

Assisted migration to adapt forests to climate change, is uncertainty too deep to decide?

Minh Ha-Duong
haduong@centre-cired.fr

Ankur Shah
shah@centre-cired.fr

Illingworth trial *Pinus contorta* data was kindly provided by **Gregory A. O'Neill**,
[Kalamalka Research Station](#), BC Ministry of Forests, Canada

Should we use seeds from warmer locations to adapt to climate change ?

1. Problem of assisted migration
2. Model of decision in deep uncertainty
3. Data from experimental tests in Canada
4. Results

1. Assisted migration

Translocate populations to compensate for observed or future climate changes.

The pace of climate change is too rapid for most populations to track changing climates.

Forestry assisted migration

common tree species moved within their ranges

≠

Conservation

endangered species moved outside their ranges

The assisted migration question is already asked

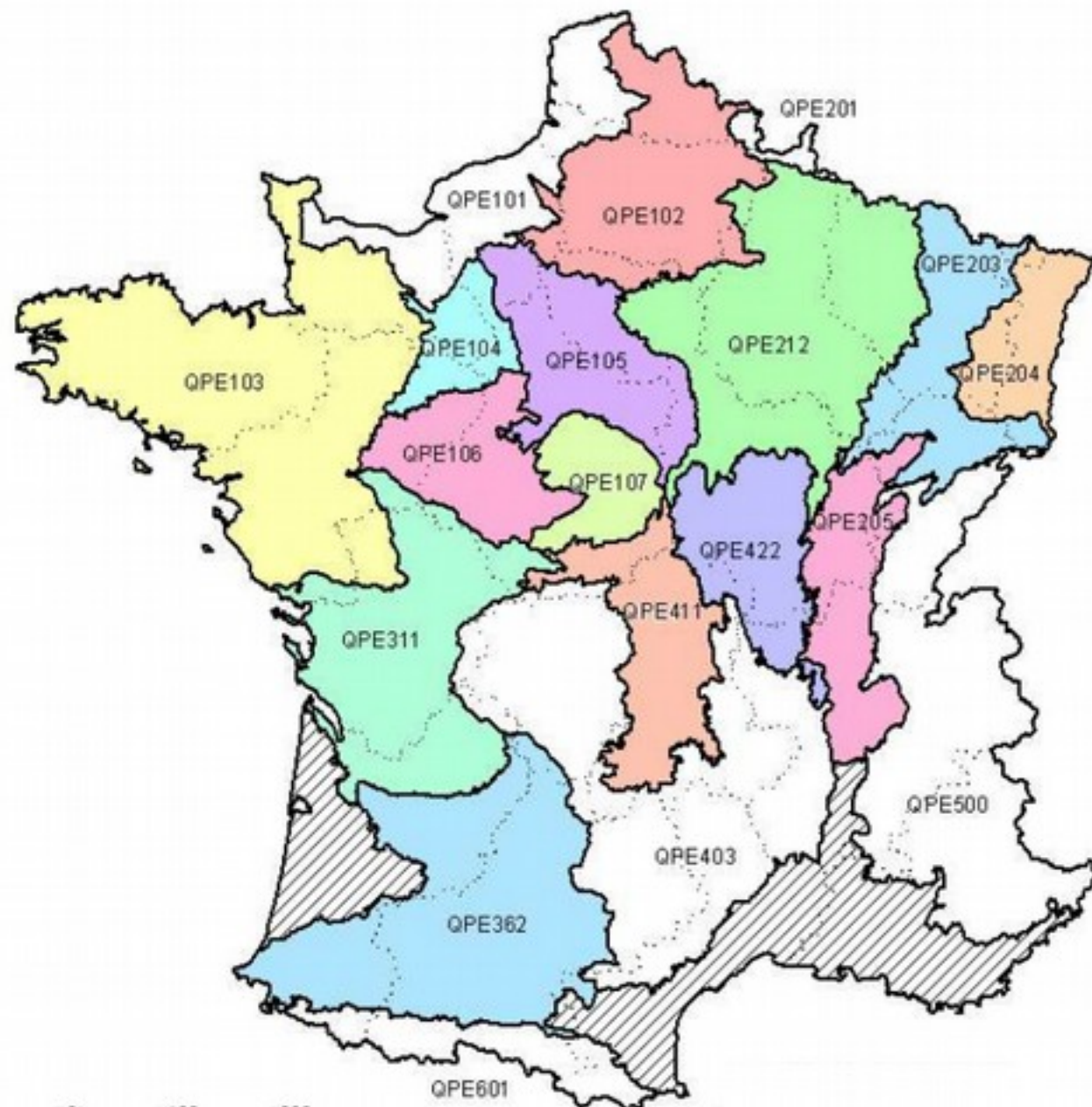
Is it time to revise the current guidelines
« use local provenance » ?

Projet ANR- 11-AGRO-0005
AMTools : Outils écologiques et légaux
pour la migration assistée des forêts





Source : Nikonaos. http://fr.wikipedia.org/wiki/Quercus_petraea#mediaviewer/File:Quercus_petraea_01.jpg

Carte des régions de provenance du Chêne sessile



Régions de provenance

- QPE101 Bordure Manche
- QPE102 Picardie
- QPE103 Massif armoricain
- QPE104 *Perche*
- QPE105 Sud Bassin parisien
- QPE106 Secteur ligérien
- QPE107 *Berry-Sologne*
- QPE201 Ardennes
- QPE212 Est Bassin parisien
- QPE203 Nord-Est limons et argiles
- QPE204 Nord-Est gréseux
- QPE205 Vallée de la Saône
- QPE311 Charentes-Poitou
- QPE362 Gascogne
- QPE411 Allier
- QPE422 Morvan-Nivernais
- QPE403 *Rouergue-Massif central*
- QPE500 Alpes et Jura
- QPE601 Pyrénées

- Limites des régions de provenance
- Limites des régions administratives
-  Zone sans récolte
-  Région de provenance sans peuplement sélectionné au 01/10/2003



Current guidelines avise local provenance

Zone d'utilisation et région de provenance conseillée	Autres matériels utilisables	
	Nom	Cat.
QPE101-Bordure Manche*	QPE102-Picardie QPE103-Massif Armoricaïn QPE104-Perche	S S S
QPE102-Picardie	QPE105-Sud bassin parisien	S
QPE103-Massif armoricaïn	QPE104-Perche QPE106-Secteur ligérien	S S
QPE104-Perche	QPE106-Secteur ligérien	S
QPE105-Sud bassin parisien	QPE102-Picardie QPE106-Secteur ligérien QPE107-Berry-Sologne	S S S
QPE106-Secteur ligérien	QPE104-Perche QPE107-Berry-Sologne	S S
QPE107-Berry-Sologne	QPE106-Secteur ligérien	S
QPE201-Ardenne s *	QPE102-Picardie QPE212-Est bassin parisien	S S

Ministère de l'Agriculture, Conseils d'utilisation des MFR du chêne sessile
http://agriculture.gouv.fr/IMG/pd/chene_sessile-2.pdf Accédé 2014-10-20

Rational, evidence-based policy ?

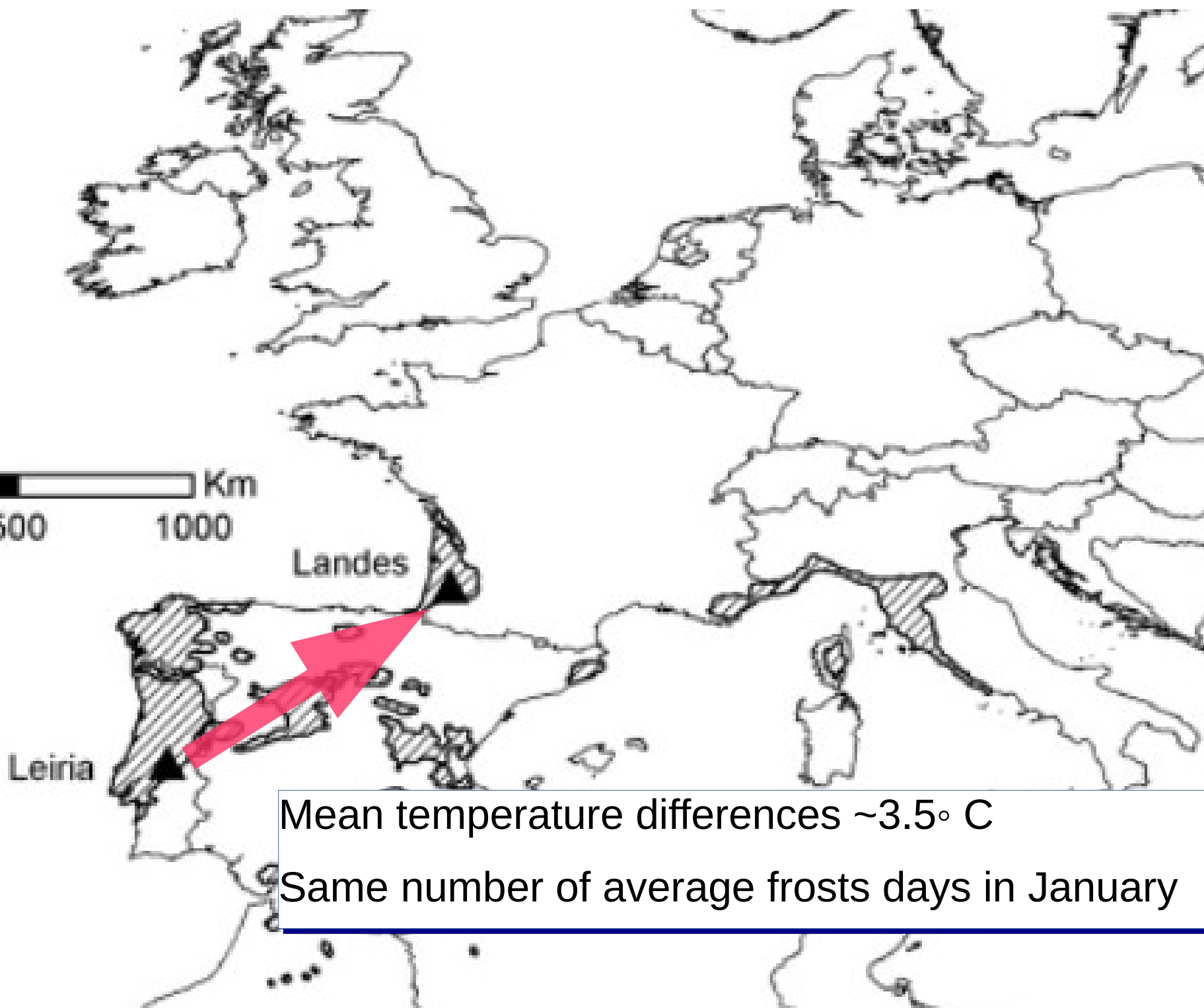
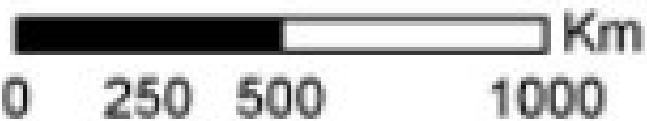
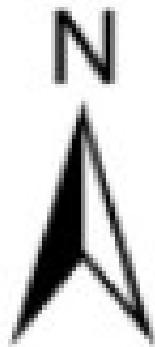
- Future climate
 - Natural weather variability
 - Radiative forcing trajectories : RCP 2.6 – 8.5
 - Climate models
- Seeds performance
 - Natural genetic variability
 - Too few experimental data
 - Ecological models
- Human factors



Historical analogue

19 june 1857 law : Afforestation of the Landes of Aquitaine with maritime pine (pinus pinaster)

1949-1950 : After great fires, use of Iberian seeds



Mean temperature differences $\sim 3.5^{\circ} \text{C}$
Same number of average frosts days in January

Assisted migration is risky

19 june 1857 law : Afforestation of the Landes of Aquitaine with maritime pine (*pinus pinaster*)

1949-1950 : After great fires, use of Iberian seeds

1956 and 1963 : frosts events, early warning

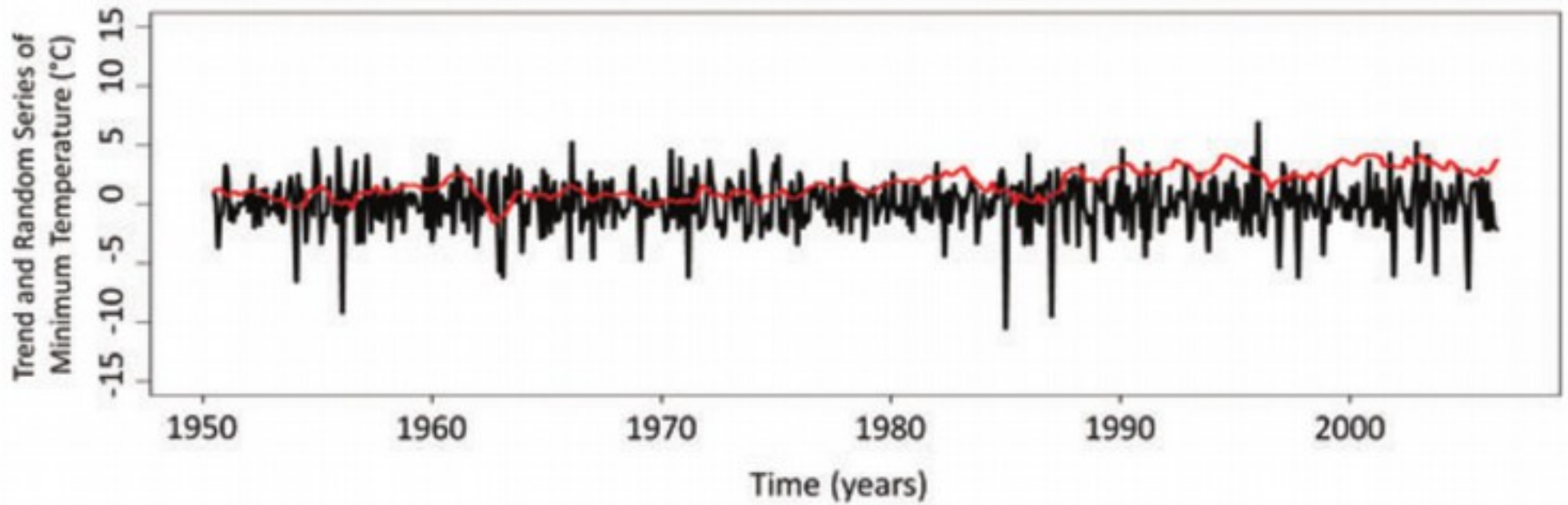
1985 : strong frost event, Iberian populations mortality increase while local populations far less affected

Outcome : 300–400 km² of the Landes forest impacted, approximately 1,400,000 m³ of wood

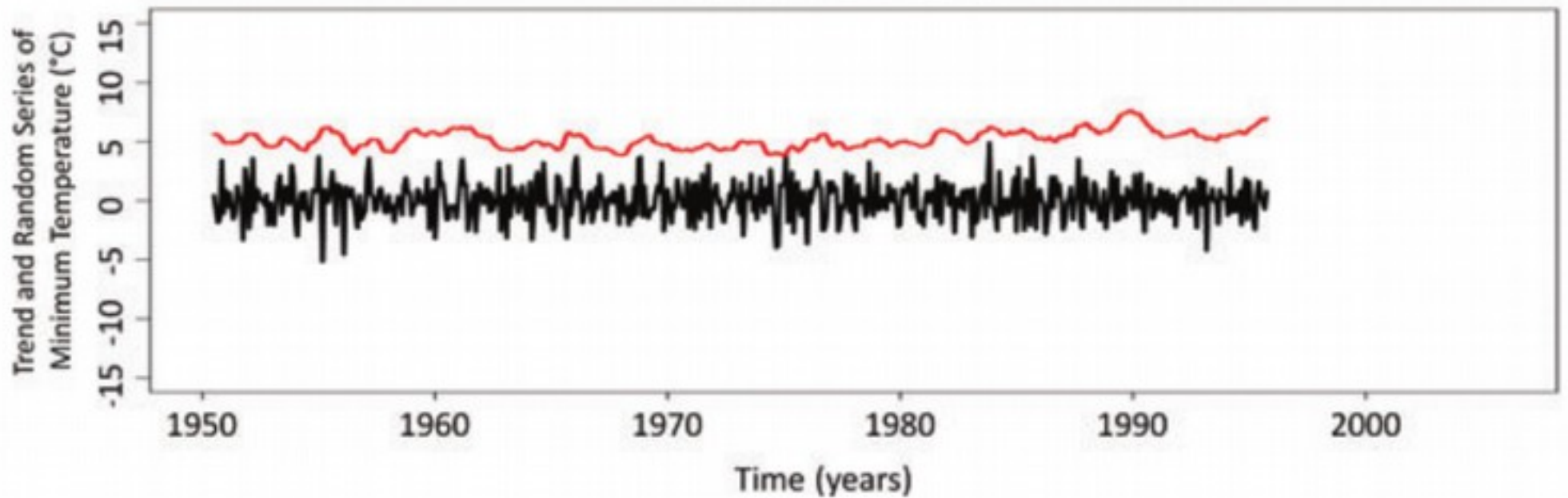


Dying pine forest les Landes, Wikimedia Commons

(a) Bordeaux (France)



(b) Coimbra (Portugal)



2. The decision analysis model

Choose a provenance among a_0, a_1, \dots, a_N

Where a_0 is the local provenance

The uncertain future climate is one of s_1, \dots, s_K

The payoff will be $u(a_n, s_k)$

Imprecise probabilities

A worldview is a probability $P = (p(s_1), \dots, p(s_K))$

There are multiple worldviews P_1, \dots, P_V

According to worldview v , the expected performance of provenance a_n is

$$E_{P_v}(u(a_n, s)) = \sum_{k=1}^{k=K} p_v(s_k) \times u(a_n, s_k)$$

A preference relation

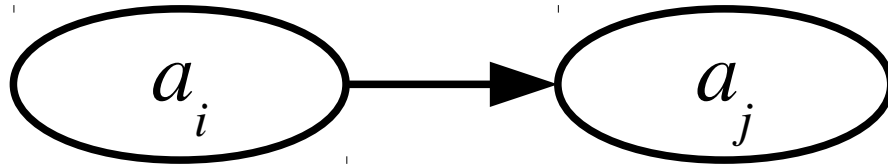
A provenance is preferred to another if and only if it has a better expected performance in all worldviews.

$$a_i \succ a_j \text{ iff } \forall v: E_{P_v}(u(a_i, s)) > E_{P_v}(u(a_j, s))$$

Desired trades

Option to plant local seeds a_0 is the default reference choice.

Decision maker is willing to switch from a_j to a_i when and only when $a_i \succ a_j$



Model properties

If only one worldview, this agrees with the standard expected utility model.

If each worldview supports one and only one state of the world, a_i is preferred to a_j iff it performs better for all scenarios without trade-offs, according to a strong precaution model.

Summary of the decision model

Prefer another provenance if and only if it is expected to perform better for all acceptable probability distributions.

Unicity not guaranteed. Default option available.

Rational and precautionary.

Can it lead to evidence based recommendations ?

3. Data

Canadian provenance tests



To assess growth and adaptation of BC's reforestation materials in BC's future climates, seedlots are tested across a wide climate range. Shown here are seedlings being planting at one of the hottest and driest test sites - the Kalamalka Research Station (Vernon).

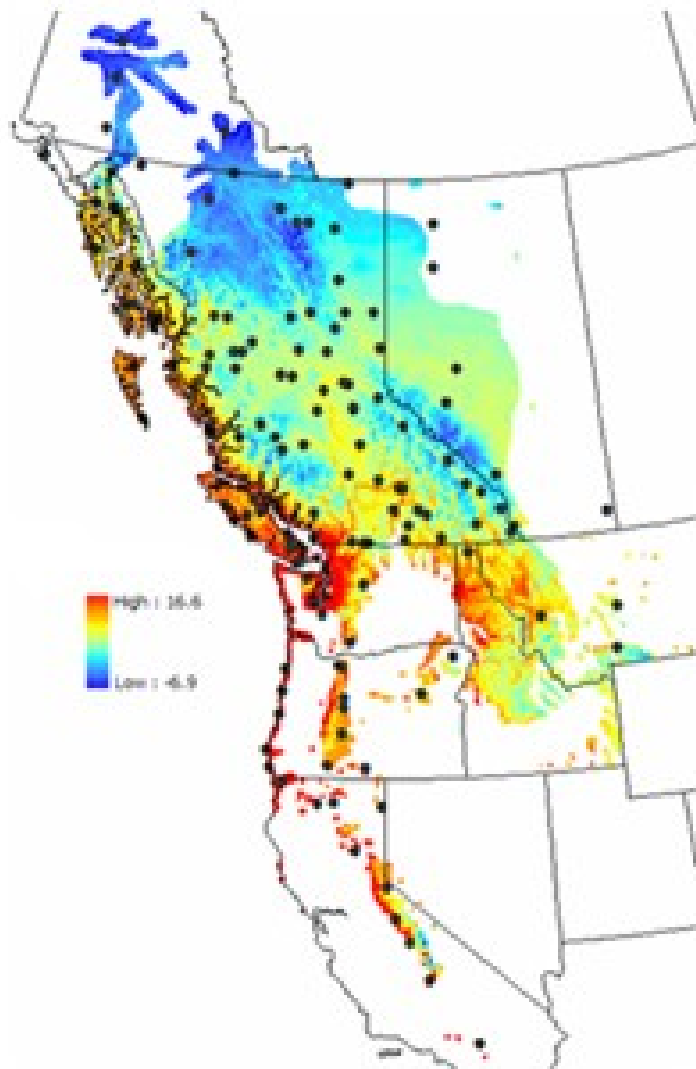
Source: Greg O'Neill <http://www.for.gov.bc.ca/HRE/forgen/interior/AMAT.htm#Photos>

Gregory A. O'Neill, Andreas Hamann, Tongli Wang (2008)
**Accounting for population variation improves estimates of the
impact of climate change on species' growth and distribution.**
Journal of Applied Ecology 45(4). [10.1111/j.1365-2664.2008.01472.x](https://doi.org/10.1111/j.1365-2664.2008.01472.x)

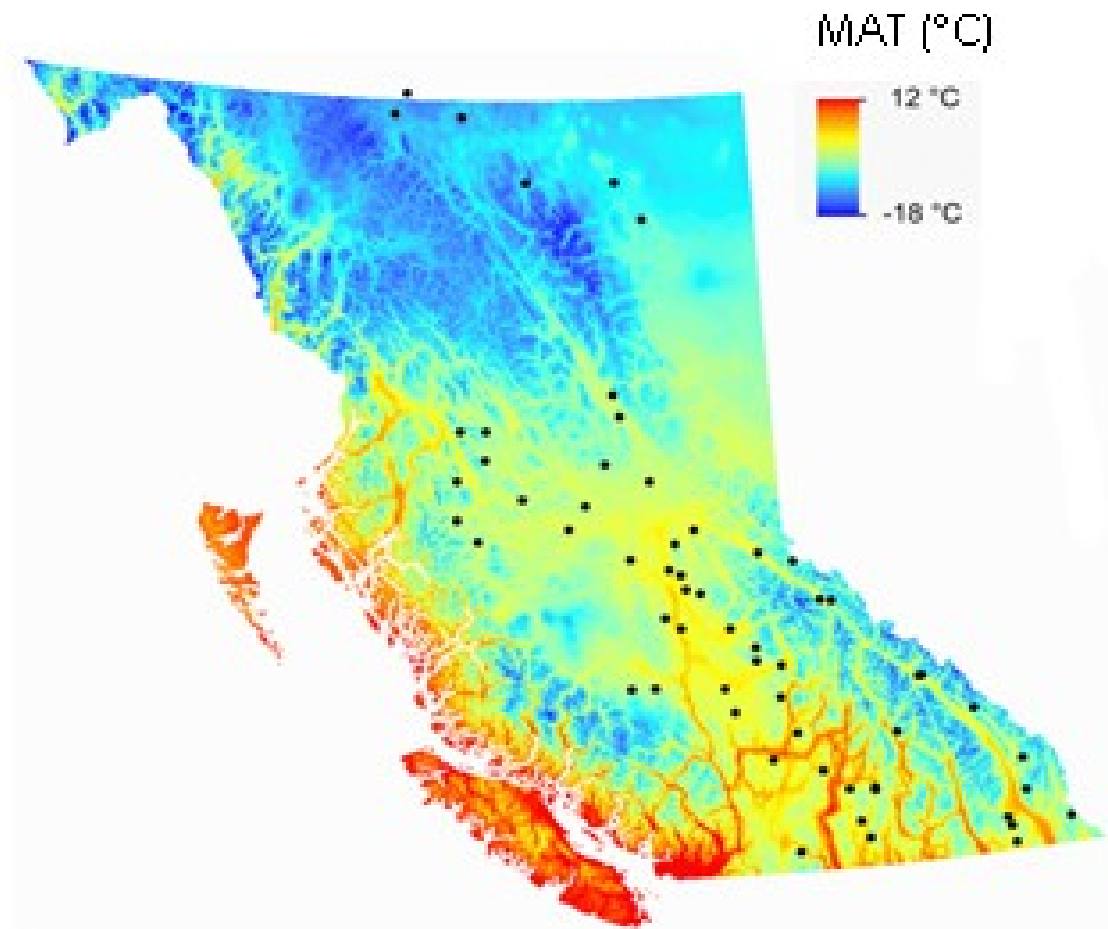
Data from the BC Ministry of Forests and Range's **lodgepole pine provenance test**, which consists of **140 populations** tested at **62 sites**. Populations planted in the test were selected in a stratified random manner across six Canadian and two USA physiographic regions from southern California (34°N latitude) to central Yukon (64°N latitude), encompassing most of the species' range and the three main varieties (*latifolia*, *contorta* and *murrayana*). Seed of each population, collected between 1966 and 1968, was bulked from collections of 50–100 cones from each of 15 trees. Test sites in **the Illingworth trial** were also selected in a stratified random sampling scheme: five sites in each of 12 geoclimatic regions in interior BC and two sites in the Yukon, encompassing 12 degrees of latitude (49°–61°), 21 degrees of longitude (114°–135°) and 1220 m of altitude (610–1830 m).

An incomplete testing design tested 60 of the 140 populations at each site, so that each population was tested at 30–40 sites. Within each site, a randomized complete block design was used, with one nine-tree square plot of each population planted in each of two blocks. The two Yukon sites contained six blocks, each comprising 40 populations. In total, 69 120 seeds were sown in 1971 and resultant seedlings were transplanted to the sites in spring 1974 at 3 × 3-m spacing. Total height (HT) and diameter at breast height (d.b.h.) were measured at 43 of the 62 sites in autumn 2005, after **32 field growing seasons** (35 growing seasons from seed).

140 provenances from
the species range



60 test sites in British Columbia



Source : Growth response of lodgepole pine to climate. From Wang, T., O'Neill, G., Aitken, S.N., 2010. Integrating environmental and genetic effects to predict responses of tree populations to climate. . Ecological Applications 20: 153-163.

<http://cfcg.forestry.ubc.ca/projects/climate-data/growth-response-of-lodgepole-pine-to-climate/>

The performance function $u(a_n, s_k)$

H_{tp} : Relative site height of a population in a plot

Differences between

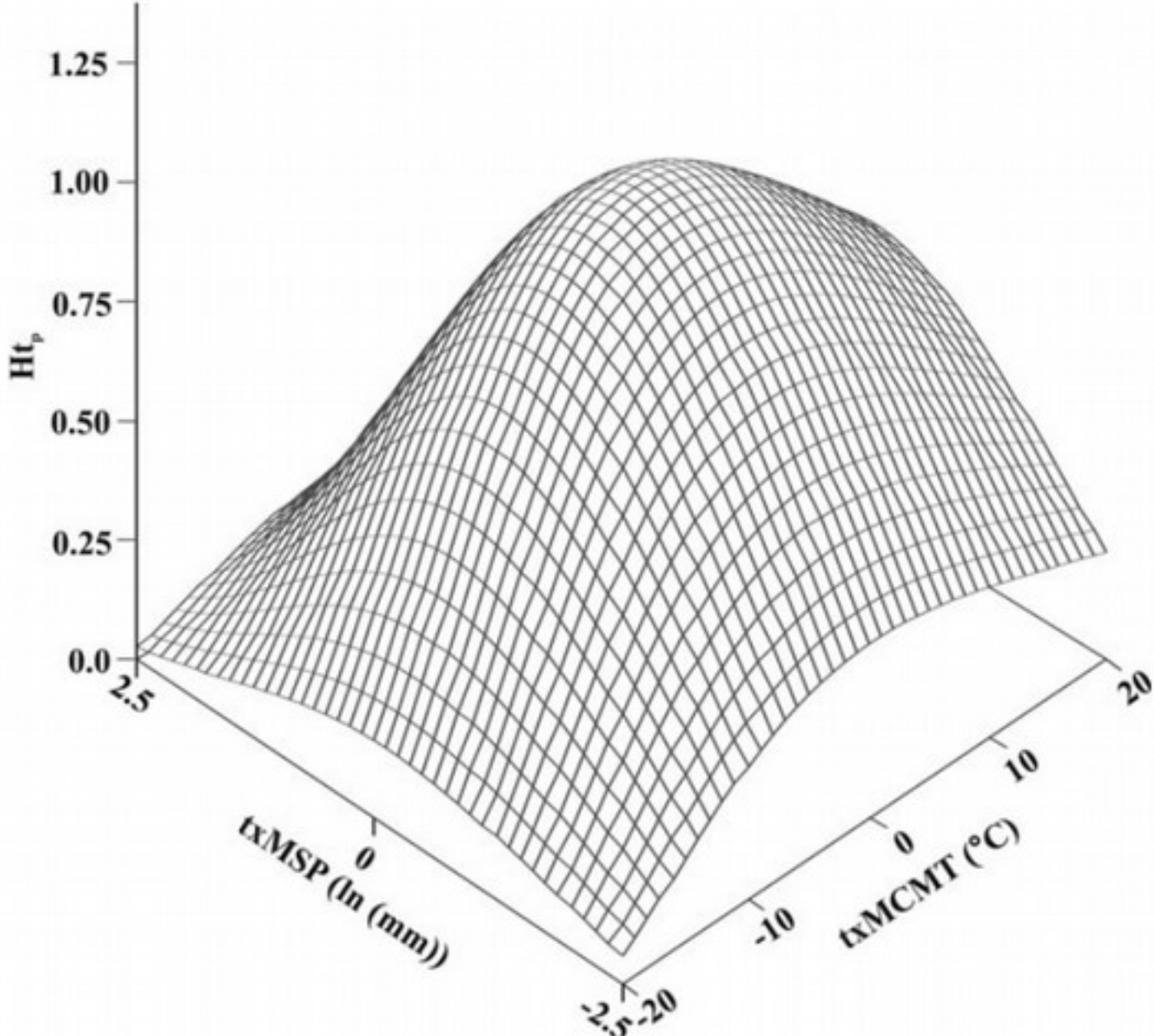
- future climate s_k
 - historical climate of provenance a_n
- decreased H_{tp}

Differences with respect to :

- Mean Coldest Month Temperature (MCMT)
- Mean Summer Precipitation (MSP)

Gord Nigh (2014) Mitigating the effects of climate change on lodgepole pine site height in British Columbia, Canada, with a transfer function.

Forestry 2014; 11 p., doi:10.1093/forestry/cpu009



***K*=8 future climates**

Model	RCP
CanESM2	2,6
CanESM2	4,5
CanESM2	8,5
CNRM-CM5	2,6
CNRM-CM5	4,5
CNRM-CM5	8,5
HadGEM2-ES	4,5
HadGEM2-ES	8,5

Source : UBC, [ClimateWMA_map](#)

M=3 Worldviews

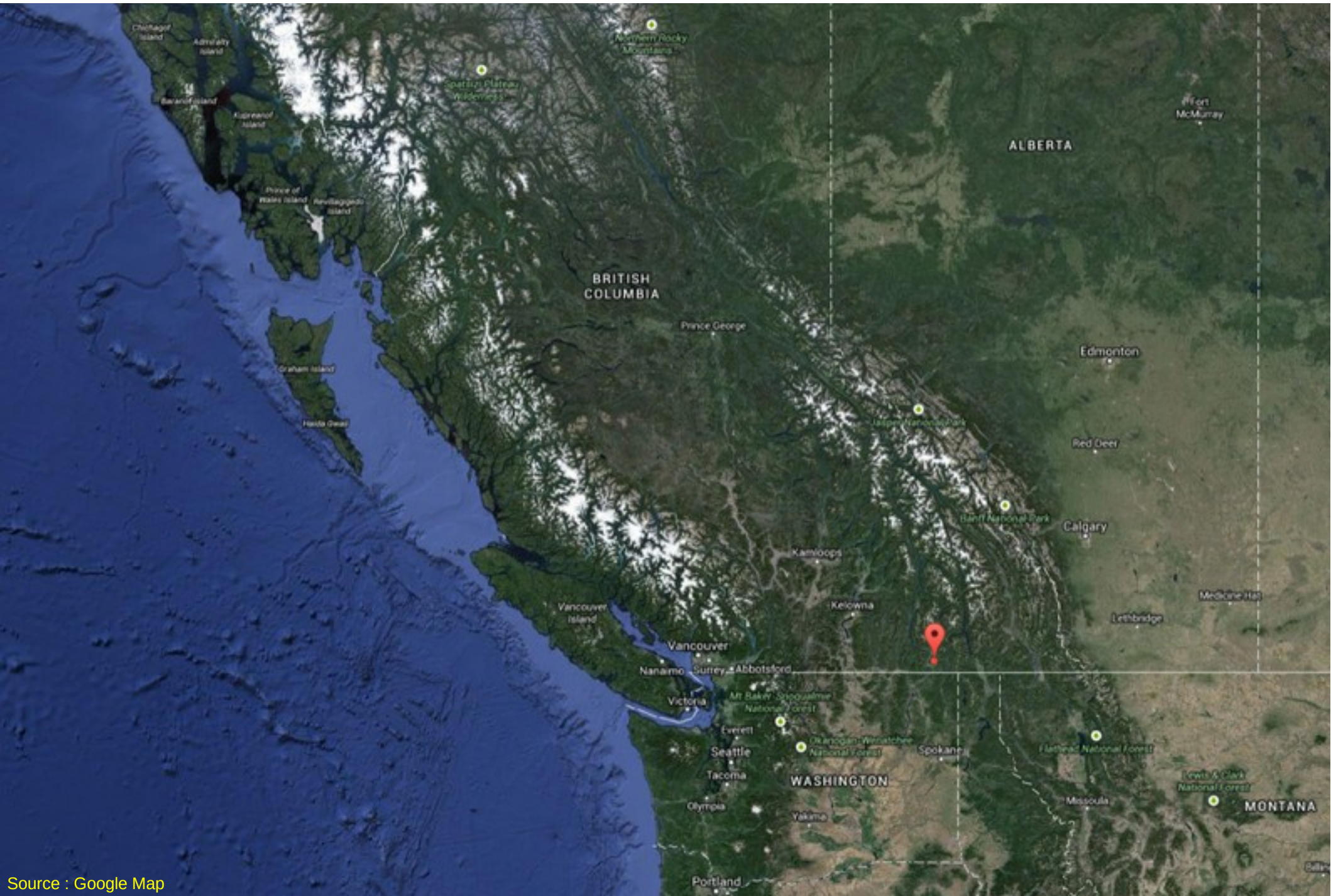
Model	RCP	I - Warm	II - Hot	III - Scalding
CanESM2	2,6	0,3	0,05	0,05
CanESM2	4,5	0,1	0,2	0,1
CanESM2	8,5	0,05	0,1	0,2
CNRM-CM5	2,6	0,3	0,05	0,05
CNRM-CM5	4,5	0,1	0,2	0,1
CNRM-CM5	8,5	0,05	0,1	0,2
HadGEM2-ES	4,5	0,05	0,2	0,1
HadGEM2-ES	8,5	0,05	0,1	0,2

Source : Authors for illustrative purposes. Not representative of any expert's opinion.

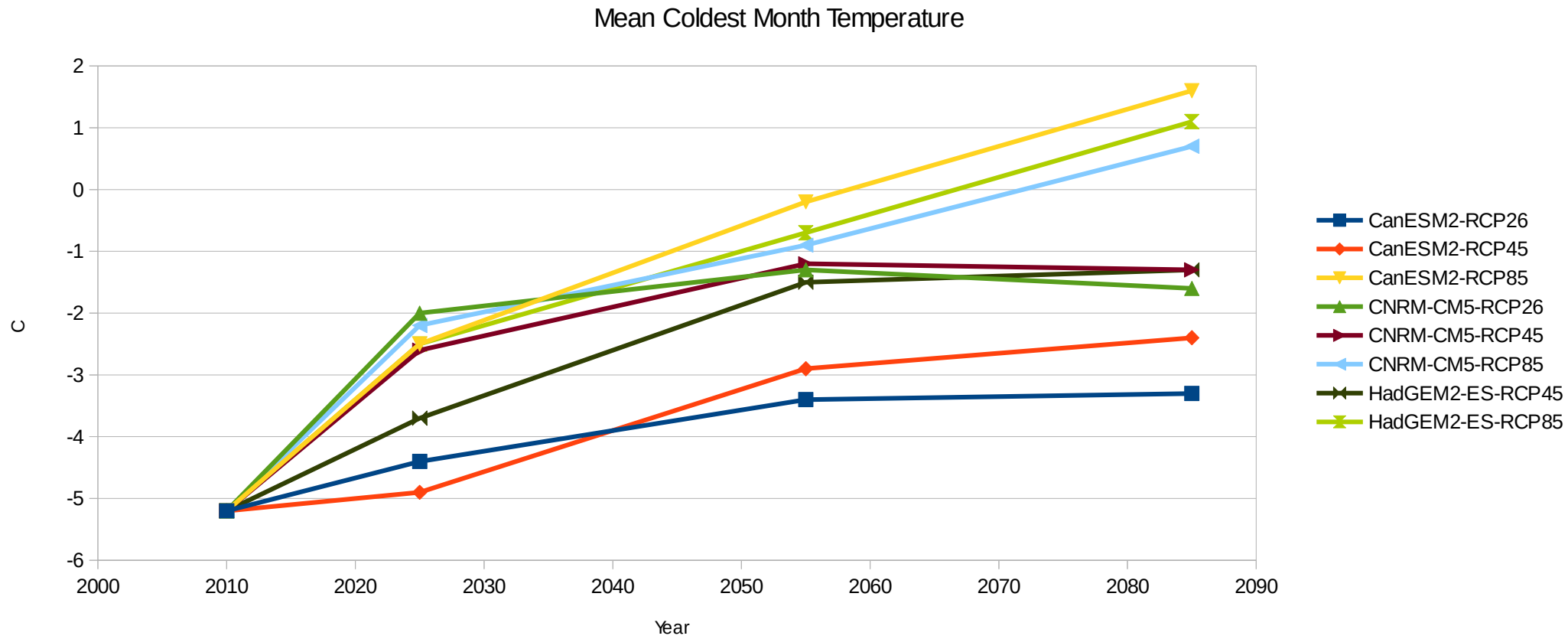
4. Results



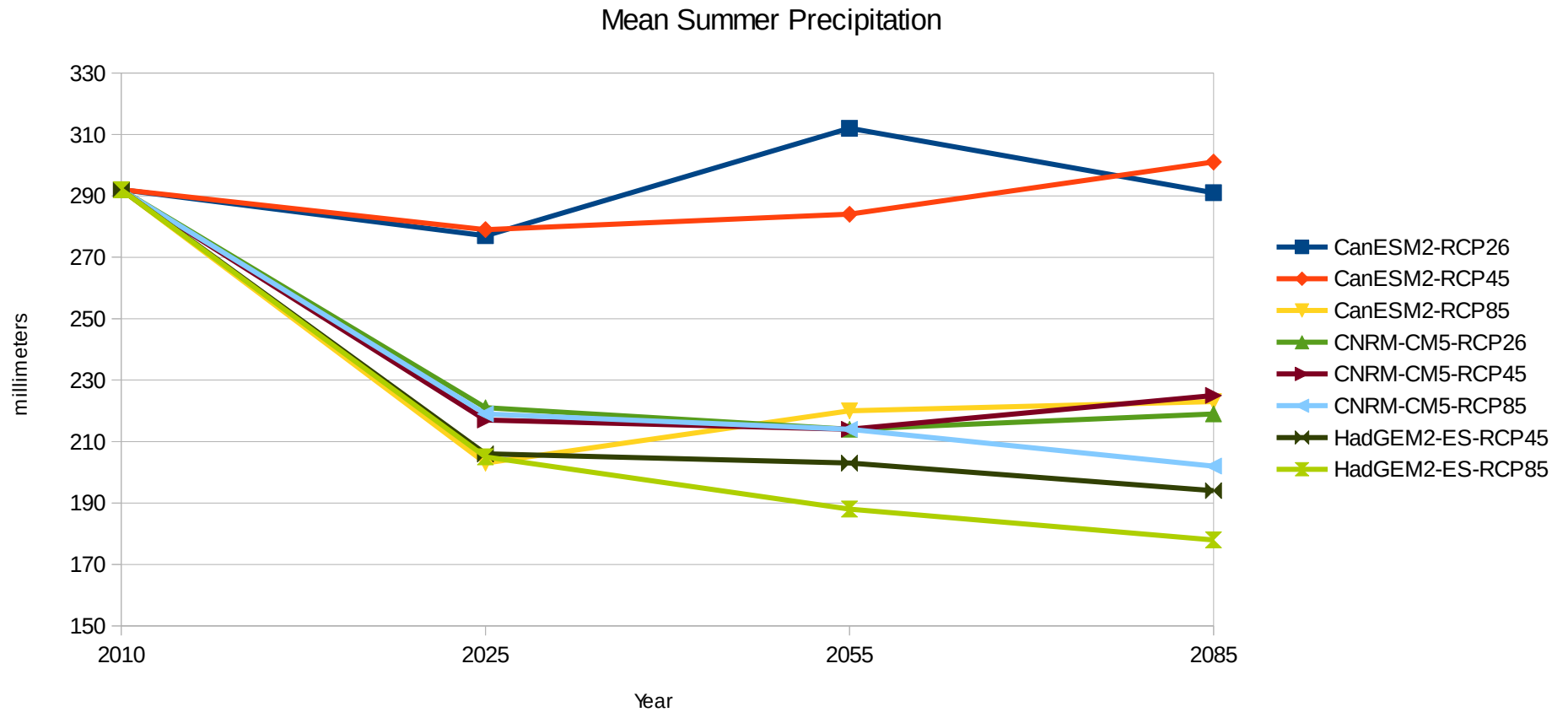
Location studied (42)



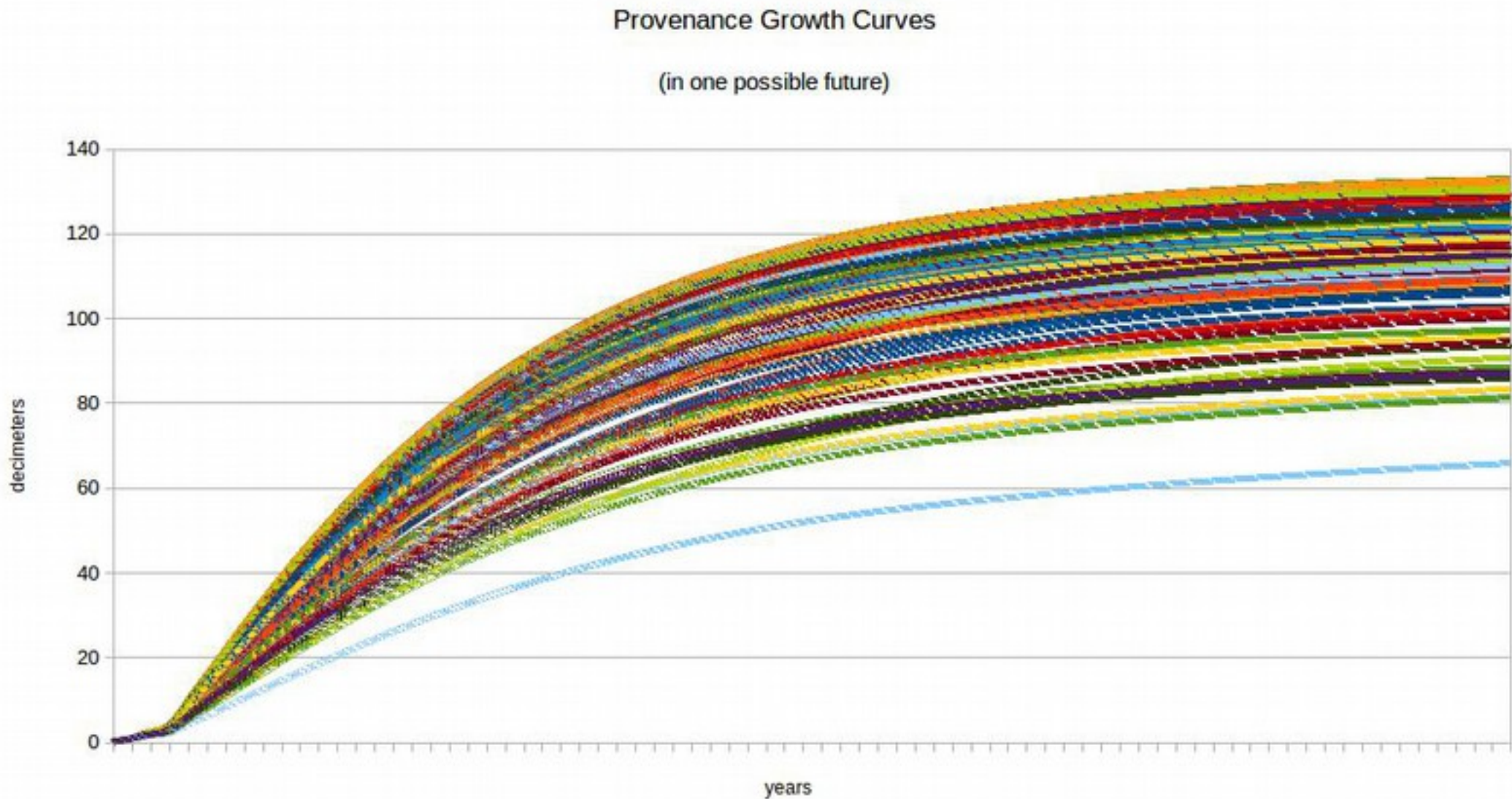
The future climates - MCMT



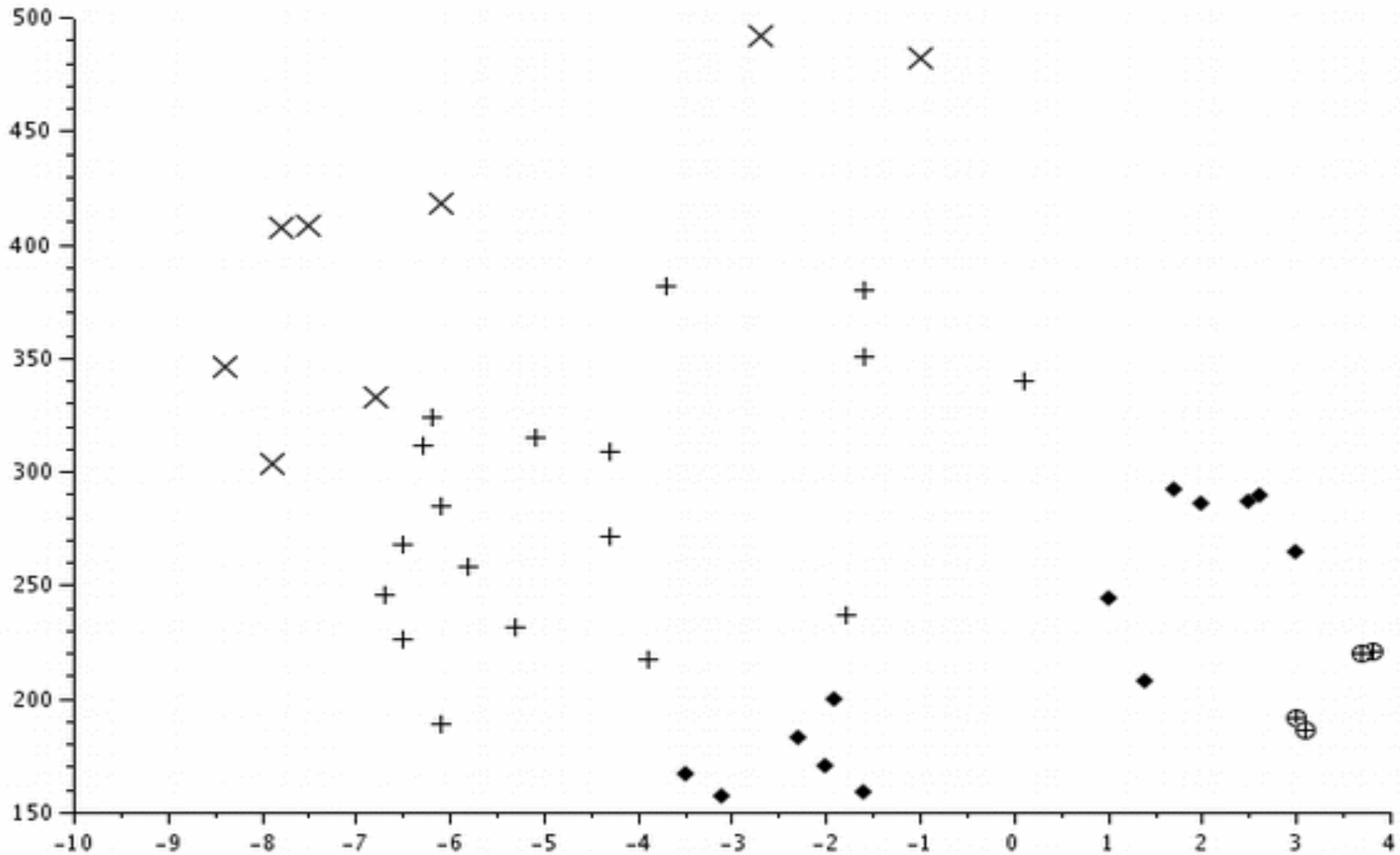
The future climates - MSP



Performance of all provenances in a given climate



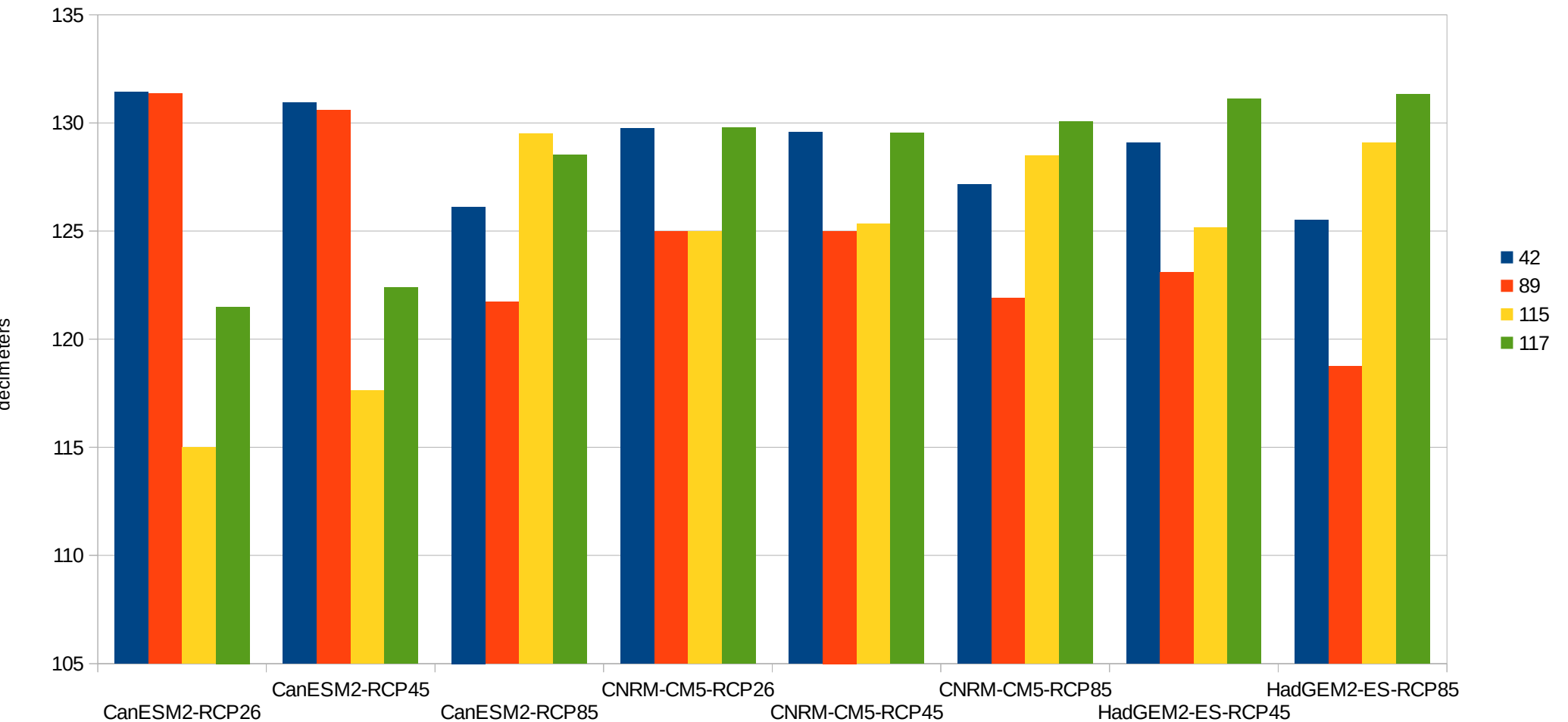
Clustering to $N=4$ provenances



The performance $u(a_{n'}, s_k)$

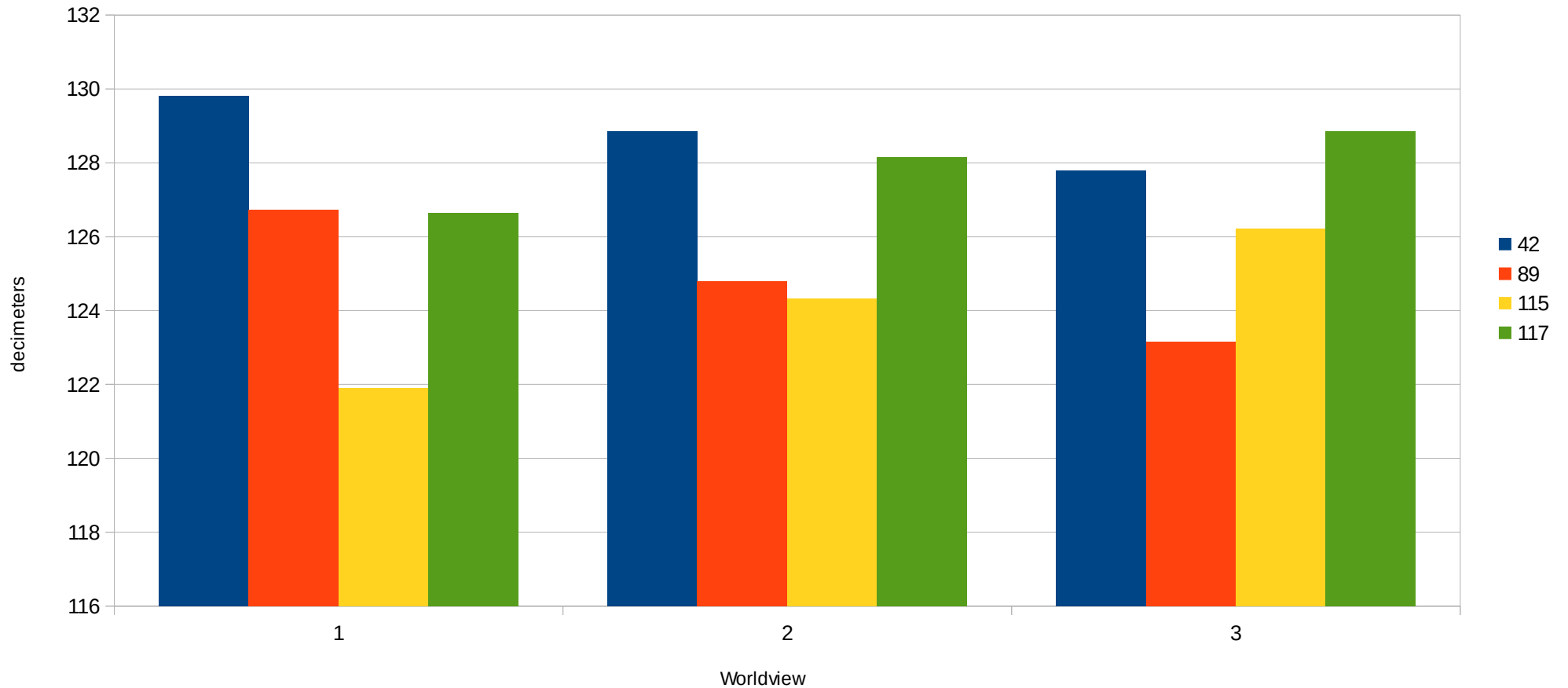
Provenance Performance

of 4 representative provenances across 8 climate futures



Expected performance $E_{PV} u(a_n, s)$

Expected Performance
for 4 provenances and 3 subjective worldviews



Preferences in SEU

Worldview

1 – Warm



2 – Hot

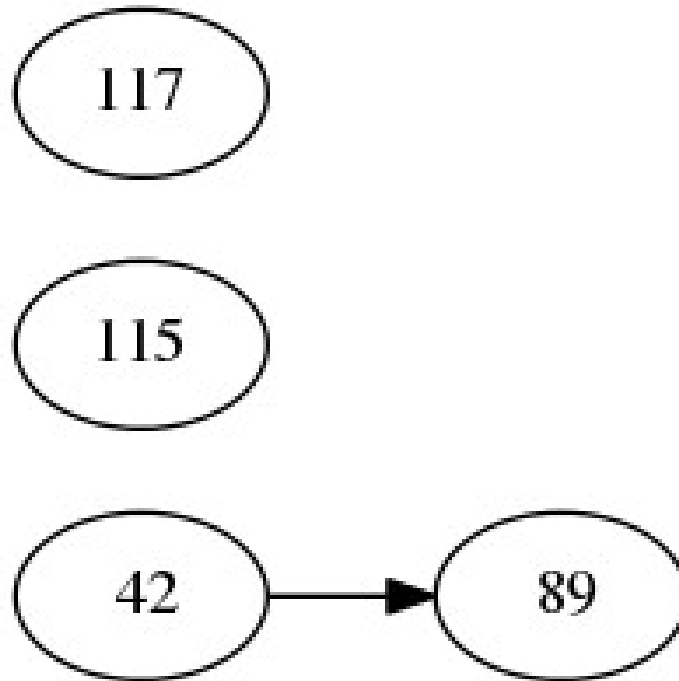


3 – Scalding

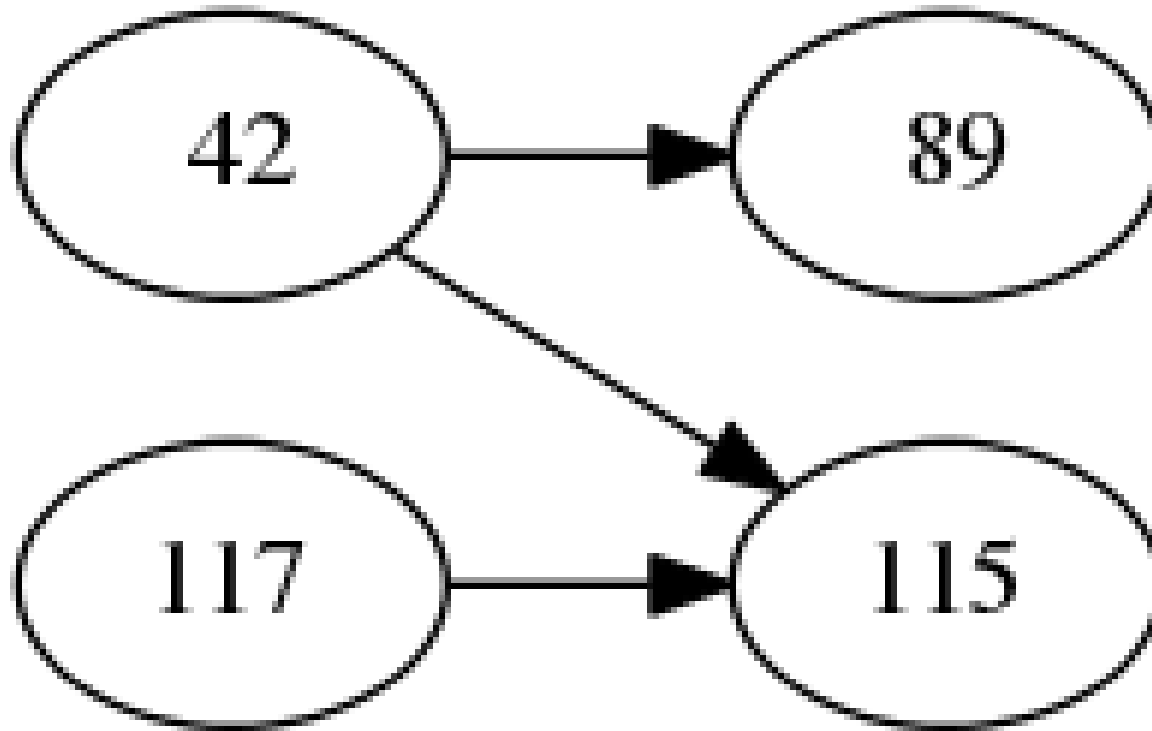


Ordering of provenance clusters

Preferences in scenario analysis

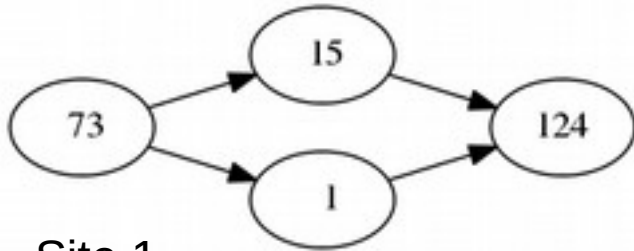


Preferences with multiple worldviews



Stay with local provenance 42
Cluster 117 is also admissible

Results for other sites



Site 1

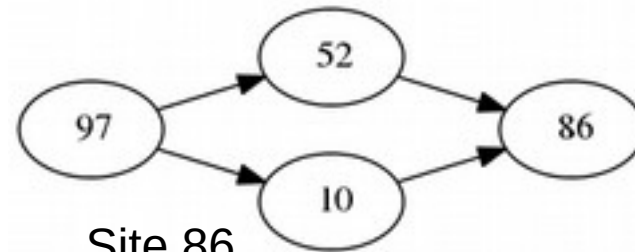
Location 49,58N 119,02W

Elevation 1006m

2010 MCMT -5,5°C

2010 MSP 221mm

Local is not better



Site 86

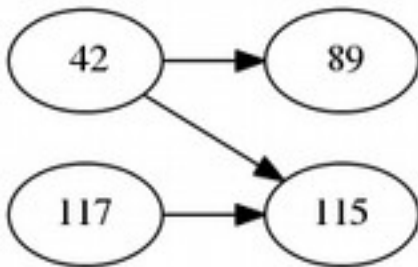
Location 54,07N 128,68W

Elevation 76m

2010 MCMT -2,6°C

2010 MSP 516mm

Local is worse



Site 42

Location 49,18N 117,58W

Elevation 998m

2010 MCMT -5,2°C

2010 MSP 292mm

Local is better



Site 23

Location 53,02N 123,23W

Elevation 1100m

2010 MCMT -8,3°C

2010 MSP 346mm

Local is worse

Future research towards policy relevance

- French species
- Extreme events
- Risk aversion
- Mixing provenances

Concluding summary

- Assisted migration is already a policy issue
- Decision making can be rational and precautionary – focus on trades not on choice
- Canadian data much easier to access and use
- Early results for assisted migration in higher latitude stations