Developing remote sensed environmental indicators for responsible resource development in Canada's Arctic

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Canada

Outline

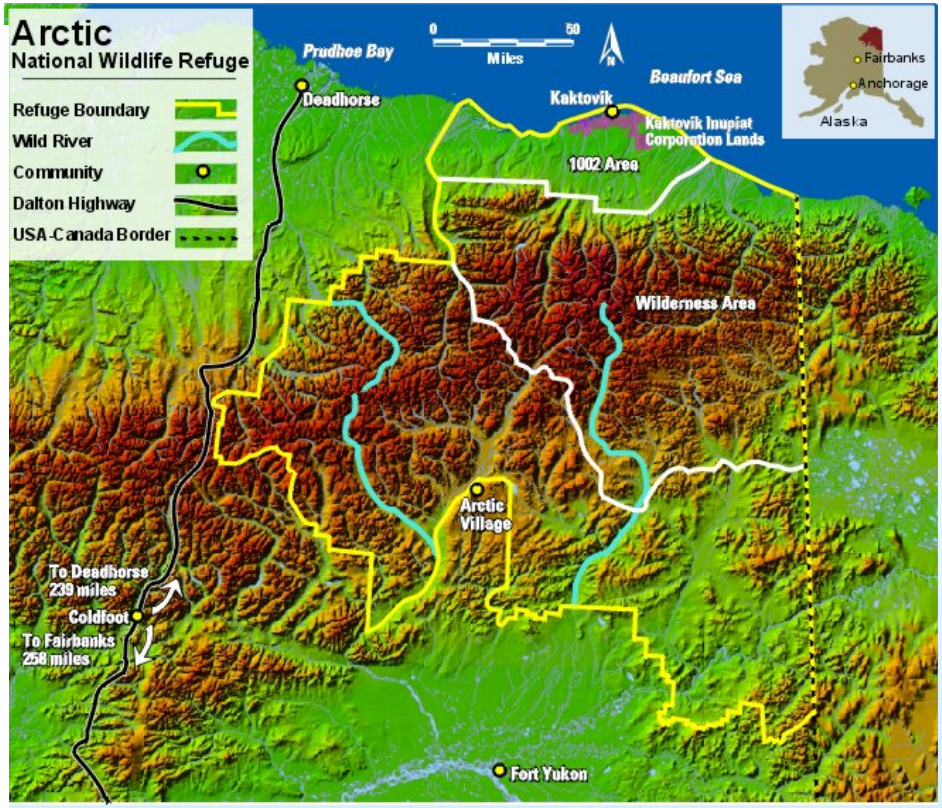
- Why are remotely sensed environmental indicators needed for responsible northern resources development?
- How to derive environmental indicators using remote sensing data?
- How to assess the impacts of habitat change on caribou?
- How to assess the impacts of resource development-caused habitat change on caribou?

Rational

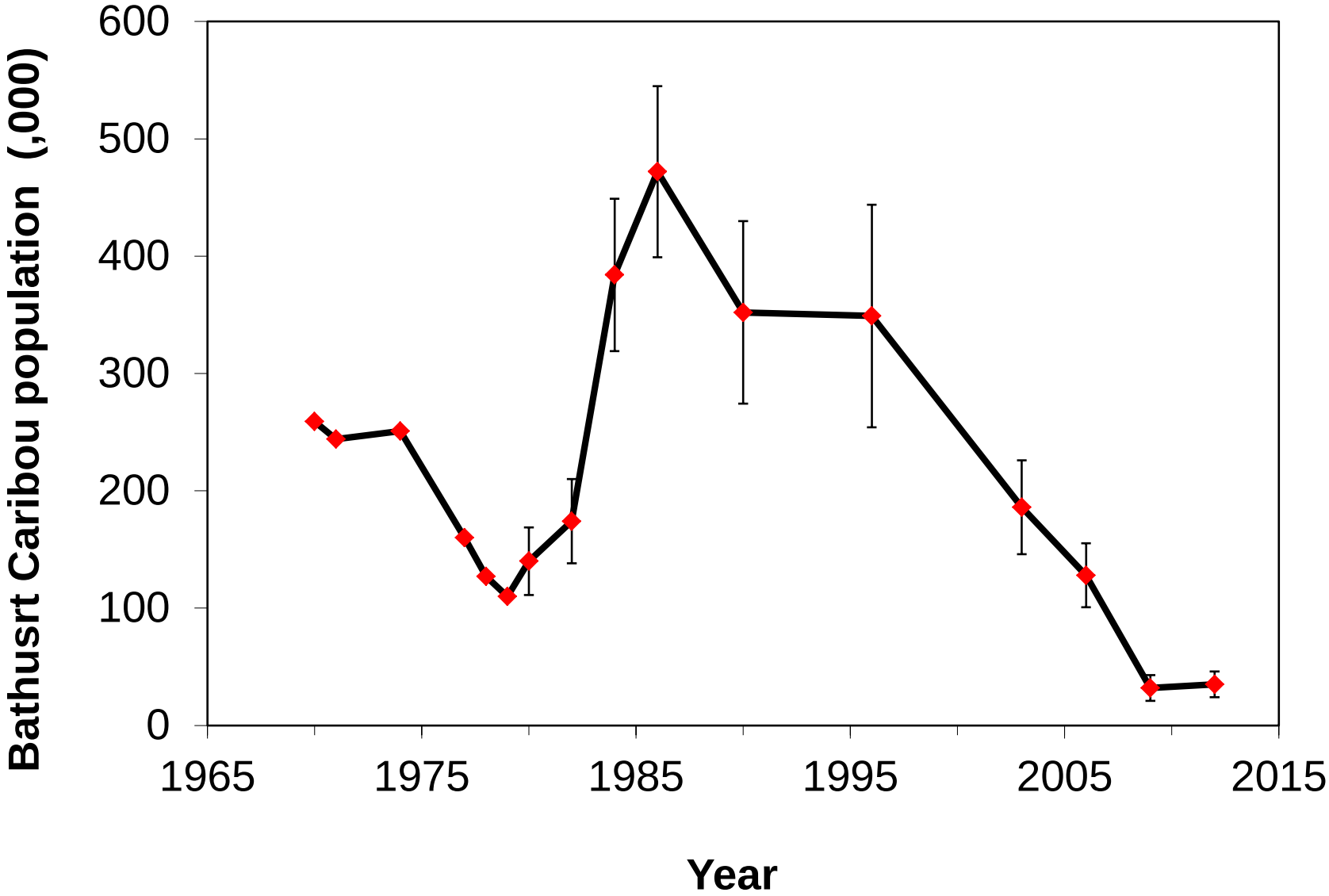
- Natural resources form a cornerstone of the Canadian economy, ~15% Canada's GDP in 2011. The natural resource potential in Canada's North is exceptional: at least 8.7 billion barrels of recoverable oil, 163 trillion feet^3 of recoverable natural gas, and over $40 billion in planned new mining developments.
- Arctic lands are the home of aboriginal peoples for thousands' of years. Wildlife (e.g., caribou) has played a important role in their economy, culture, health, and way of life.

“The big issue”

- Debate on “resource development vs. environmental protection” has been ongoing for a long time.
- A well-known example is the “1002 area” of the 77,000 km^2 Arctic National Wildlife Refuge (ANWR). The question of whether to drill for oil there has been an ongoing political controversy in US since 1977: the amount of economically recoverable oil vs. the potential harm on wildlife (e.g., Porcupine caribou).



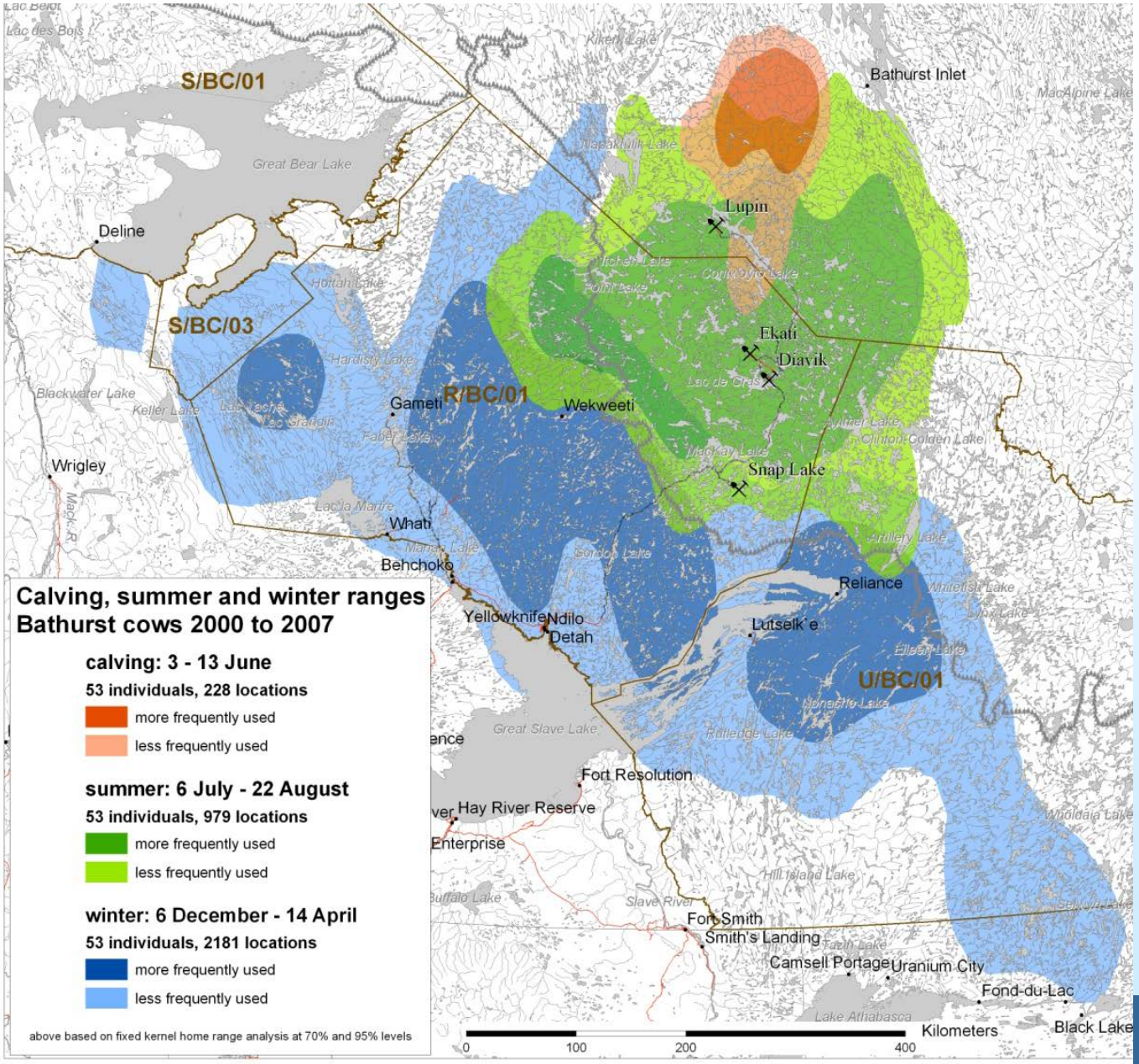
- **Public opinions are divided. Nevertheless, “resource developments vs. environmental protection (including land, water, and wildlife)” is undoubtedly the big issue of policy making and governance in Canada Arctic.**



- One of the largest among 13 barren-ground caribou herds in North America
- Used by 10 NWT & Nunavut communities: Gamètì, Whatì, Wekweètì, Dettah, N'Dilo, Lutsel, Yellowknife, K'e Kugluktuk, & Cambridge Bay)

Mines around Bathurst caribou habitat

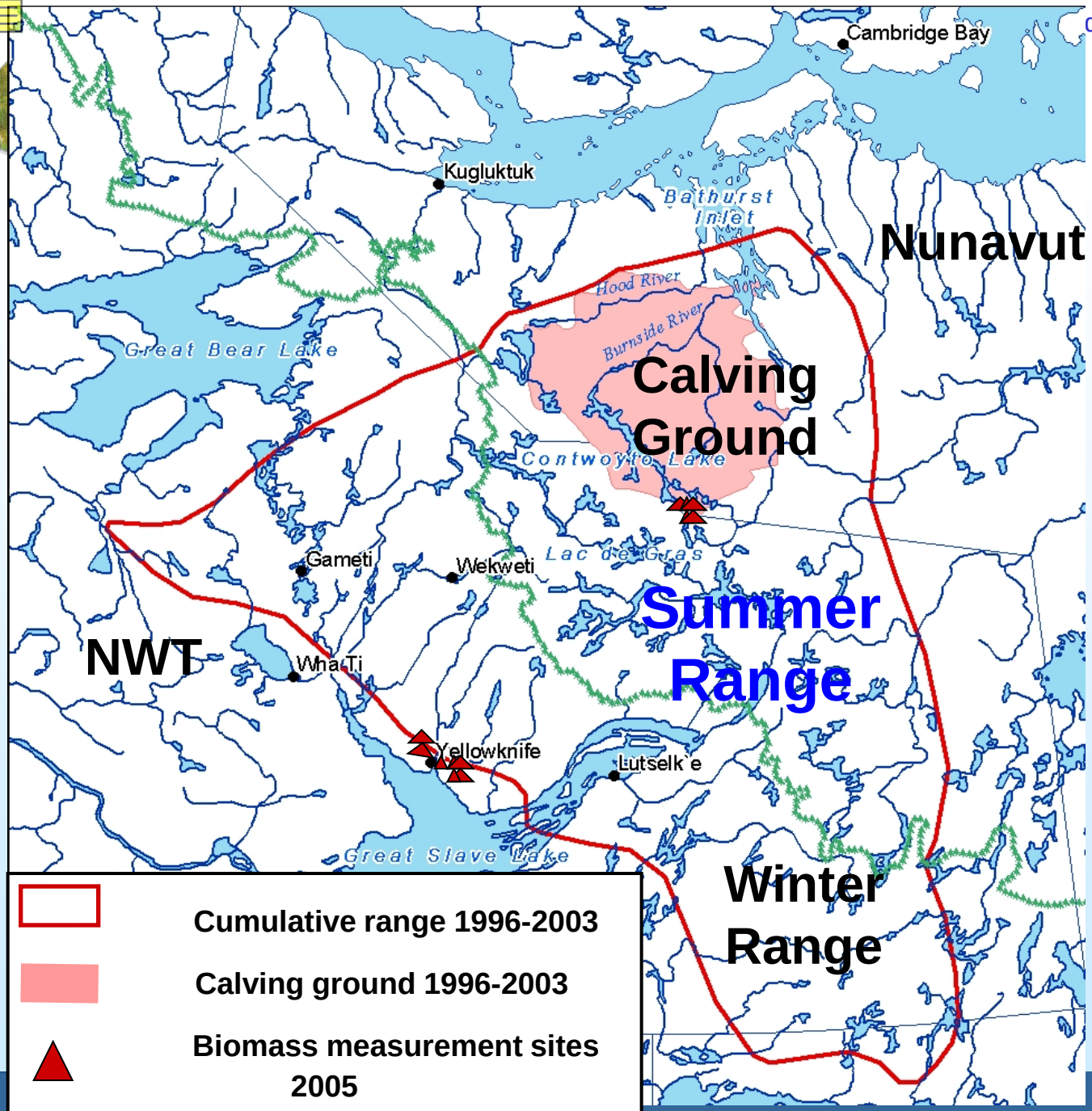
Within or around the Bathurst caribou habitat alone, there are several mining operations (zinc-silver, gold, & diamond), with more developments likely to come.



How can remote sensing help monitoring & assessing the impact of developments on caribou?

- Many factors (e.g., habitat, harvest, predators, parasites /diseases, extreme weather, climate change, industrial developments, pollution) might impact caribou's productivity and abundance
- Satellite remote sensing is arguably the most cost-effective tool for monitoring and assessing habitats in Canada's north
- Resource developments impact caribou mainly through affecting habitat conditions (e.g., removal of vegetation, blockage of access, avoidance of areas influenced by developments). The impact of resource development on caribou can be assessed if we know
  - Area affected by development
  - Quantitative relationship between habitat change and caribou productivity/abundance

How to derive environmental indicators using remote sensing data?



Study area:
Bathurst caribou summer range

Indicators:
Forage availability and quality (leaf biomass at various periods, phenology, leaf nitrogen content) over the summer range and calving ground

Noisy seasonal profile due to residue cloud and aerosols

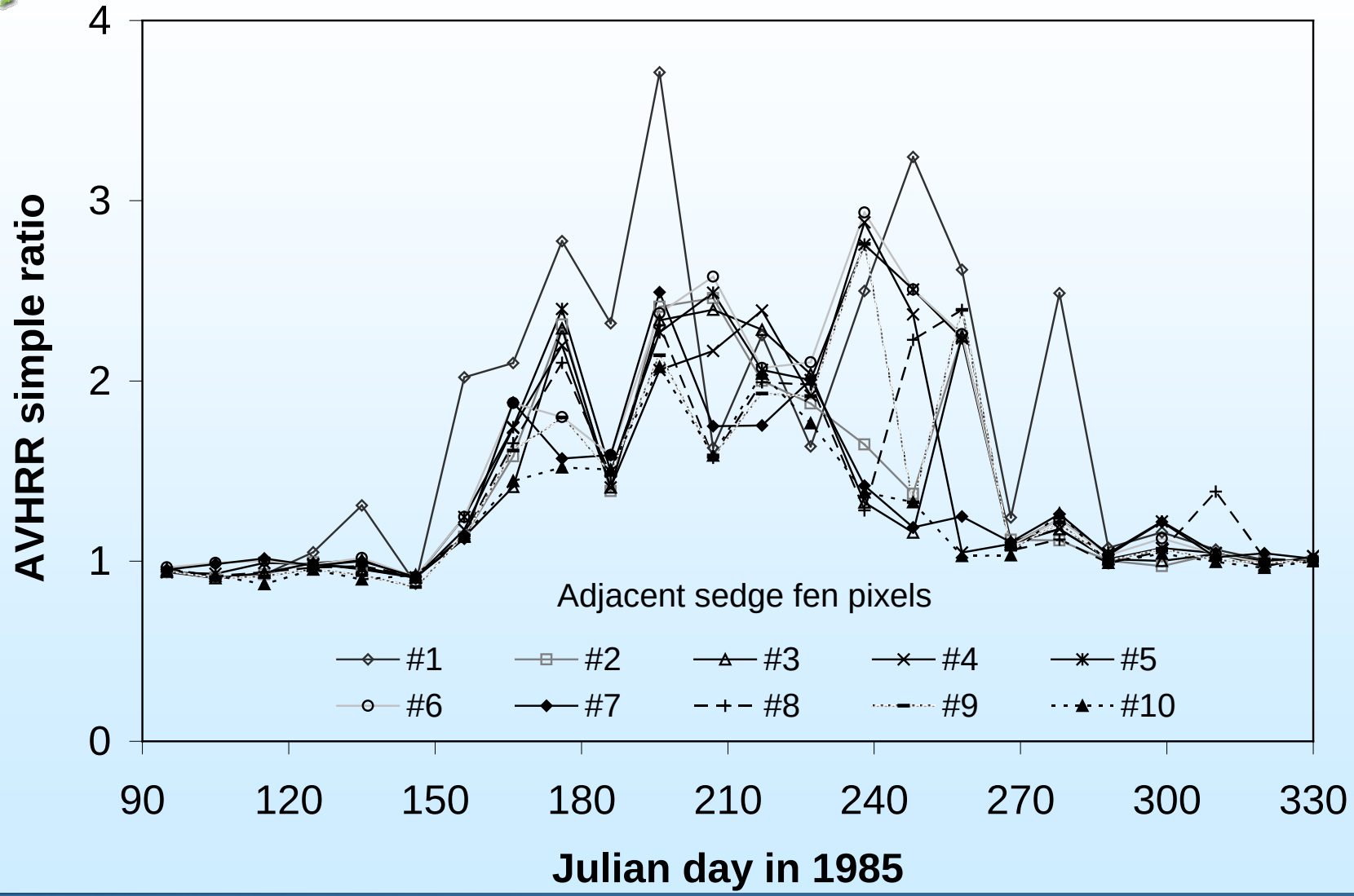
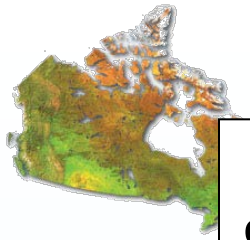


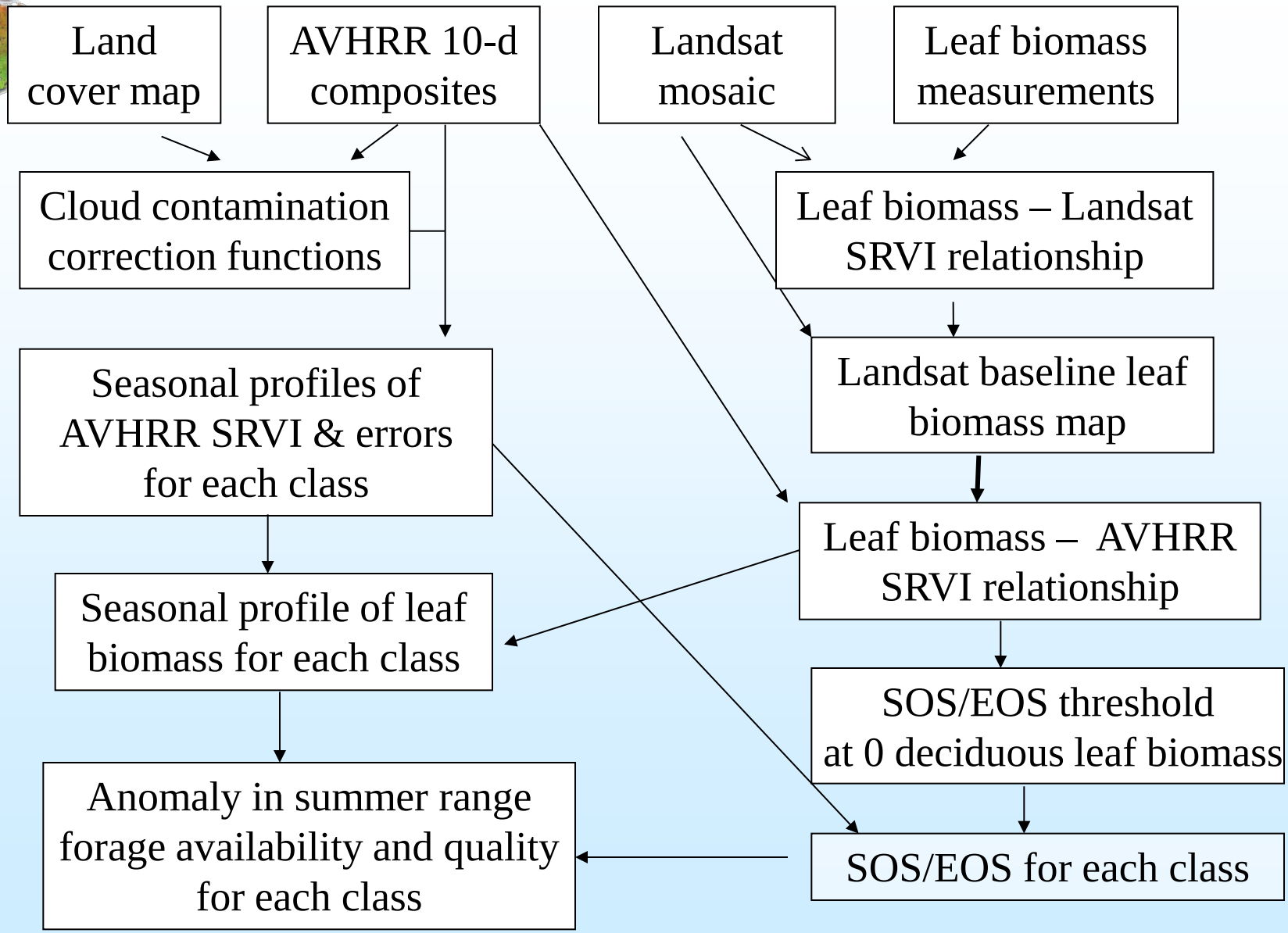
Figure 1

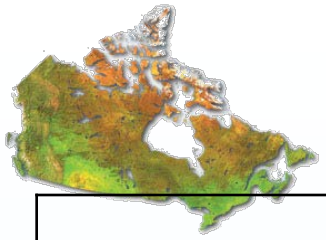
Thresholds and filtering/smoothing algorithms for detecting SOS in literatures

Threshold definition (category, rationale)	Filtering/smoothing algorithms	Application area (reference)
AVHRR NDVI = 0.09 (1, citing Markon et al. 1995)	BISE filter + filling	Northern Alaska (Jia et al. 2004)
MODIS NDVI = 0.09 (1, citing Reed et al. 1994, Jia et al. 2004)	Double logistic	> 60ºN circumpolar (Zeng et al. 2011)
AVHRR NDVI = 0.2 (1, set at a value > 0.1, considering snow effect)	3-compsition moving max	Northern Asia (Suzuki et al. 2003)
AVHRR NDVI = 0.3 (1, not given)	No filtering /smoothing	North America (White et al. 2009)
SPOT-VGT NDVI = 0.4 (1, based on in-situ leaf appearance)	Filtering out data of NDSI < 0.4	Central Siberia (Delbart et al. 2005)
AVHRR $NDVI_{ratio}$ = 0.5 (2, time of max NDVI increase)	BISE filter	Continental USA (White et al. 1997)
Landsat $NDVI_{ratio}$ = 0.5 (2, most stable and well constrained point in the curve)	Double logistic	New England, USA (Fisher et al. 2006)
PAT50: 50% pixels in a phenoregion of $NDVI_{ratio}$ > 0.5 (2, citing White et al. 1997)	No filtering/ smoothing	Eastern Canada (White and Nemani 2006)
AVHRR $NDVI_{ratio}$ = 0.1 (2, not given)	Asymmetric Gaussian + upper enveloping	Africa (Jonsson and Eklundh 2002)
MODIS $NDVI_{ratio}$ = 0.1 (2, not given)	6 noise-reduction techniques	Alberta, Canada (Hird and McDermid 2009)
0.2 spring SPOT-VGT NDSI amplitude (2, in situ leaf appearance & estimated error)	Filtering out data of NDSI < 0.4	Central Siberia (Delbart et al. 2005)
Max curvature point of a logistic fit to MODIS EVI (3, Not given)	Piecewise logistic	New England (Zhang et al. 2003)
Moving average crossing smoothed AVHRR NDVI (3, a sudden increase signals the onset)	line-smoothing	Continental USA (Reed et al. 1994)

Method for monitoring summer range indicators

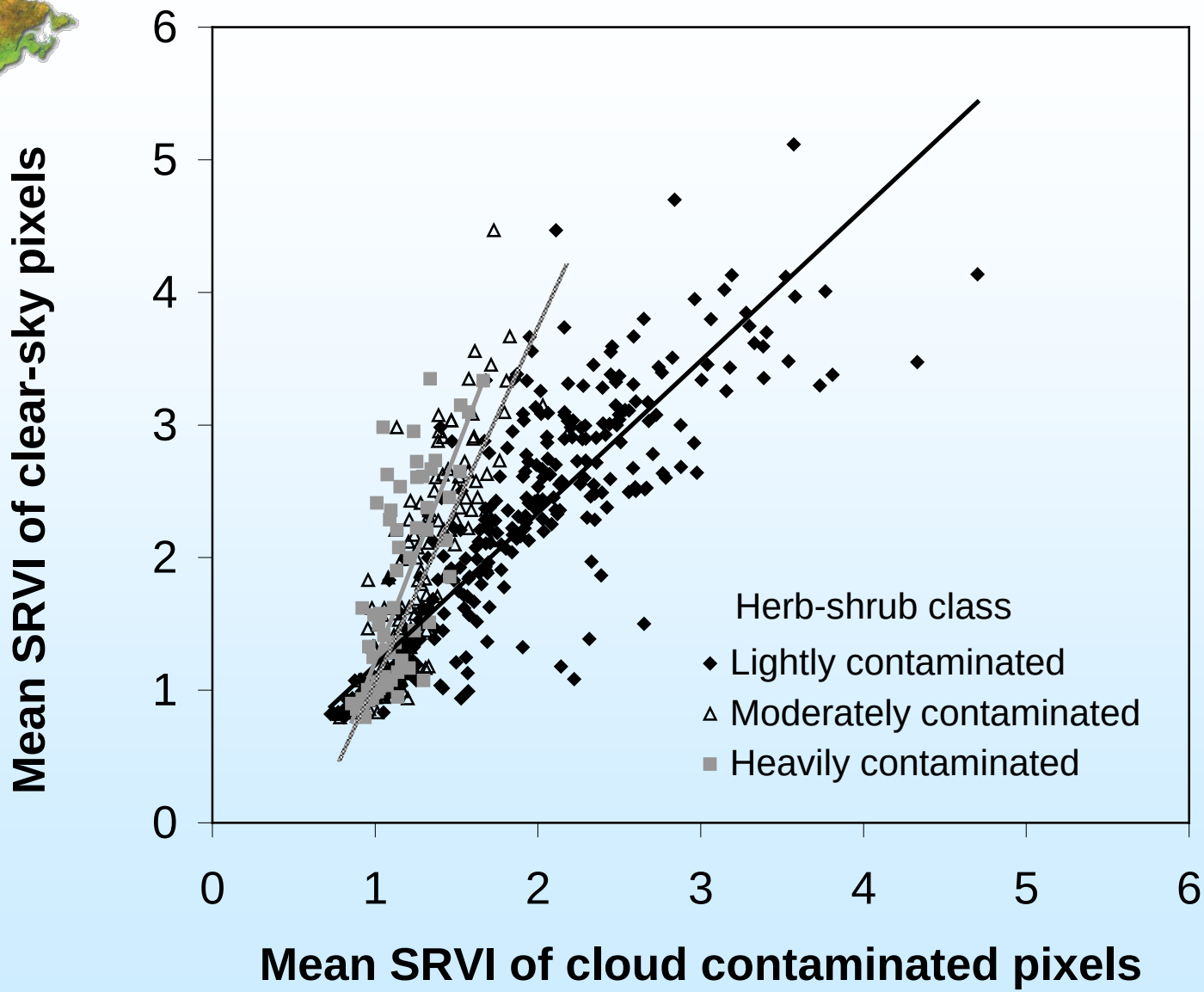


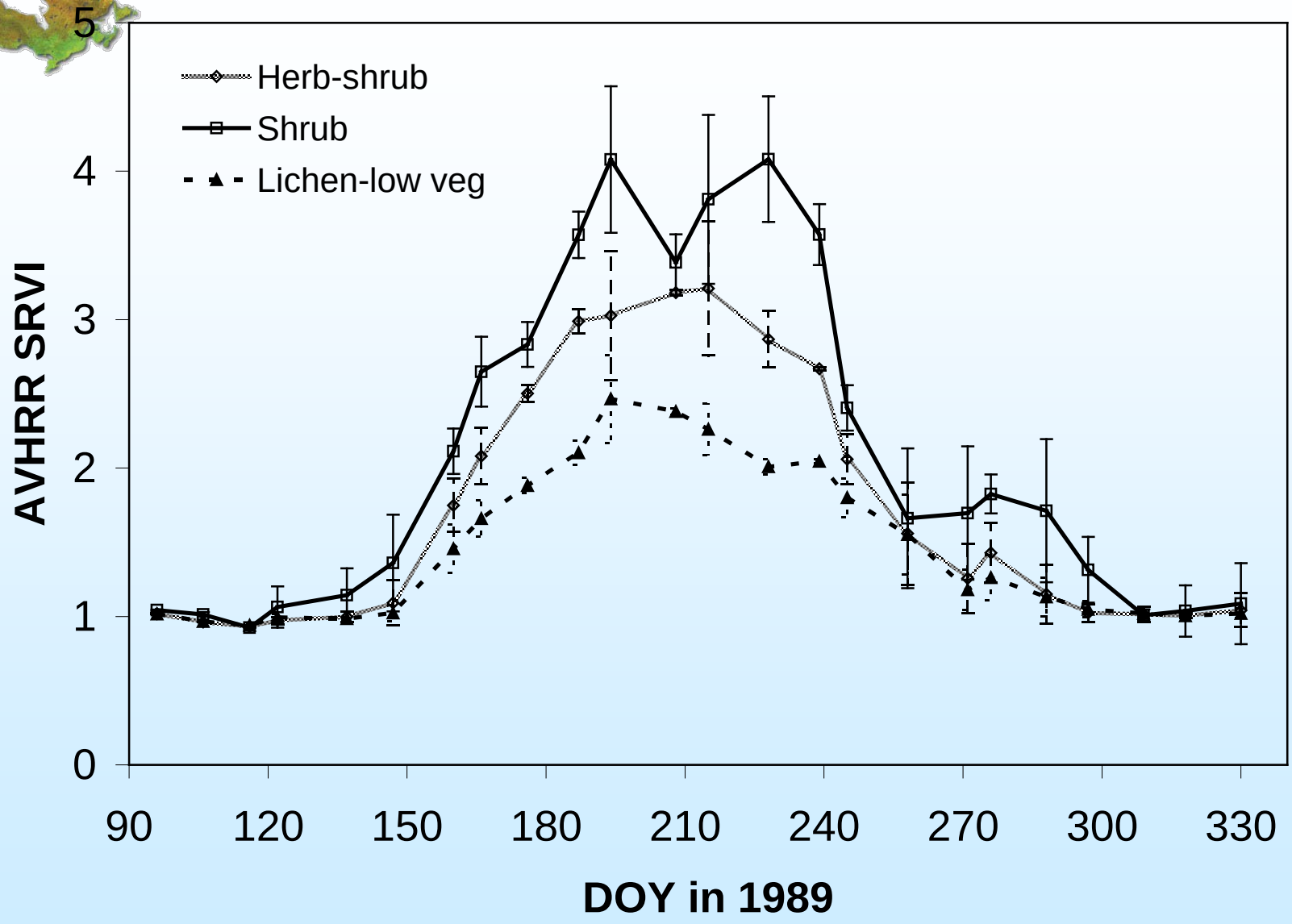




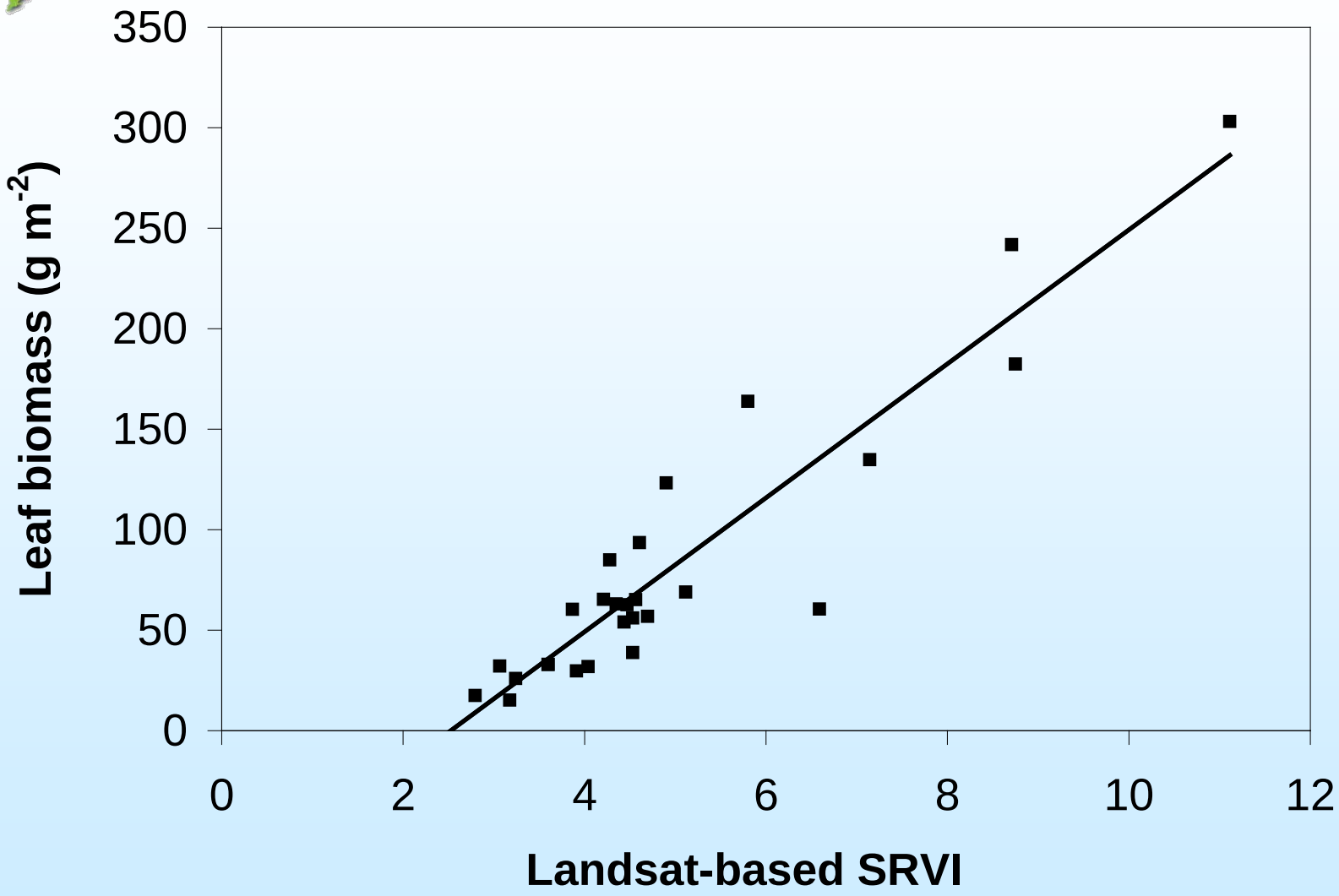
Number of 50% pure AVHRR pixels

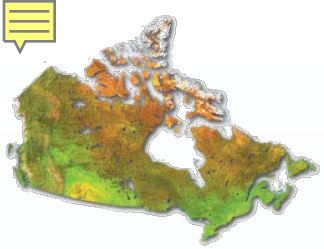
	Combined land cover class			
	Shrub	Herb-shrub	Lichen low veg	Treed
1 Evergreen forest (>75% cover) - old				3
15 Low regenerating to young mixed cover				20
16 Deciduous shrubland (>75% cover)	1			
19 Shrubs-herb-lichen-bare	2			
22 Sparse coniferous (density 10-25%), herb-shrub cover				596
23 Herb-shrub		9774		
24 Shrub-herb-lichen-bare	10			
25 Shrub-herb-lichen-water bodies	19			
26 Lichen-shrubs-herb, bare soil or rock outcrop			15	
28 Low vegetation cover (bare soil, rock outcrop)			72	
35 Lichen barren			1369	
36 Lichen-shrub-herb-bare			3590	
37 Sparse coniferous (density 10-25%), lichens-shrub-herb cover				58
38 Rock outcrop, low vegetation cover			5	
39 Recent burns				2
41 Low vegetation cover			107	
Subtotal	32	9774	5158	679

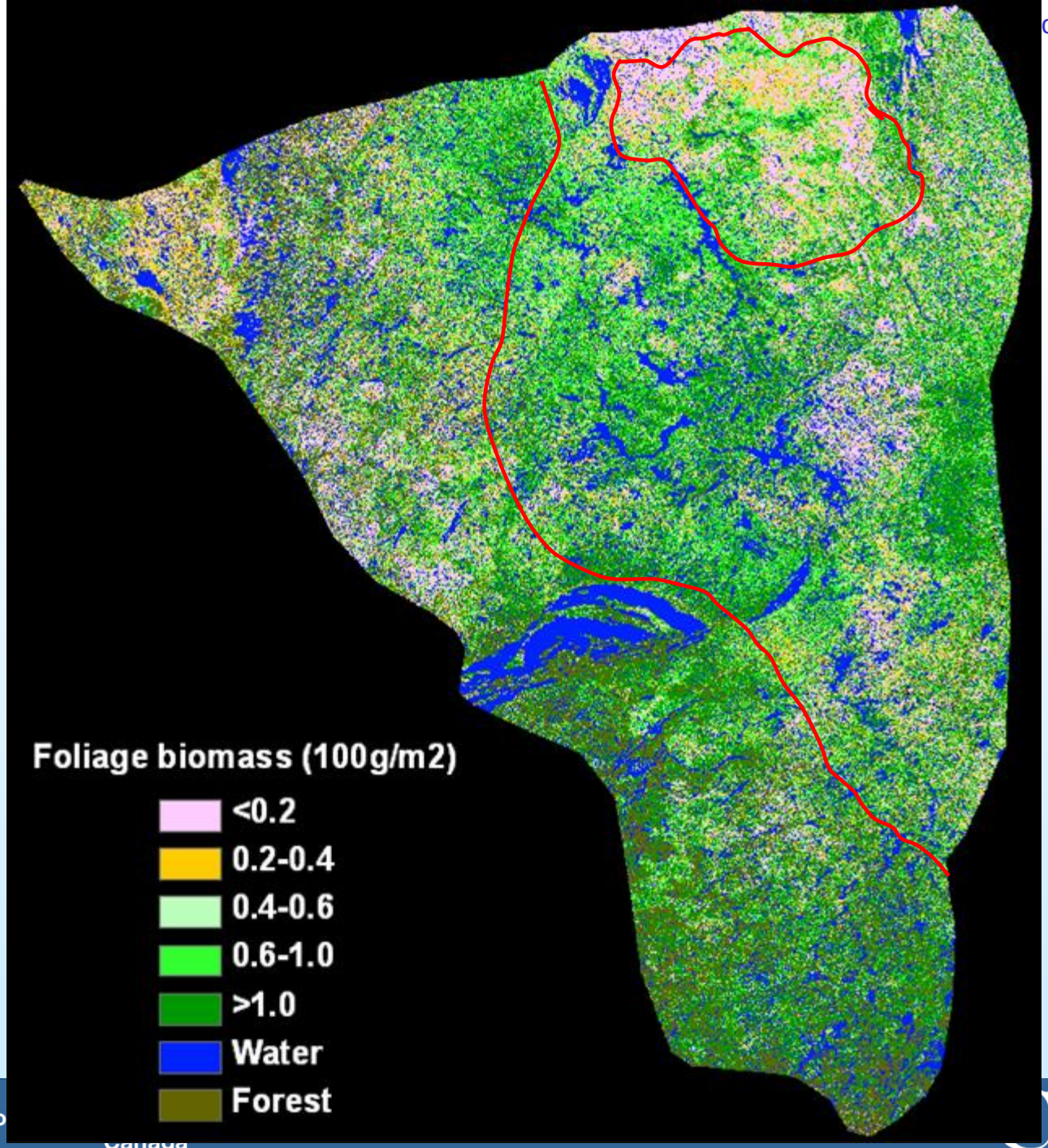

Mean SRVI of clear-sky pixels
Mean SRVI of cloud contaminated pixels
0
1
2
3
4
5
6
Herb-shrub class
Lightly contaminated
Moderately contaminated
Heavily contaminated

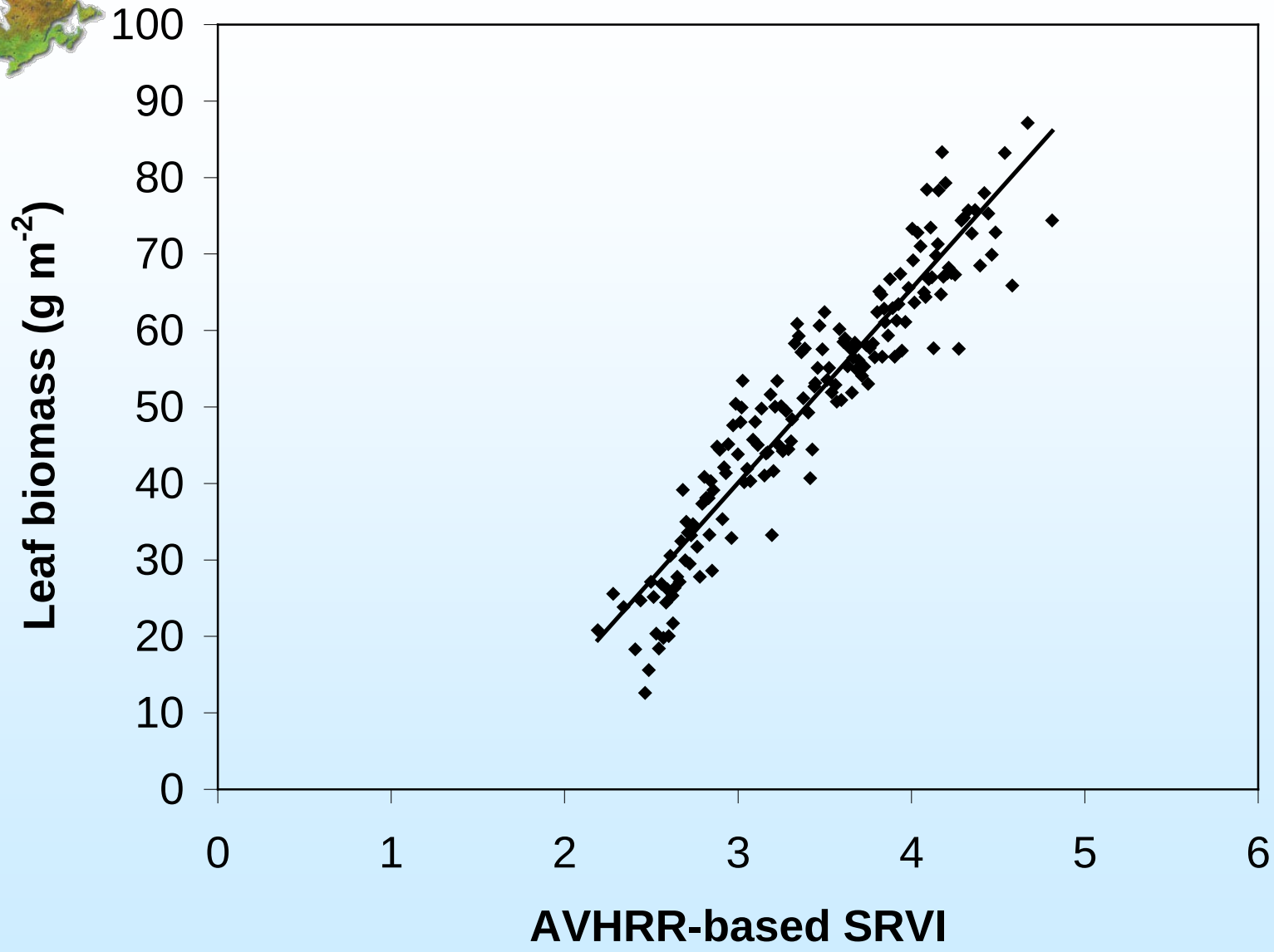

Herb-shrub
Shrub
Lichen-low veg
AVHRR SRVI
0
1
2
3
4
5
90
120
150
180
210
240
270
300
330
DOY in 1989

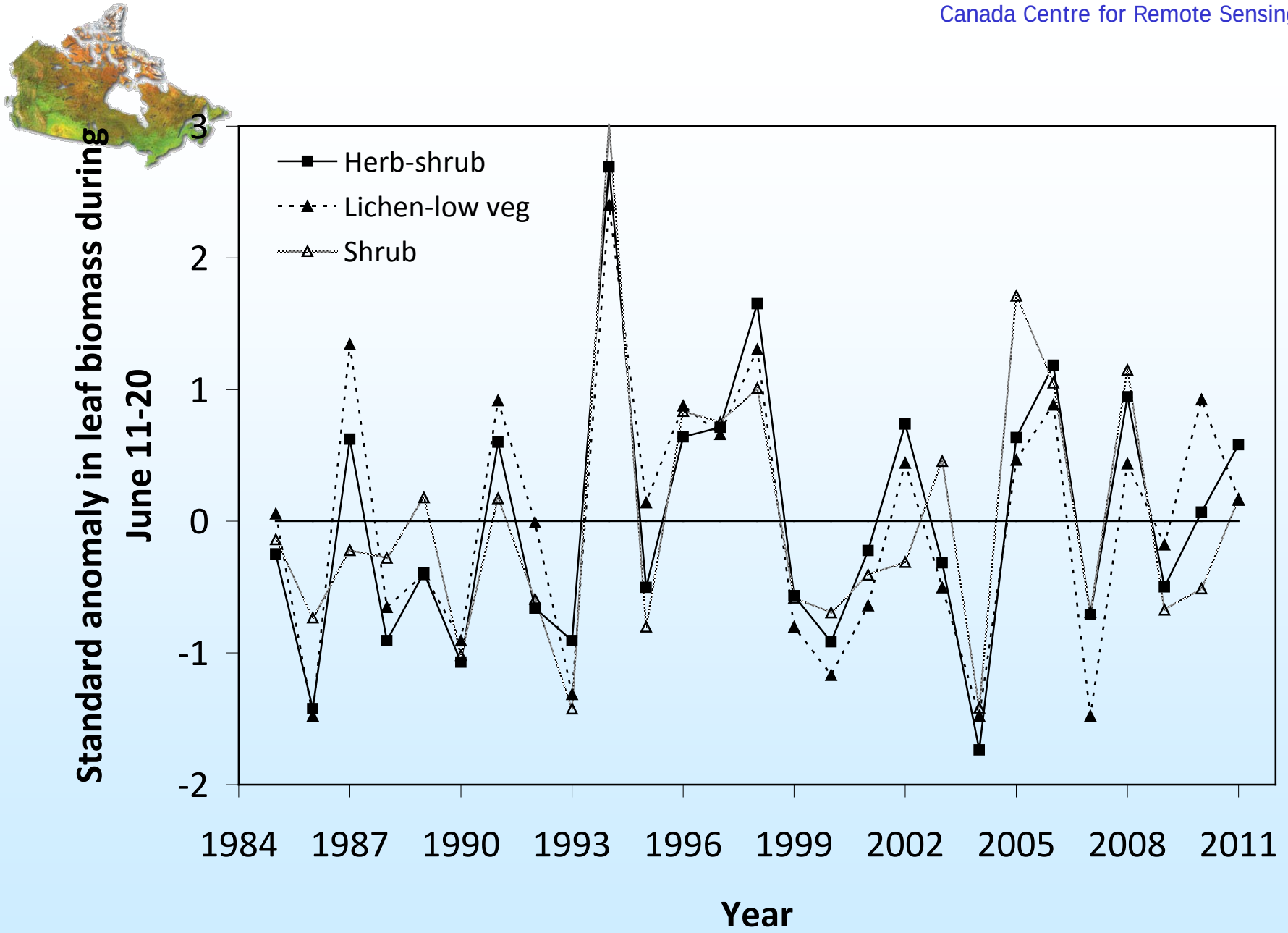
Field measurement of biomass in Bathurst habitat


Leaf biomass (g m-2)
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
Landsat-based SRVI

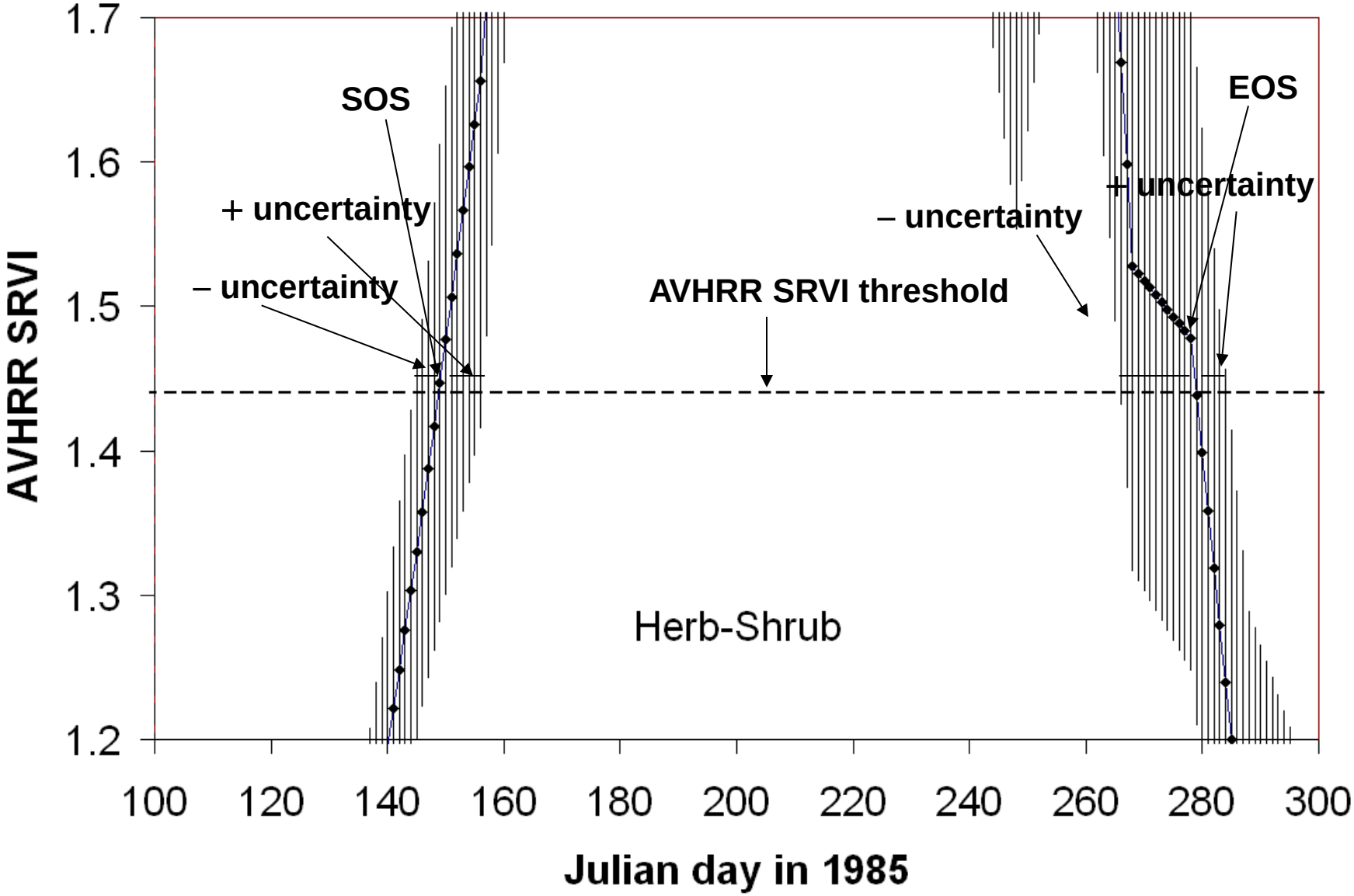


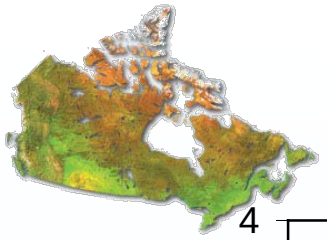

Foliage biomass (100g/m2)
<0.2
0.2-0.4
0.4-0.6
0.6-1.0
>1.0
Water
Forest

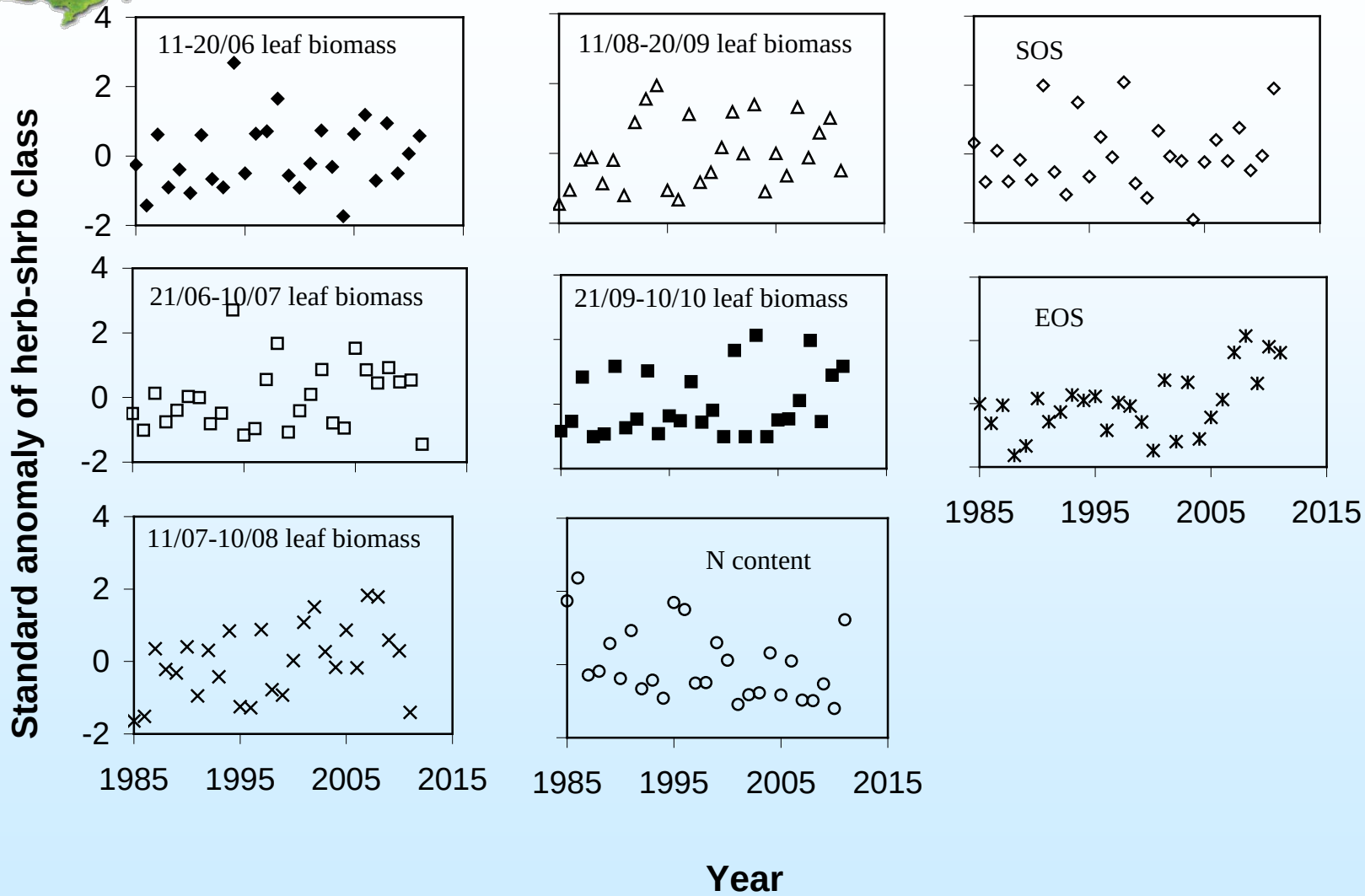

Leaf biomass (g m-2)
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
AVHRR-based SRVI


Herb-shrub
Lichen-low veg
Shrub
Standard anomaly in leaf biomass during June 11-20
3
2
1
0
-1
-2
1984
1987
1990
1993
1996
1999
2002
2005
2008
2011
Year

Biologically-based and objective satellite seasonality observation method (BLOSSOM)





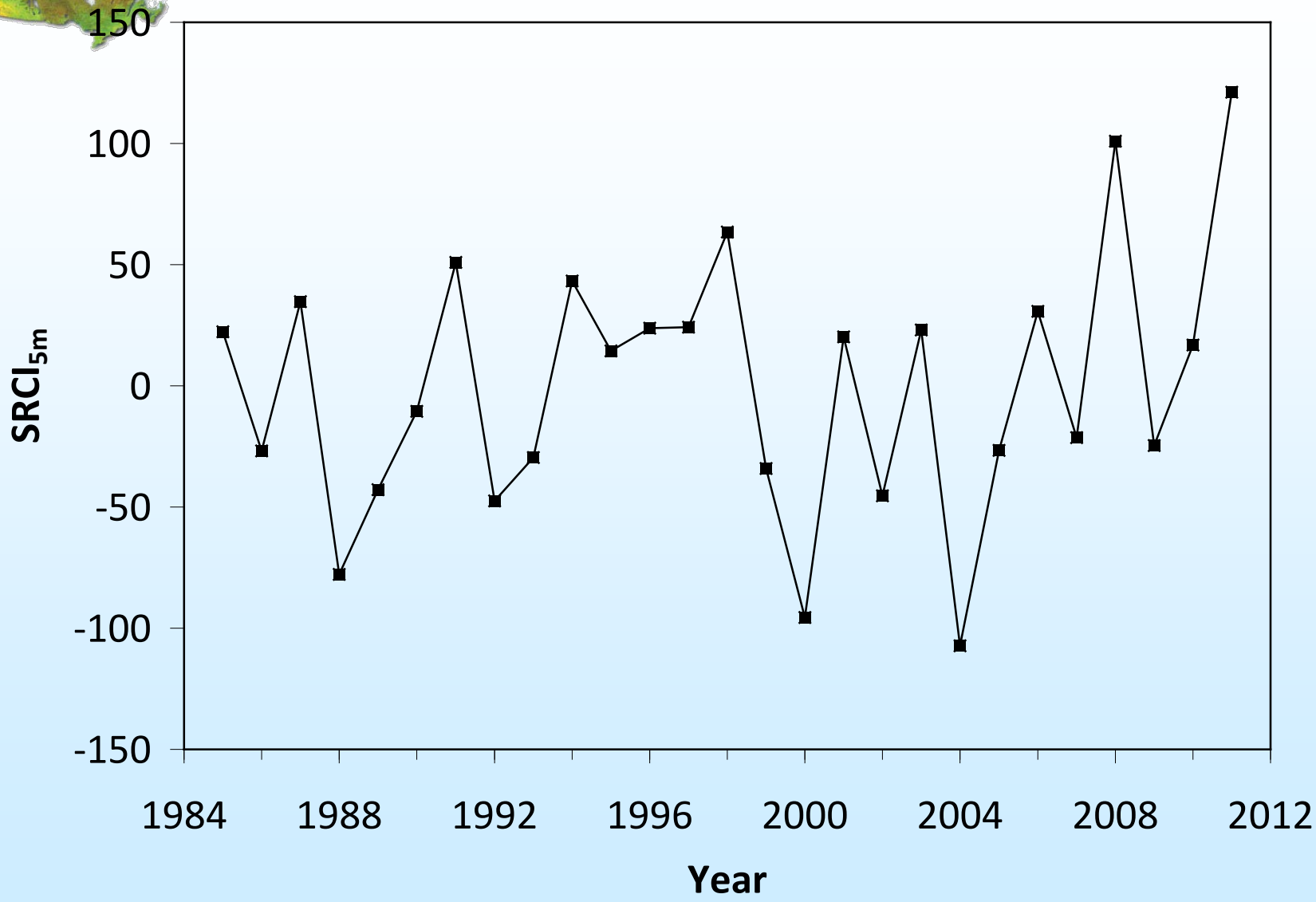

11-20/06 leaf biomass
11/08-20/09 leaf biomass
SOS
21/06-10/07 leaf biomass
21/09-10/10 leaf biomass
EOS
11/07-10/08 leaf biomass
N content
Standard anomaly of herb-shrb class
4
2
0
-2
1985
1995
2005
2015
Year

Summer range cumulative indicator

- We also investigated various combinations of these summer range measures, e.g.,

$$\mathrm{SRCI}_{5\mathrm{m}} = (SRM_{lb1} + SRM_{lb5} + SRM_{SOS} + SRM_{EOS} + SRM_{lnc})/5 \,.$$

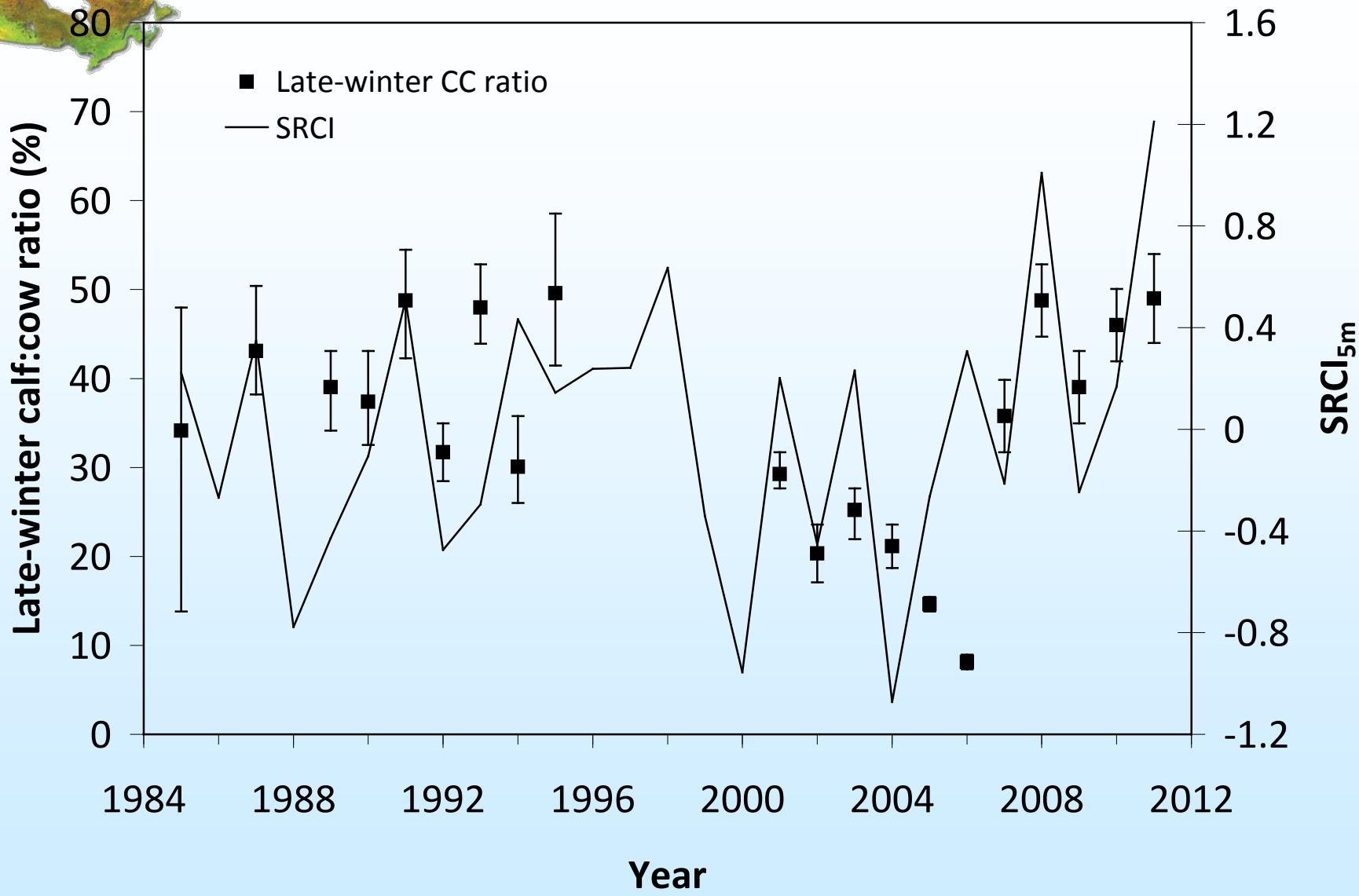
- Note that while it is possible that one of these summer range measures has more serious impact on caribou demographic variables than that of others, we don't have enough information to assign different weights to them. Therefore, a simple average is used to calculate SRCI.


150
100
50
0
-50
-100
-150
SRCI5m
1984
1988
1992
1996
2000
2004
2008
2012
Year

How to assess the impact of habitat change on caribou?

- Many factors (e.g., habitat, harvest, predators, parasites /diseases, extreme weather, climate change, industrial developments, pollution) might impact caribou productivity cumulatively over time and space. Each factor could have numerous variables.

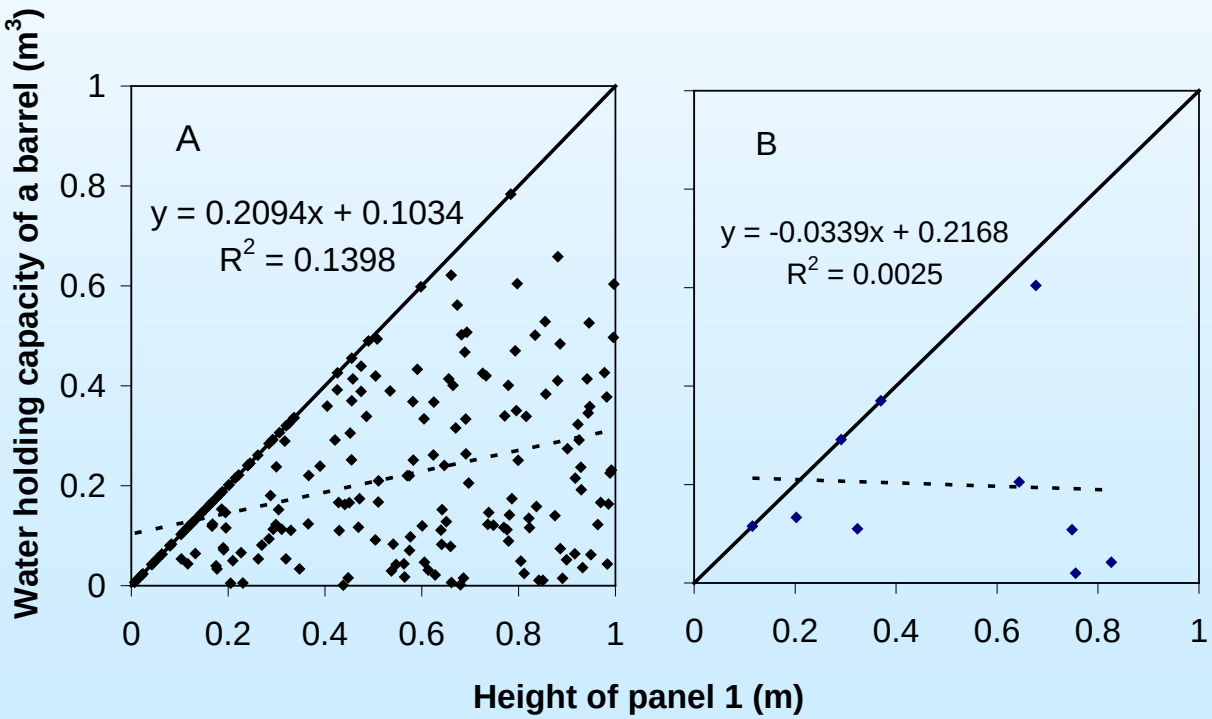
- Data, especially historic records, are not available for many of these factors/variables, e.g., diseases/parasites


Late-winter CC ratio
SRCI
Late-winter calf:cow ratio (%)
SRCI5m
Year
0
10
20
30
40
50
60
70
80
-1.2
-0.8
-0.4
0
0.4
0.8
1.2
1.6
1984
1988
1992
1996
2000
2004
2008
2012

- **More importantly, the conventional regression might be not suitable for deriving causal-effect relationship between habitat indicators and caribou productivity, because the underlying assumption of such regression method is that the impacts of all other factors/variables are randomly distributed. In reality, the impacts of many factors, such as extreme weather events, outbreak of diseases/parasites, and implementation of a harvest ban, would likely to occur infrequently.**
- **When these rare events did occur, especially if they happened in years with good habitat conditions, they could severely distort the regression relationship between habitat indicators and caribou productivity.**
- **we need a method that can give us the real causal-effect relationship habitat indicators and caribou productivity, regardless when these rare events occurred or if their data are available.**

One way to move forward

Let's start with an simple example. Assuming a cubic water barrel has 4 panels, with their heights varies from 0 to 1 m and the bottom area = 1 m^2. The relationship between water holding capacity of the water barrel and the height of panel 1 is showed in the following figures.

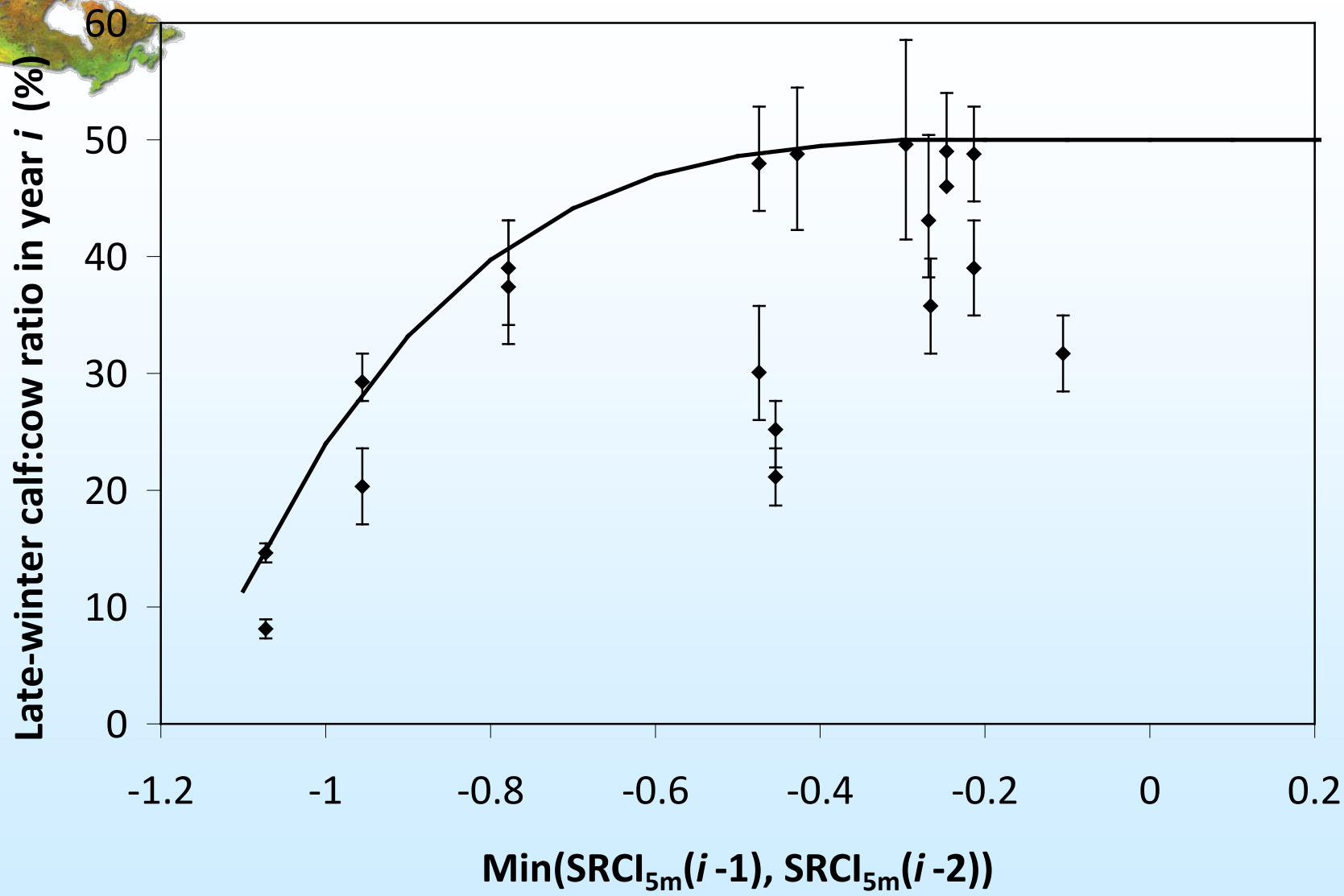


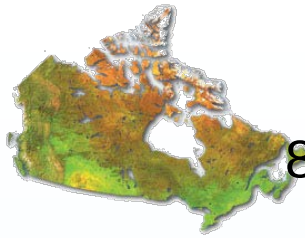
- **Fig. A shows the plot of water holding capacity of the barrel and the height of panel 1 with 200 data points, while Fig. B has 10 points. Each data point represents a random composition of panel heights.**
- **Note that these two regression equations are significantly different, although they stand for the same relationship.**
- **On the other hand, the upper envelopes of the barrel's water holding capacity in terms of panel 1's height remain the same in both cases. The upper envelopes are determined by the data points in which the barrel's water holding capacity is limited by panel 1's height, whereas data points below the upper envelopes represent cases in which the water holding capacity is limited by heights of other panels.**

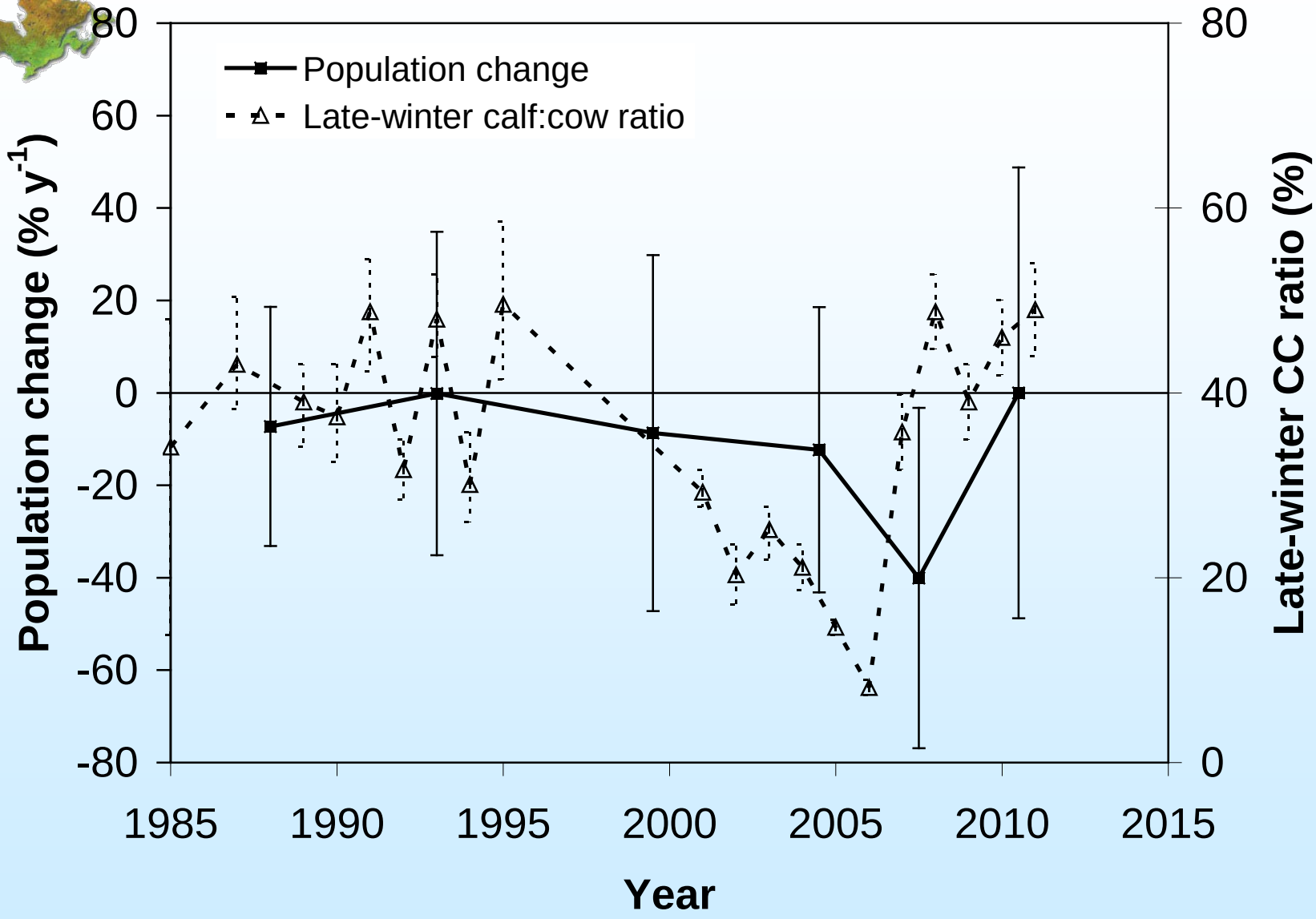
Upper envelop method

- **Can separate the impact of one factor from that of other factors even if data of these other factors are not available**

- **Used in other ecological studies (e.g., light response curve of plants, marine phytoplankton maximum growth rates and temperature)**


Late-winter calf:cow ratio in year *i* (%)
60
50
40
30
20
10
0
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
Min(SRCI5m(*i* -1), SRCI5m(*i* -2))




Population change
Late-winter calf:cow ratio
Population change (% y-1)
Late-winter CC ratio (%)
Year
80
60
40
20
0
-20
-40
-60
-80
1985
1990
1995
2000
2005
2010
2015

How to assess the impact of resource development on caribou?

There are two types of habitat disturbance features

(1) Line feature (e.g., roads, air transportation routes).

- Main impact: habitat fragmentation
  - E.g., the range of the Hardangervidda wild reindeer in Norway has been fragmented substantially by power lines, roads, and resorts in the 20th century, resulting in a nearly 90% reduction in area located > 5 km from infrastructures, and the original population split into 26 sub-populations.
  - Assessment tool: fragmentation index
- Main impact: Increase in energy cost from point A to B
  - Assessment tool: energetic model on individual animal's energy cost
- So far no quantitative relationship has been established with productivity and population change

How to assess the impact of resource development on caribou?

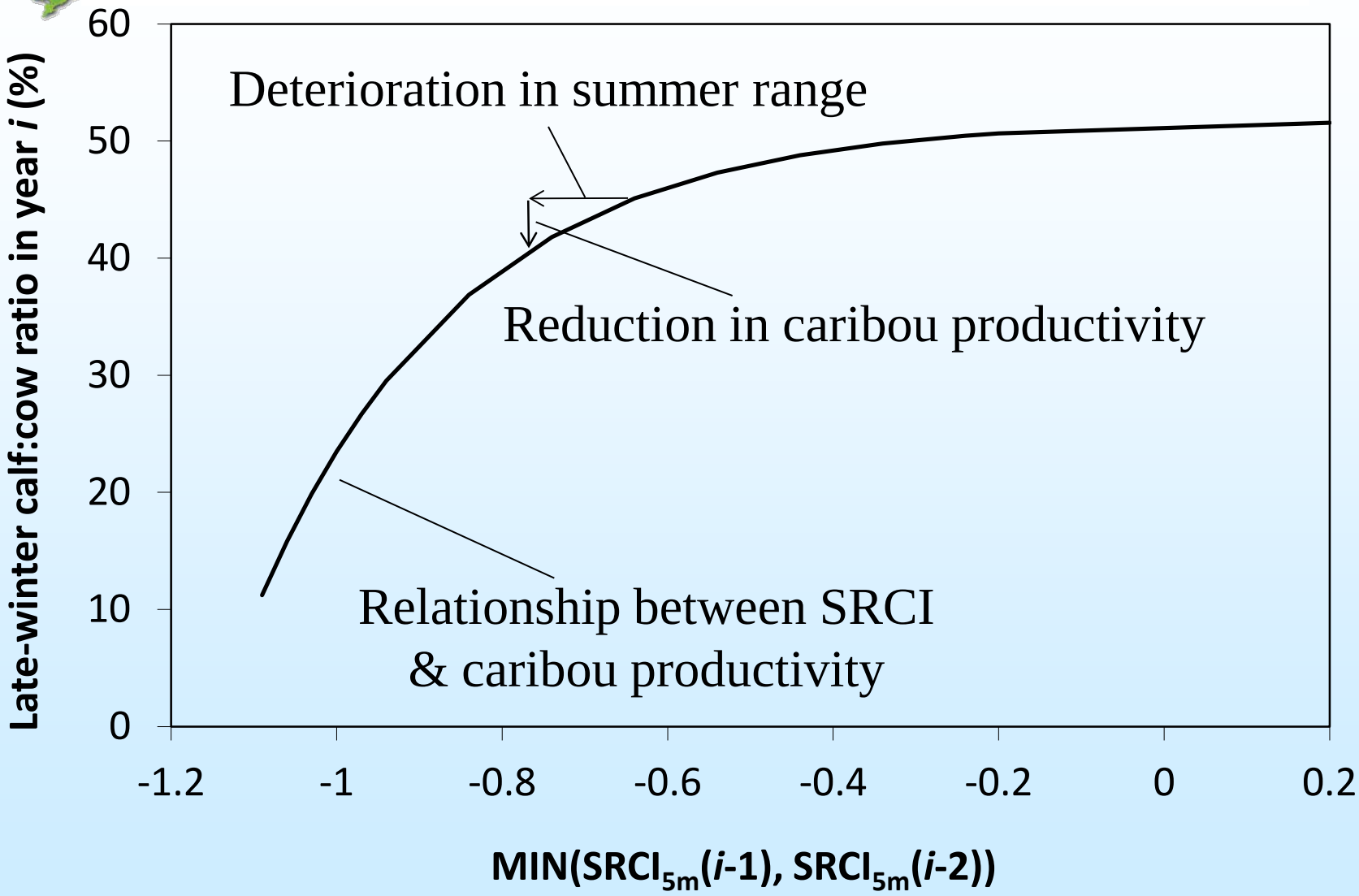
(2) Polygon feature (mining sites, mining trailing, buffer zones around linear features)

- **Main impact: reduction of foraging area**
- **Assessment tool: to be developed in this study**
  - **Using the SRCI and caribou productivity relationship as an analog**

$$SRM_{lb1} = \sum_{k=1}^{m} \left[\frac{B_{l1}(i,k)\left(1 - \frac{C_{avd}(i,k)}{C_{ta}(k)}\right) - \mathrm{mean}(B_{l1}(k))}{\sigma(B_{l1}(k))} \right]$$

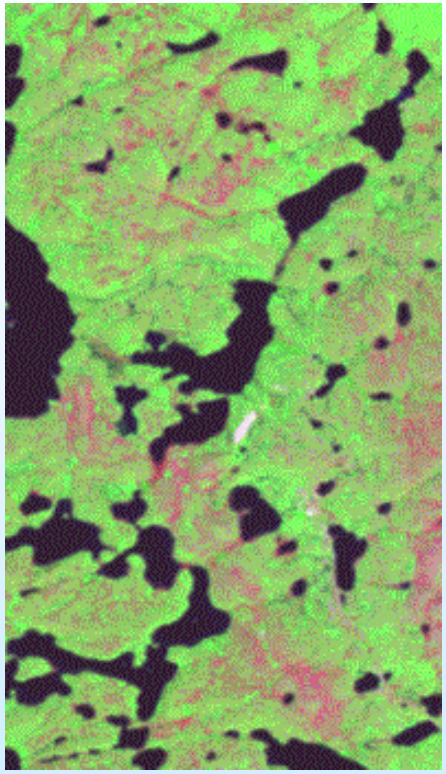
where $C_{avd}(i,k)$ is the class *k* cover area that caribou would avoid due to human activities in year *i* within the summer range.

Impact of resource development on caribou productivity

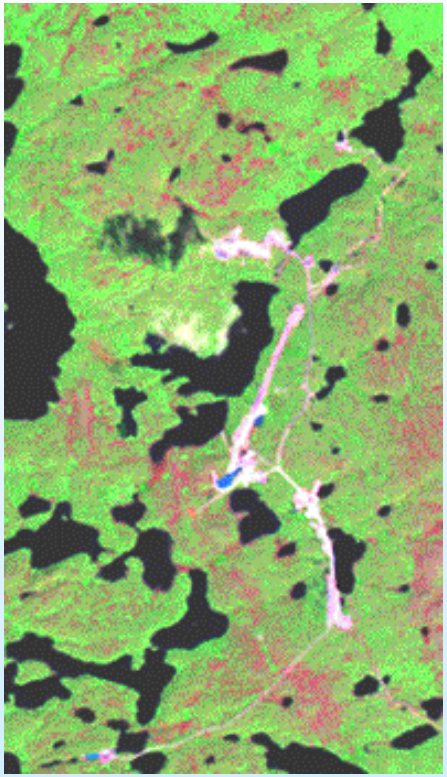


Mines in the Bathurst caribou range

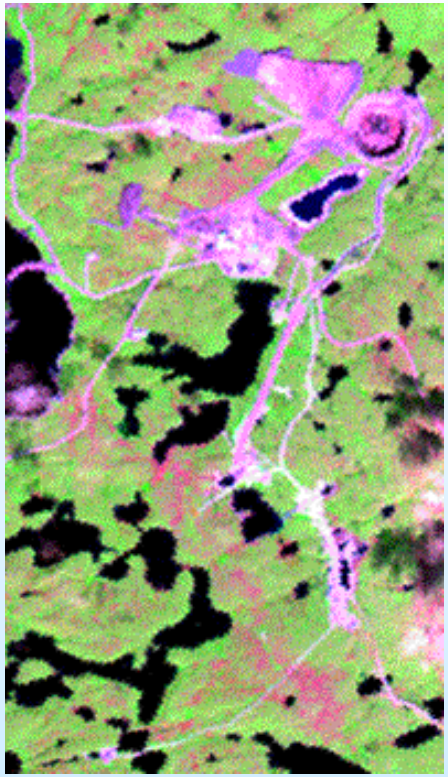
Landsat time series over the Ekati diamond mine in the Bathurst range



1989



1994

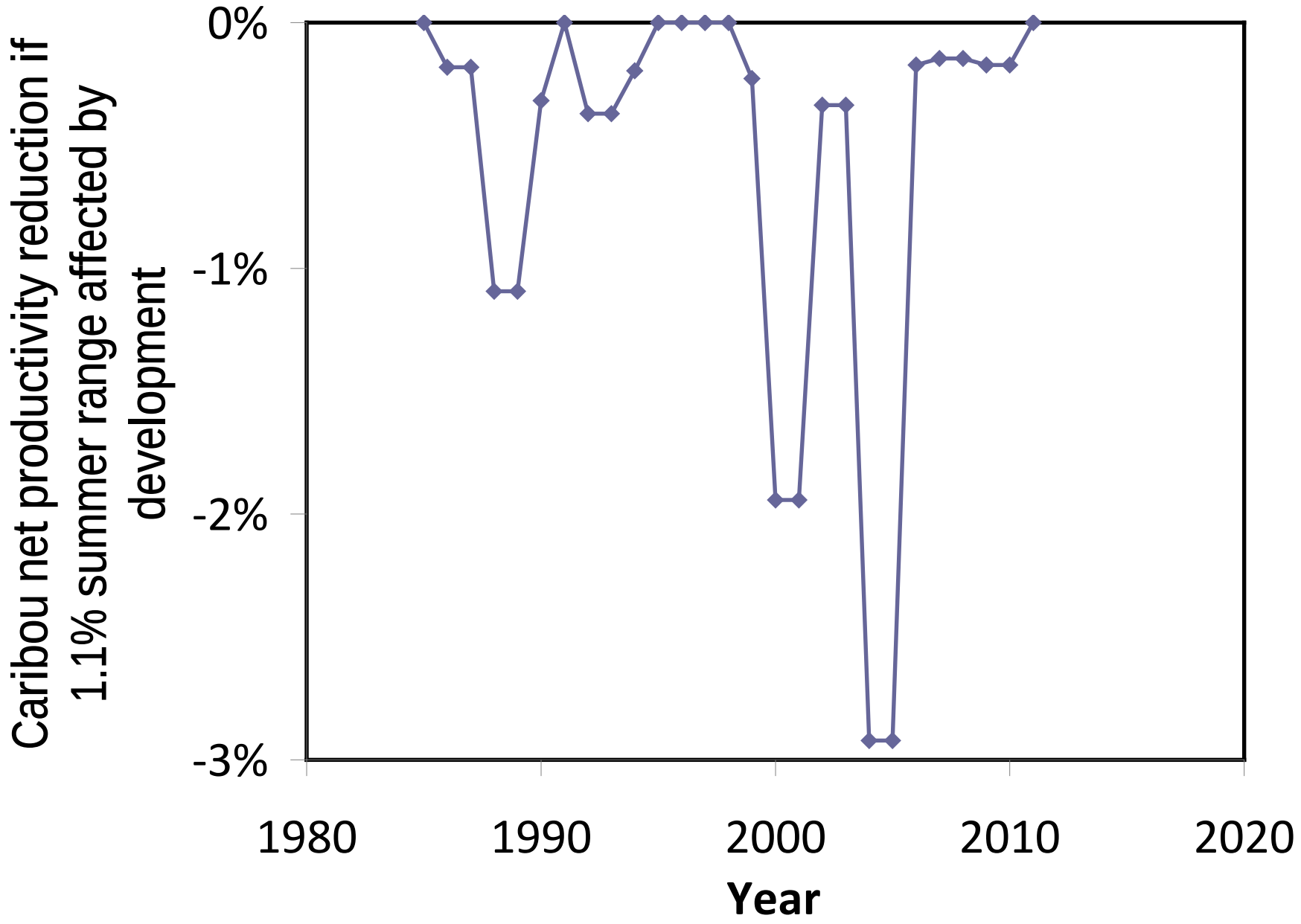


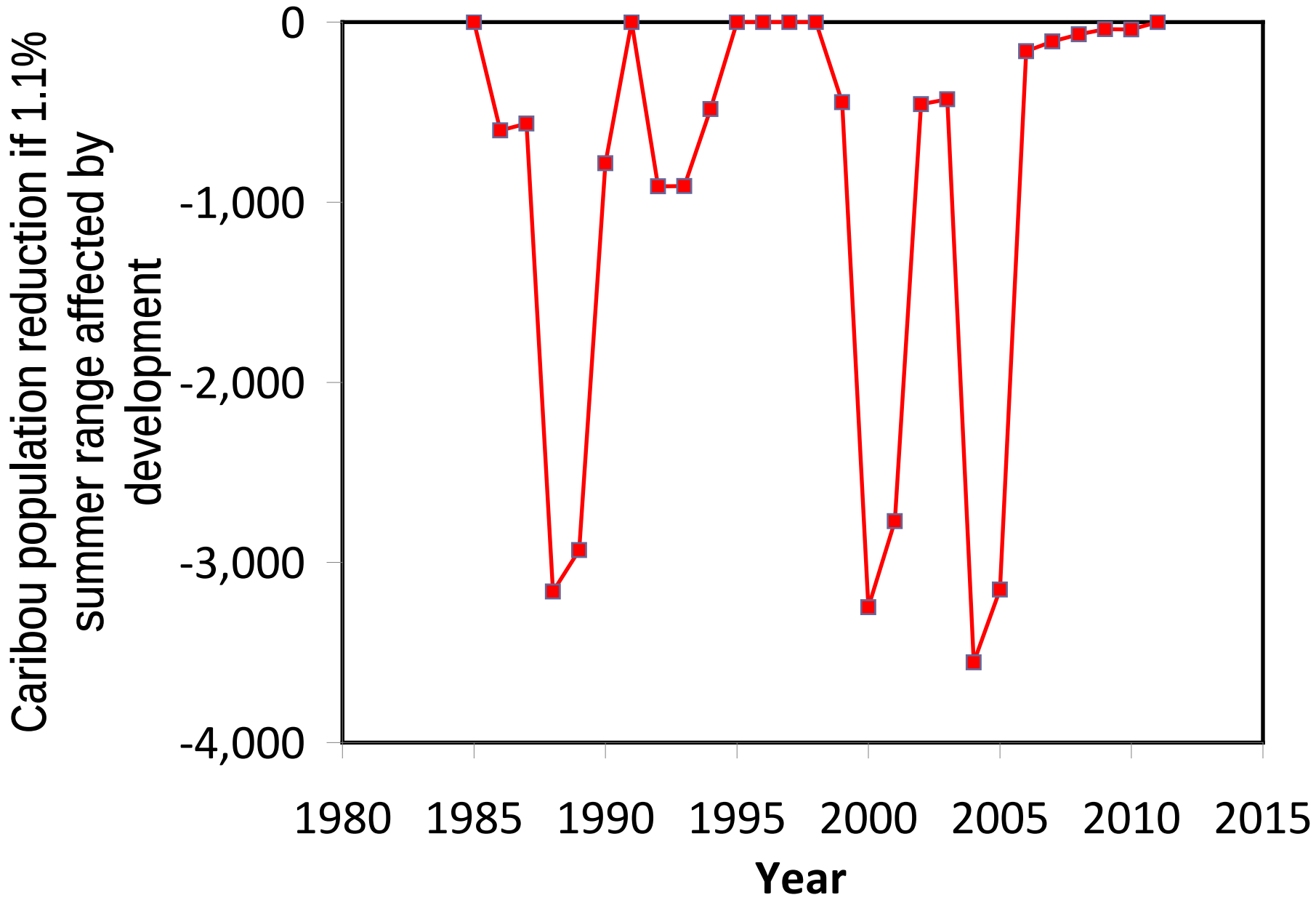
1999

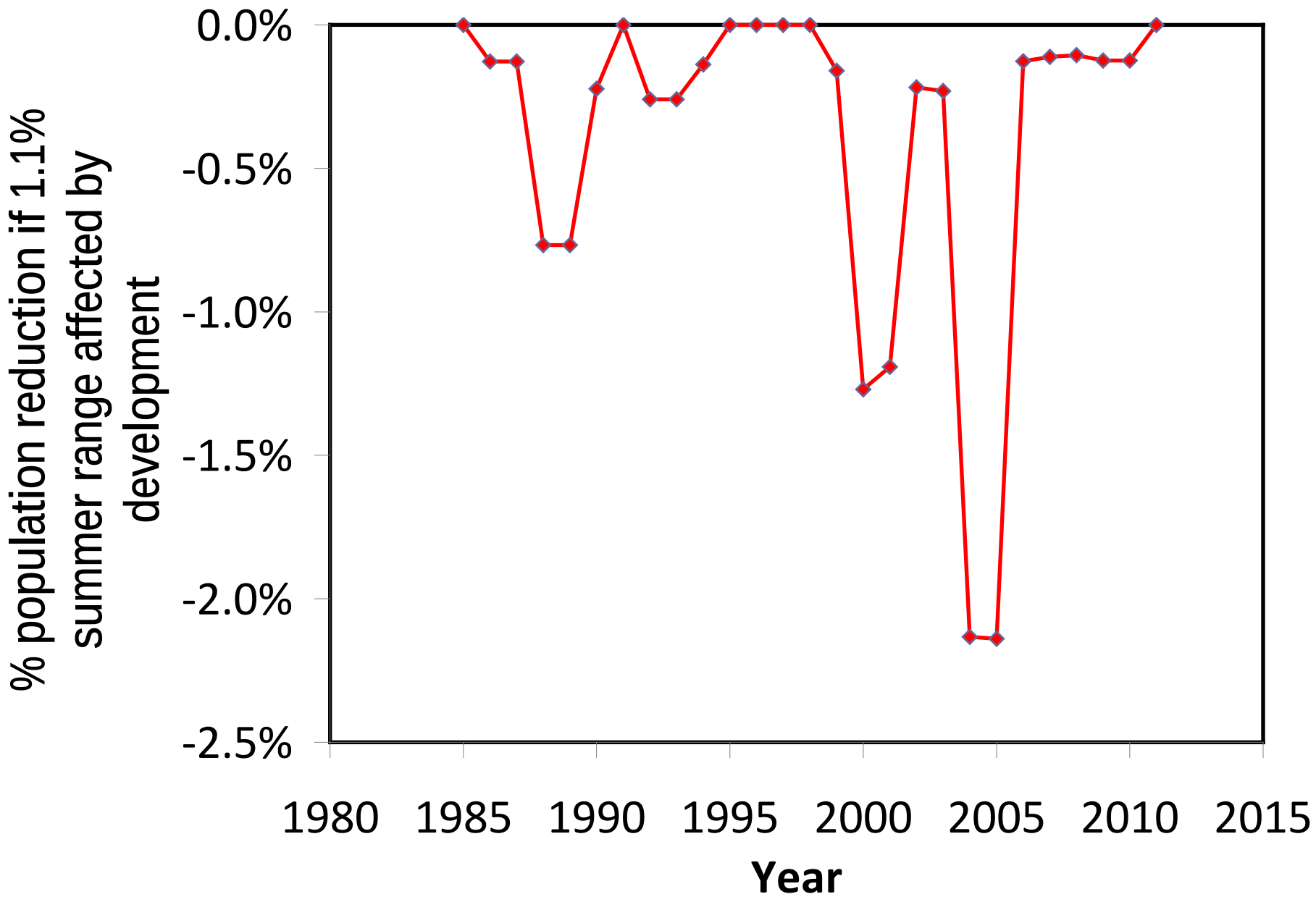
Ikonos image 2000

Area affected by resource development in the Bathurst caribou summer range

Area directly affected by Ekati Mine in 2000 (km^2)	line feature	11.1
	polygon feature	3.7
5-km buffer zones + area directly affected by Ekati Mine (km^2)	line feature	176.7
	polygon feature	90.0
Total area affected by Ekati Mine (km^2)		266.8
Total area of Bathurst summer range (km^2)		96134
Percentage of area affected by Ekati Mine		0.28%
Percentage of area affected by 4 mines		1.11%


Caribou net productivity reduction if 1.1% summer range affected by development
0%
-1%
-2%
-3%
1980
1990
2000
2010
2020
Year


Caribou population reduction if 1.1% summer range affected by development
0
-1,000
-2,000
-3,000
-4,000
1980
1985
1990
1995
2000
2005
2010
2015
Year


% population reduction if 1.1% summer range affected by development
0.0%
-0.5%
-1.0%
-1.5%
-2.0%
-2.5%
1980
1985
1990
1995
2000
2005
2010
2015
Year

Caution on estimated impact of resource development on caribou

The estimated impact represents a rough first-cut

- on the one hand, not all mines operated simultaneously during 1985-2011
- Areas affected by Lupin Gold Mine and Snap Lake Diamond Mine might be smaller because they are mostly underground operations
- The use of 5-km buffer zones, which are ~50 times the size of area directly affected, needs further investigation.
- On the other hand, the area affected by Ekati Mine was based on 2000 Landsat data. More expansion of the mine has occurred.
- Also, difference in habitat changes caused by climate inter-annual variations (over the entire summer range) and resource development (concentrated on affected area)