenarios, optimistic and conservative perspectives

	Climate scenarios (c)												
x_0^*	0	1	2	3	4	5	6	7	8	9	10	Opt	Cons
Vol (x_0^*, c)	<u>334</u>	371	<u>412</u>	360	381	378	394	398	368	363	358	412	334
FlowD (x_0^*, c)	<u>0.0</u>	11.1	13.4	<u>16.9</u>	15.9	9.2	11.7	9.7	11.6	8.1	7.5	0.0	16.9

Analysis of strategies

using SYM model outcomes:

- ▶ Cumulative volume: $Vol(x, c)$
- ▶ Flow Deviation: $FlowD(x, c)$

Cumulative volume (mil. m³)

calculated for 11 SYM strategies and different climate scenarios, optimistic and conservative perspectives

	Climate scenarios (c)												
X _j *	0	1	2	3	4	5	6	7	8	9	10	Opt	Cons
0	334	371	412	360	381	378	394	398	368	363	358	412	334
1	321	372	370	368	372	353	374	365	365	351	339	374	321
2	348	421	454	443	423	405	440	427	411	390	382	454	348
3	306	339	340	359	339	327	345	336	333	323	316	359	306
4	315	366	370	363	372	351	373	361	361	344	335	373	315
5	329	387	424	386	392	387	416	406	380	372	365	424	329
6	329	380	389	389	385	366	393	379	374	358	349	393	329
7	333	375	402	379	373	369	387	389	368	361	356	402	333
8	312	361	361	348	363	345	365	355	356	342	332	365	312
9	339	395	426	393	399	392	420	410	387	380	369	426	339
10	318	380	411	387	386	376	404	395	375	362	358	411	318
												454 Max max	348 Max min

Flow deviation (mil. m³)

Calculated for 11 optimal strategies and different climate scenarios, optimistic and conservative perspectives

	Climate scenarios												
x_j^*	0	1	2	3	4	5	6	7	8	9	10	Opt	Cons
0	0.0	11.1	13.4	16.9	15.9	9.2	11.7	9.7	11.6	8.1	7.5	0.0	16.9
1	11.5	0.0	6.4	6.9	4.1	5.5	5.0	3.4	2.2	5.0	7.2	0.0	11.5
2	10.3	3.9	0.0	4.3	6.2	4.6	3.8	5.0	3.5	5.8	7.8	0.0	10.3
3	7.7	3.5	<u>7.8</u>	0.0	2.8	4.8	4.5	4.4	3.6	5.3	5.9	0.0	<u>7.8</u>
4	12.6	4.9	5.4	13.8	0.0	3.4	3.6	3.4	4.0	7.3	7.3	0.0	13.8
5	8.6	5.7	3.8	5.5	5.2	0.0	2.2	3.4	5.4	3.0	5.1	0.0	8.6
6	14.9	4.0	9.0	9.8	2.1	4.0	0.0	4.6	4.1	7.6	8.4	0.0	14.9
7	9.9	4.7	5.4	6.8	6.1	4.6	2.5	0.0	4.6	8.1	5.0	0.0	9.9
8	9.1	1.7	5.9	7.6	3.7	3.2	3.3	2.8	0.0	3.7	3.7	0.0	9.1
9	6.0	4.0	8.4	8.6	9.6	4.3	7.6	3.9	4.0	0.0	3.4	0.0	9.6
10	5.1	5.2	6.3	12.1	9.3	4.6	4.7	2.8	4.4	3.9	0.0	0.0	12.1
												0.0 Min min	7.8 Min max

Strategies for consideration

C#2 and C#3 SYM strategies:

- C#2 strategy is best from both the optimistic and conservative perspectives in terms of cumulative harvest volume
- C#3 strategy is best from the conservative perspectives in terms of flow deviation

Analysis of the C#2 and C#3 SYM strategies

For C#2 strategy:

- period harvests are at least 29.8 mil. m³ (33.5% increase relative to the lowest period harvest for C#0 SYM strategy)
- *FlowD* is below or equal to 10.3 mil. m³ (39% improvement relative to the highest *FlowD* for C#0 SYM strategy)

For C#3 strategy:

- period harvests are at least 23.7 mil. m³ (6.3% increase relative to the lowest period harvest for C#0 SYM strategy)
- *FlowD* is below or equal to 7.8 mil. m³ (54% improvement relative to the highest *FlowD* for C#0 SYM strategy)

Are the C#2 and C#3 SYM strategies robust?

- ▶ Yes if stakeholders are satisfied with the strategy outcomes.
- ▶ No if stakeholders are not satisfied with the outcomes of either strategy.
 - Next steps:
 - ▶ consider additional criteria for evaluation
 - ▶ examine new management/adaptation scenarios
 - ▶ generate additional management strategies
 - ▶ repeat the process described in Slides 19–25

Discussion

- ▶ Results of the case study represent relative, rather than absolute values
- ▶ Results are valid only under given assumptions
- ▶ The period harvests are determined in the context of 'status quo' management scenario without consideration for adaptation (e.g. assisted migration by changing current species distribution in the area)
- ▶ Decay and mortality due to drought, pests and fire are not accounted for

Discussion (continued)

Additional uncertainty is created by different ways of implementing climate impact projections into the model:

- BEC zone projections for 2020, 2050, 2080
 - Modeling needs to provide a portfolio of management treatments over time (in 10-year periods)
 - Challenge: how to interpolate projections of BEC zones?
- Suitability of species to BEC zones is modeled as a binary indicator
 - Challenge: how to better estimate the suitability index?
- Productivity projections
 - Challenge: how to assess impacts of drought & natural disturbances on reduced productivity & mortality?

Recommendations

- ▶ Defining multiple objectives for evaluations of the strategies
- ▶ Diversifying management portfolios by including many adaptation scenarios
- ▶ Projecting forest impacts of various climate scenarios
- ▶ Satisfying rather than optimizing
- ▶ Expecting the unexpected

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