Assessing the Likely Impact of Climate Change on Fish Habitat in Canada’s Lakes: A Lake Trout Case Study

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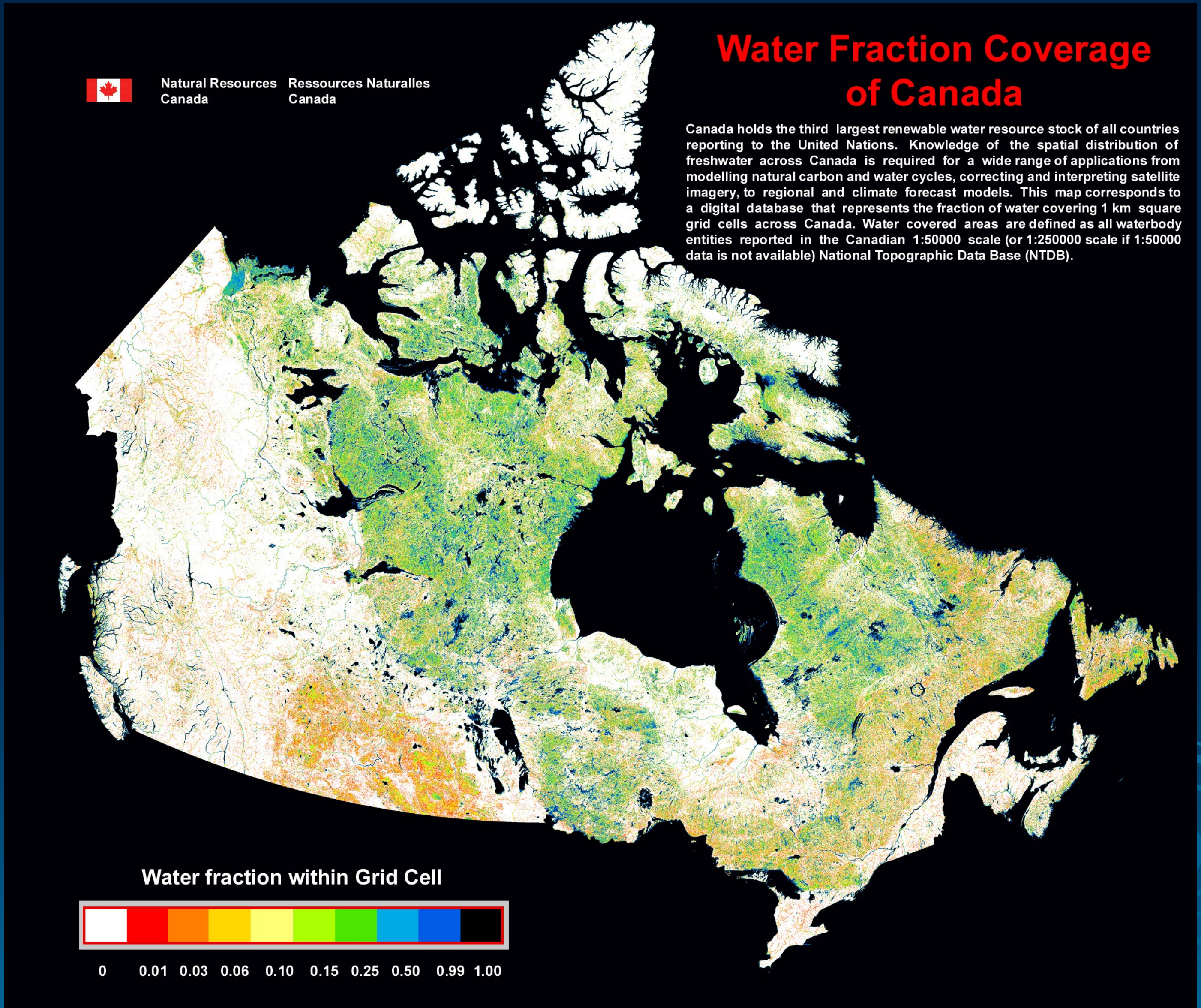
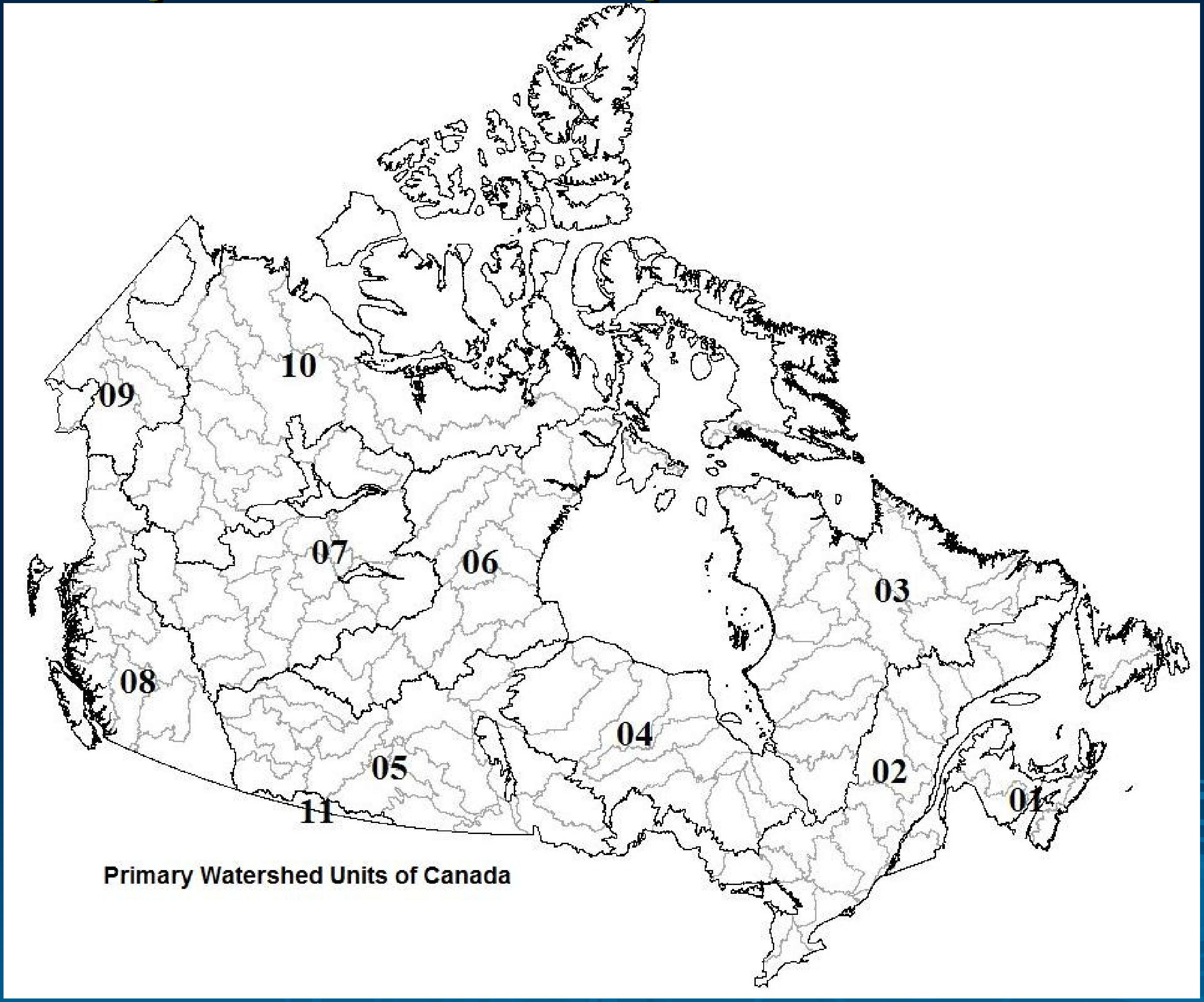
Outline

- Canada's freshwater resources
- Climate change
- Likely impacts on fishery resources
- Lake trout: a case study using CLAM
- Implications
- Future work

Canada's Freshwater Ecosystems

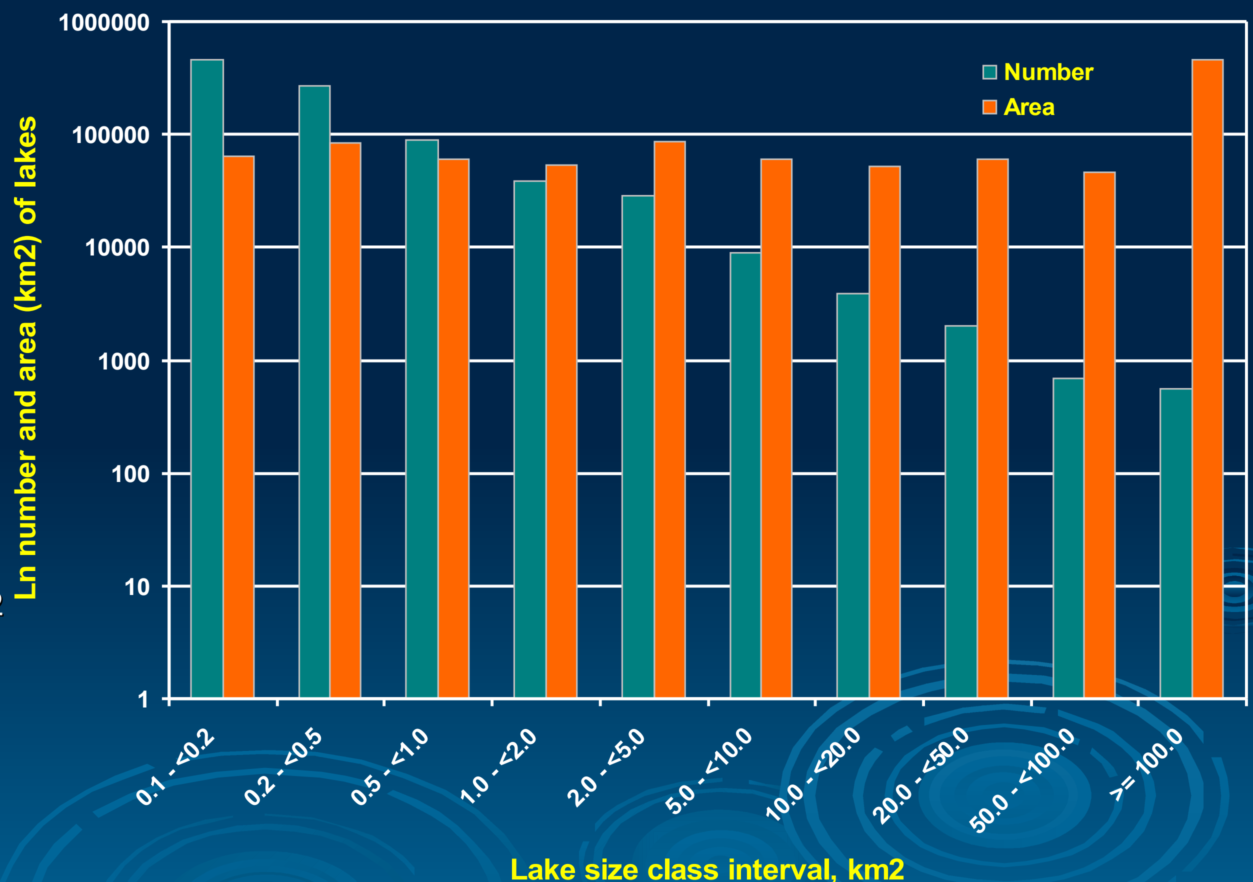


Primary & Secondary Watershed Units



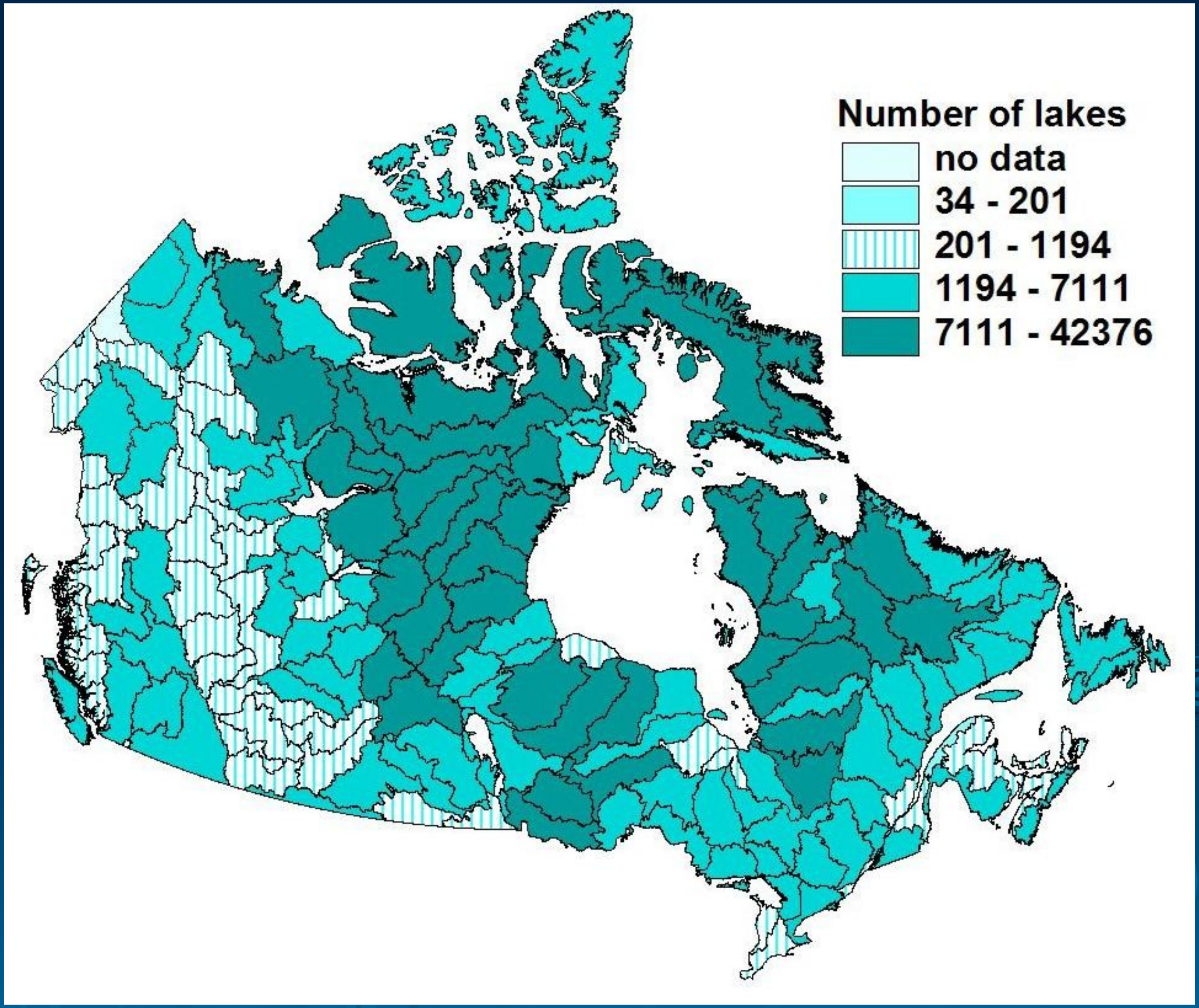
Numbers and Areas of Canadian Lakes

- Like many phenomena lake numbers follow a Pareto distribution:
- $N (a \geq A) = \alpha A^{\beta}$ where $\beta \sim -1$
- Used WWF's Global Lakes and Wetlands DB for lakes > 1 km^2
- There are 910,000 lakes ≥ 0.1 km^2 (10 ha) with a total area 1,028,000 km^2
- 37% of global lake resources

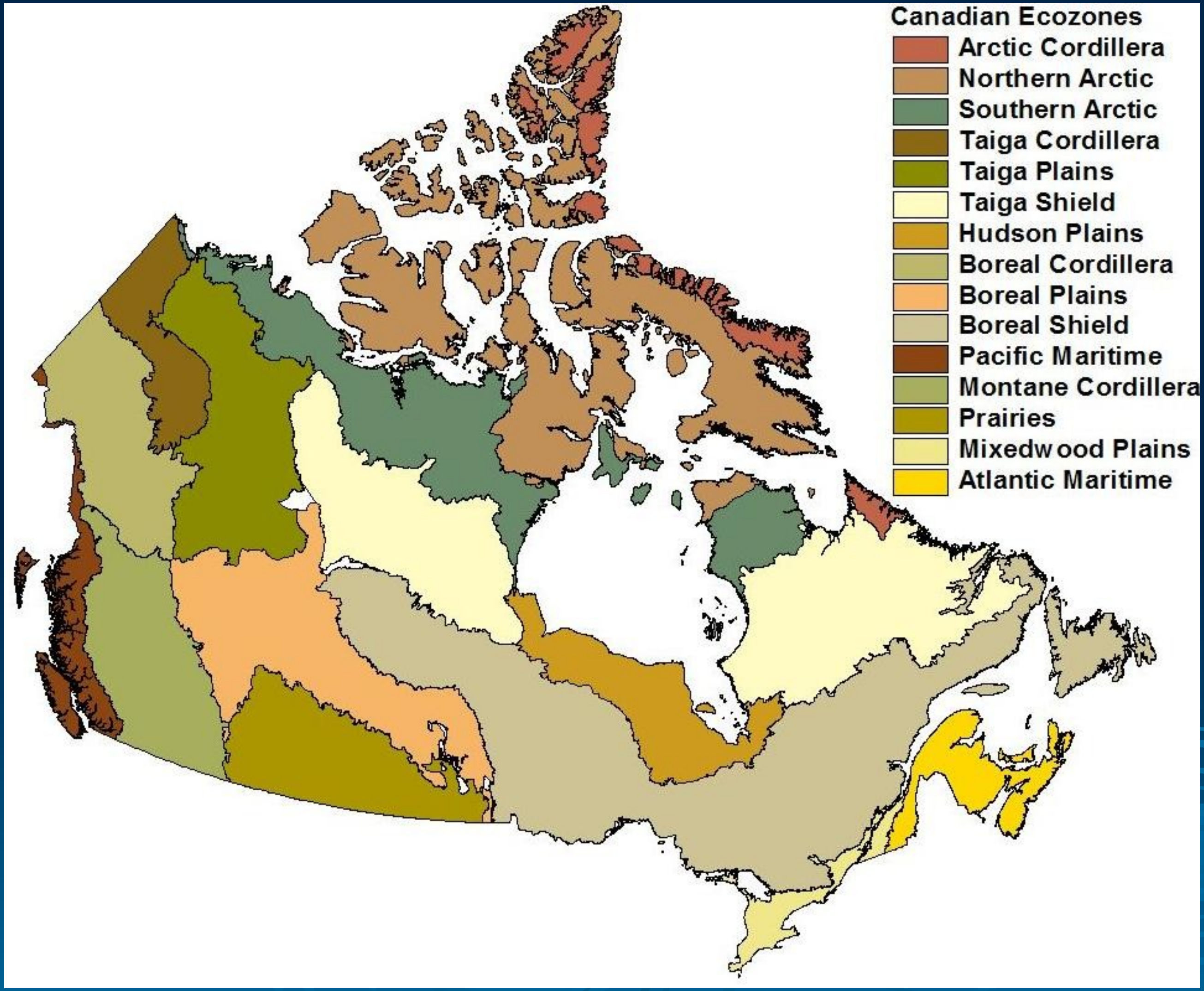


Canadian Lake Distribution

- # lakes with area (≥ 0.1 km2 or 10 ha) by secondary watershed
- Greatest #s on the Canadian Shield around Hudson's Bay



Terrestrial Ecozones



Concentration of Lakes

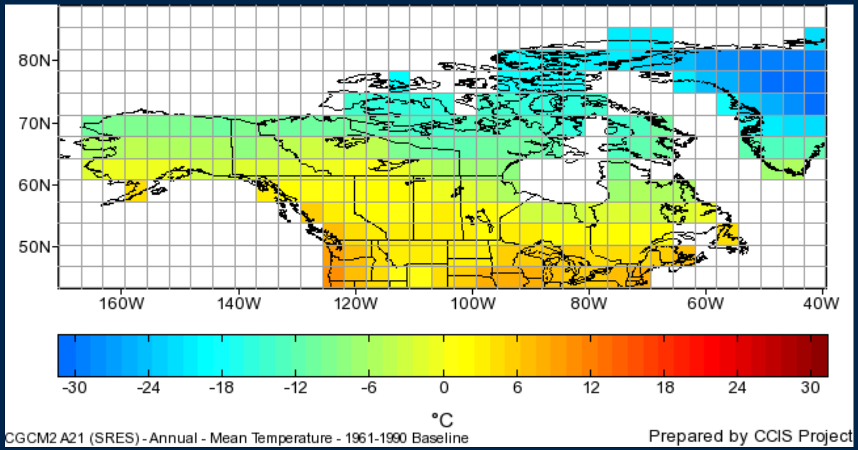
	Percent of total	
Ecozone	Number	Area
Boreal shield	26.25	30.67
Taiga shield	27.42	23.99
Southern arctic	15.68	11.11
Northern arctic	13.78	10.02
Sub-total	83.13	75.79

Climate Change

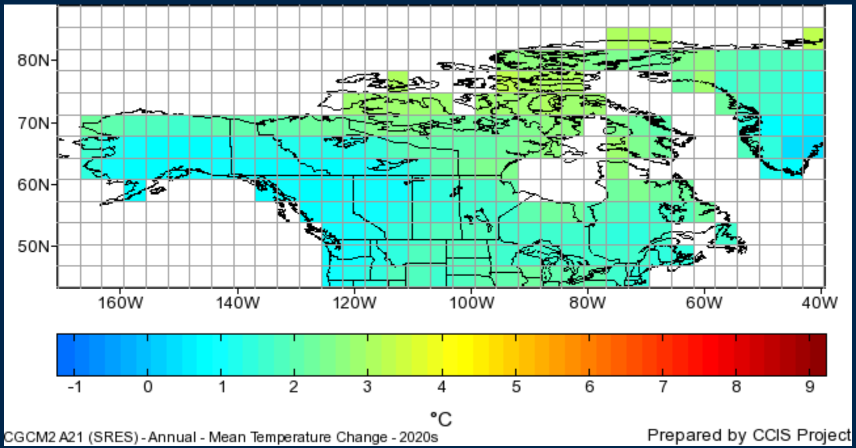
- The earth is now committed to relatively high temperature increases during this century due to the slowness of efforts to control GHG emissions, notably in Canada
- I used the 1961-90 norms period as a baseline and the increments in the CGMC2 A2 scenario (business as usual) as an estimate of changes in the 21st century

Temperature Changes in the 21st Century

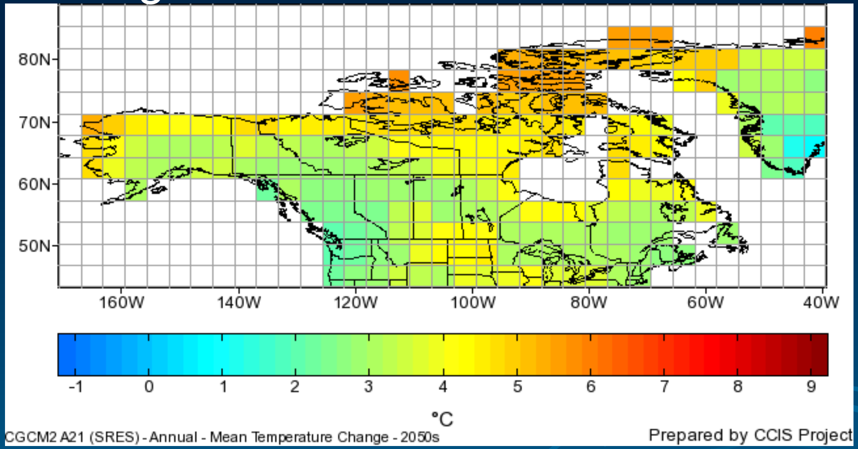
Norms 1961-90



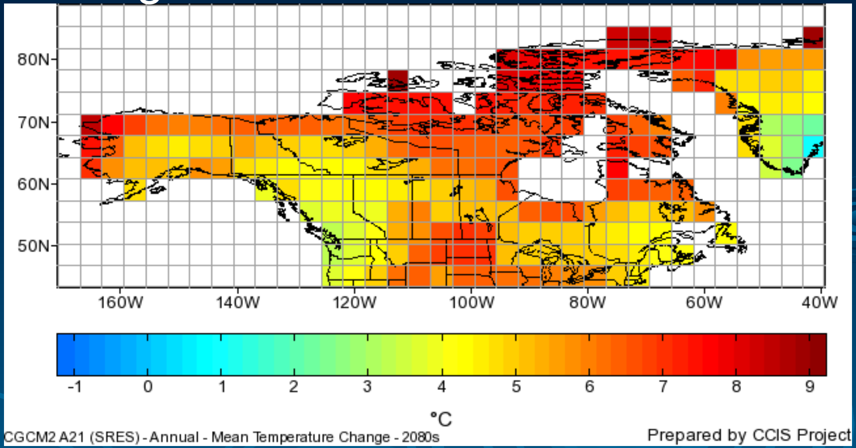
Change to 2011-2040 or 2020s



Change to 2041-2070 or 2050s



Change to 2071-2100 or 2080s



Scenarios – CGCM2_A21 from www.cics.uvic.ca

Ecosystem Change

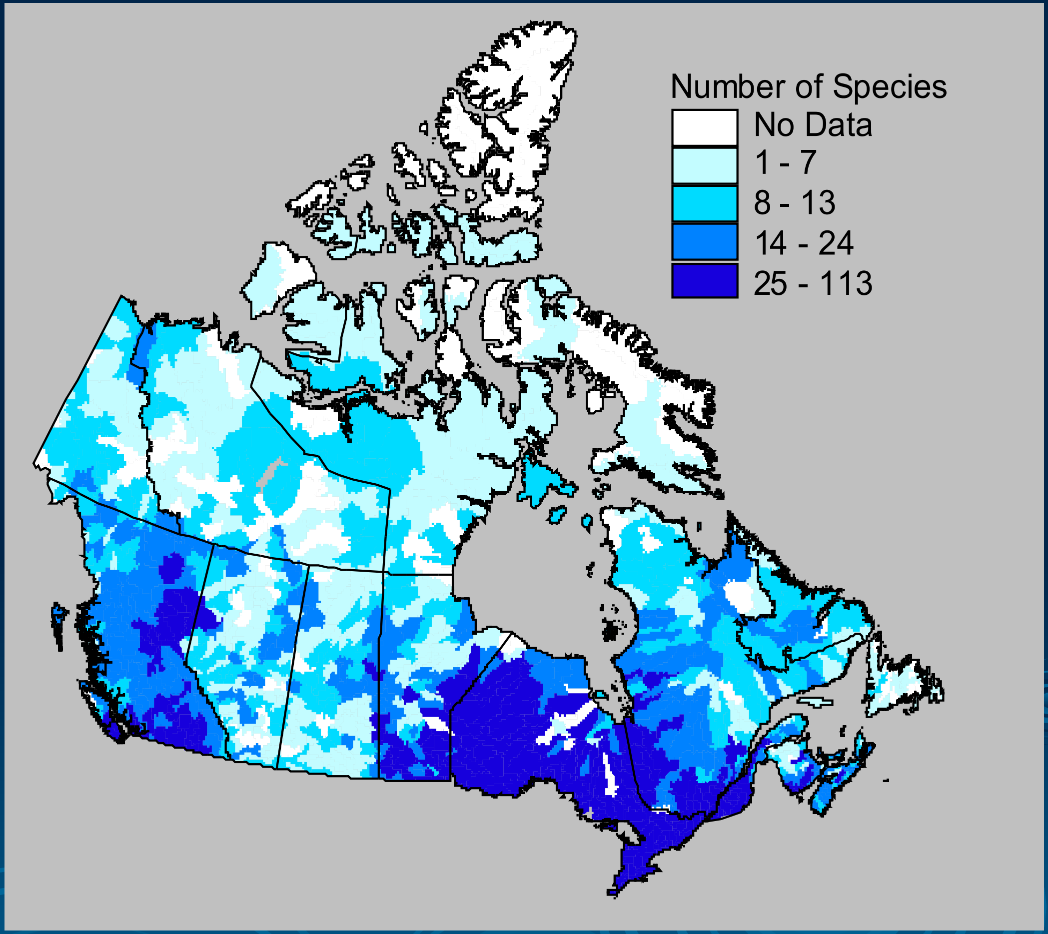
- Alongside warming, increased evaporation will lead to decreased runoff and water levels
- The boreal, taiga, and southern arctic ecozones will undergo massive change
- Much of the freshwater resources are in those ecozones

Likely Impacts of Climate Change on Fish Ecology and Fisheries

Fish Ecology	Fisheries
Change in **overall fish production** in a particular aquatic ecosystem	Change in **sustainable harvests** for all fish populations in the ecosystem
Change in relative **productivity of individual fish populations** in a particular aquatic ecosystem	Change in **sustainable levels of exploitation** that can be directed against the fish populations of the ecosystem
Large-scale **shifts in geographic distribution** of species	Change in **mixture of species** that can be sustainably harvested within a specific region. Change in **location** of profitable fishing grounds
Small-scale **shifts in the spatial distribution** of members of a specific population	Change in **sustainable harvest** for the population Change in **efficiency of fishing gear**, leading to change in sustainable levels of fishing effort

Freshwater fish biodiversity

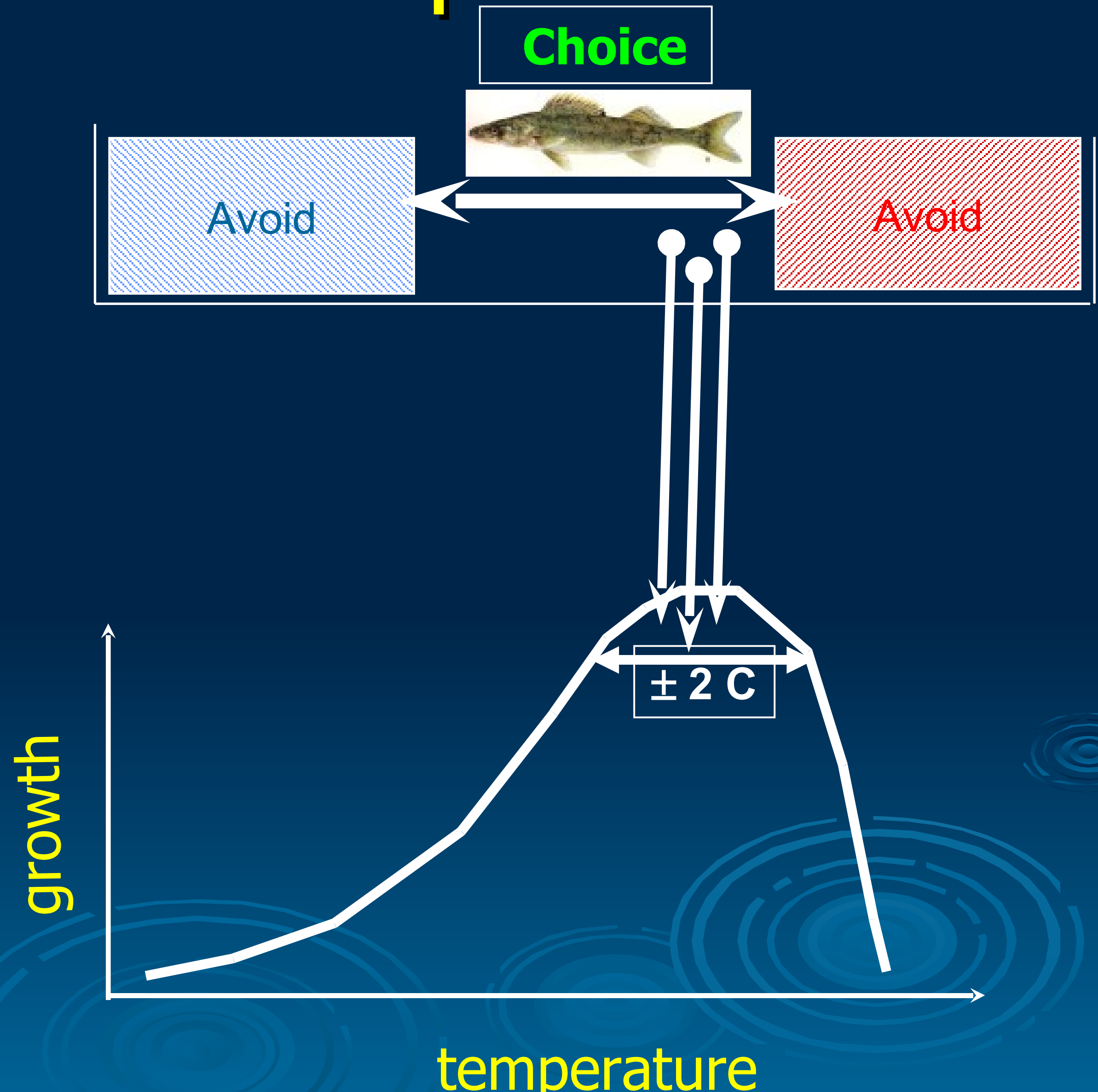
- Species richness is linked to temperature, the supply of freshwaters, and colonization since the last glaciation
- Cold and cool species will be displaced by warm ones; extirpations and extinctions will increase; and more species will be put at risk
- Arctic char, lake trout, lake whitefish will be particularly vulnerable

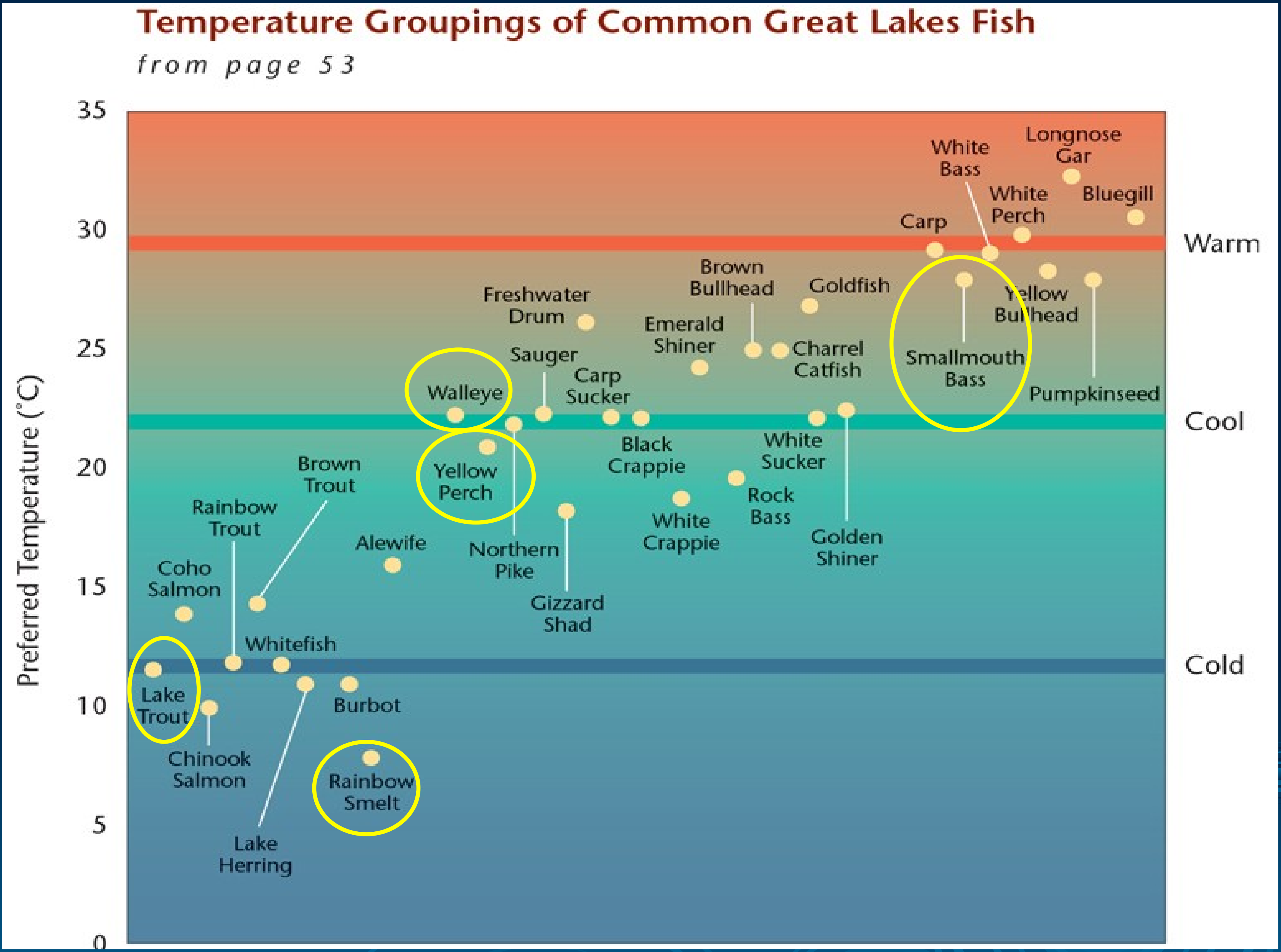


Chu *et al* CJFAS 60:624-34 2003

Preferred Temperature

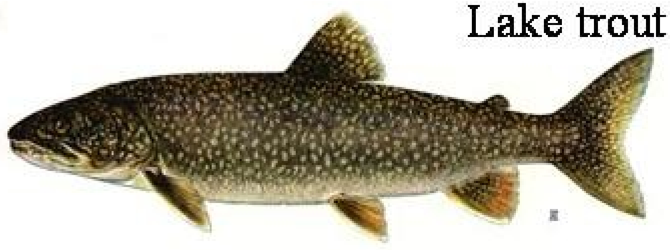
- Fish are poikilotherms
- Species typically have a range of 4-6 ºC where measures like growth are maximal
- In preference expts. fish will choose a range to maximize fitness: Fundamental thermal niche





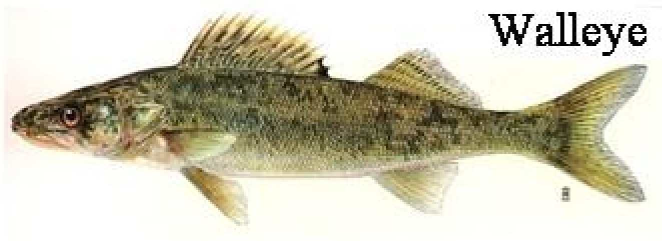
Kling, G.W. et al.. 2003. Confronting climate change in the Great Lakes Region. Union of Concerned Scientists and Ecological Society of America, Washington, D.C.

Typical Representatives of Each Thermal Guild



Lake trout - **preferred temperature range**
10 - 15 C

Cold -ve



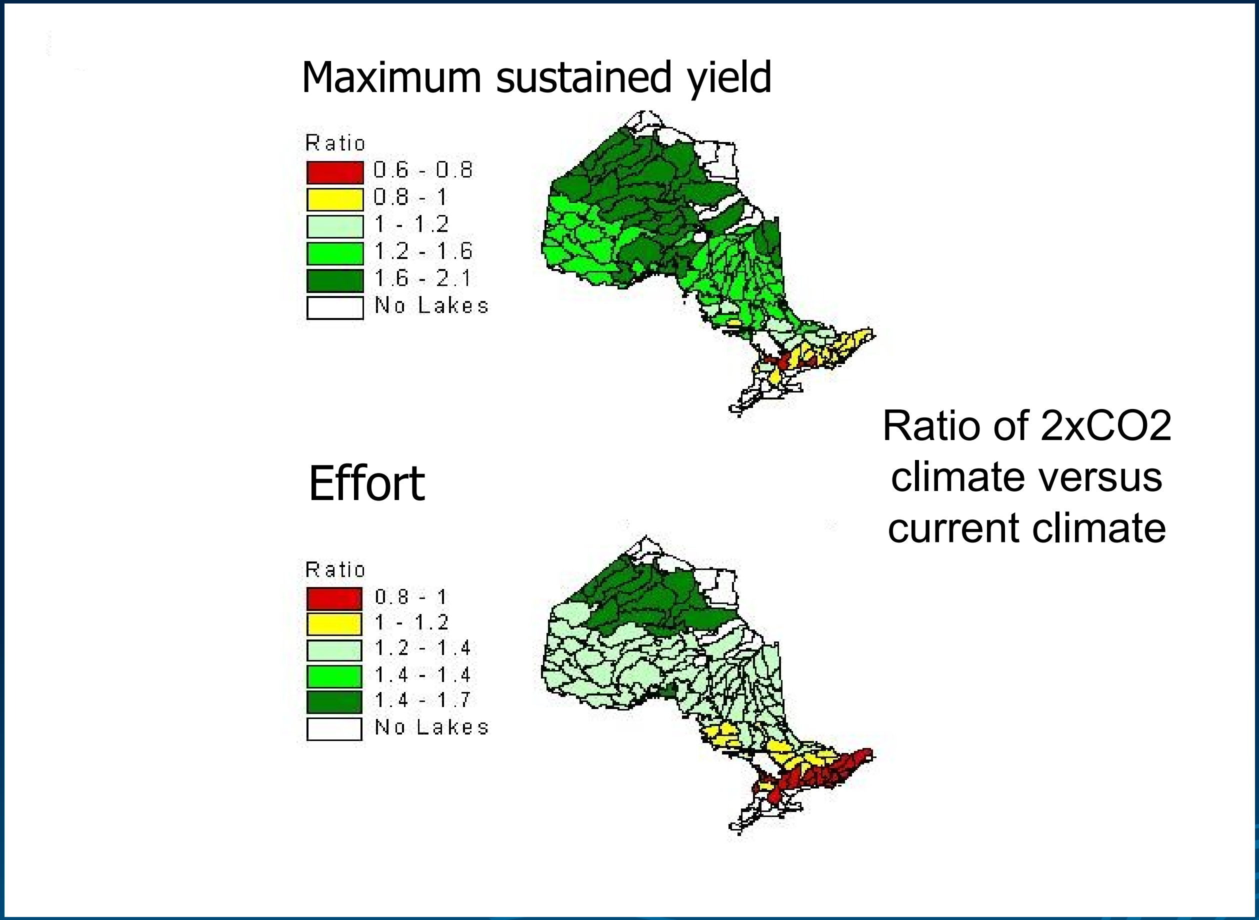
Walleye - **preferred temperature range**
20-25 C

Cool -/+ve

Smallmouth bass - **preferred temperature range**
26 - 31 C

Warm +ve

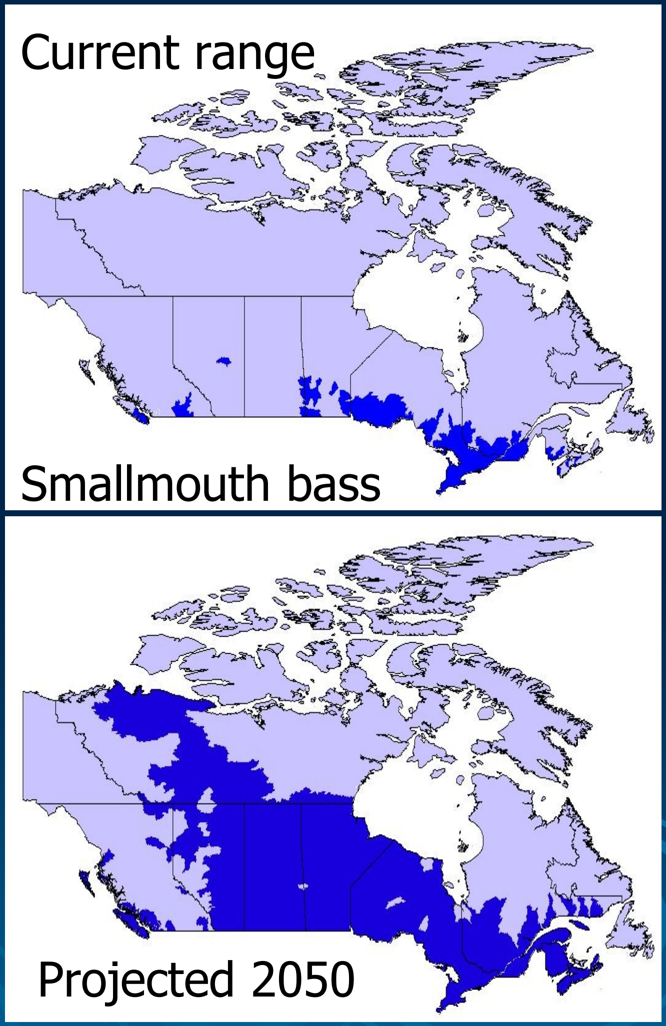
Inland walleye (sander) lakes



- Projected equilibrium production and effort ratio in walleye lakes by TWS 2xCO2 vs. 1xCO2 climate scenarios in Shuter et al 2002 Proc (based on Lester et al TOHA model linking walleye production to degree days and water clarity)

Invasive species

- Smallmouth bass (SMB) have already invaded many areas in Ontario since the 1930s' introductions
- There are many warmwater species, like bass, present in the Great Lakes region poised to expand northward with climate change
- Competition and predation from invaders will increase problems for cold and cool native species
- Humans will likely continue to aid invasions to "improve" fisheries without regard to native species or ecosystem consequences
- Sapna Sharma's recently completed PhD further developed our appreciation of the potential range expansion of SMB

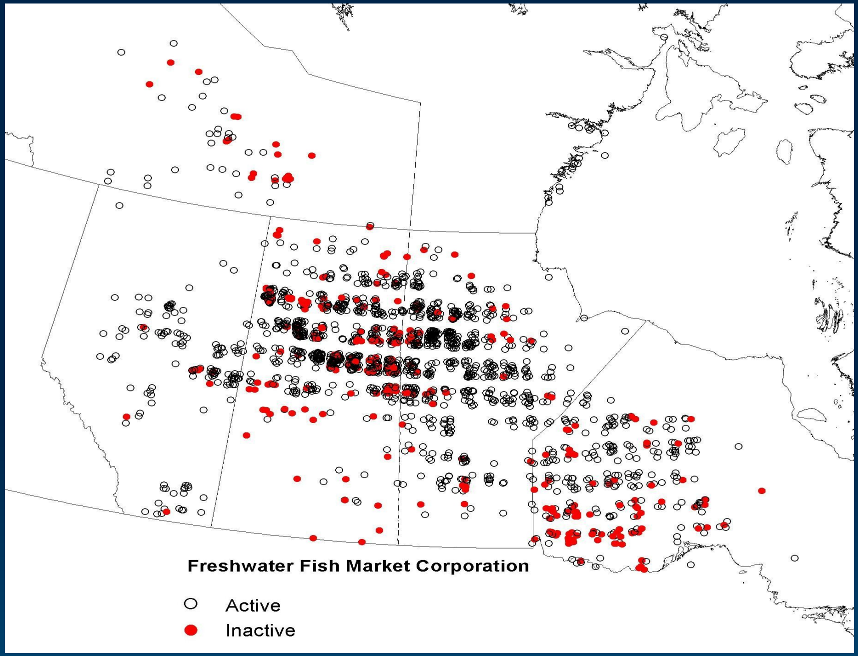


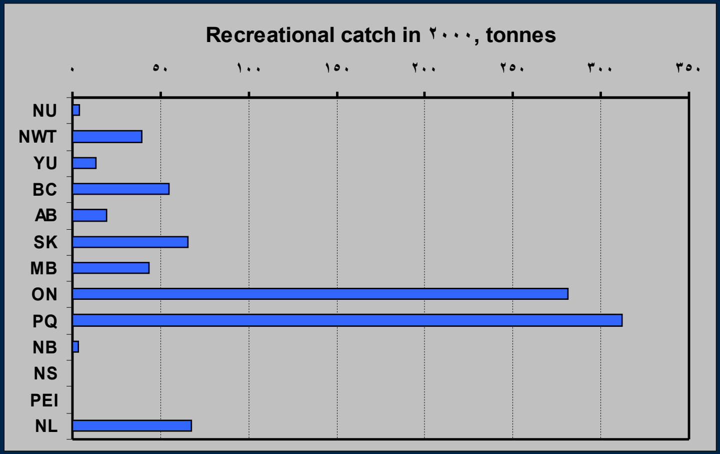
Lake Trout: A Case Study

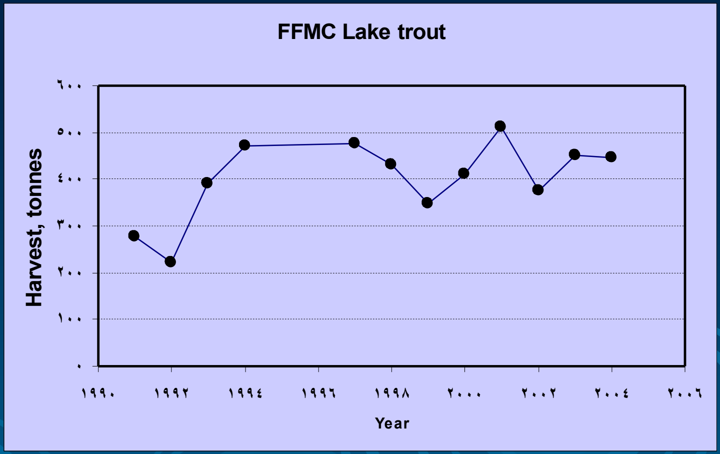
- Lake trout (*Salvelinus namaycush*)
- Cold stenotherm of larger, deeper, clearer lakes
- Primarily a piscivore where prey resources allow
- Important fisheries (commercial, recreational, subsistence, and first nations)

Lake Trout Fisheries

Commercial fishing sites for all species







FFMC Statistics 1991-2004
Recreational Fishing Survey 2000

CLAM

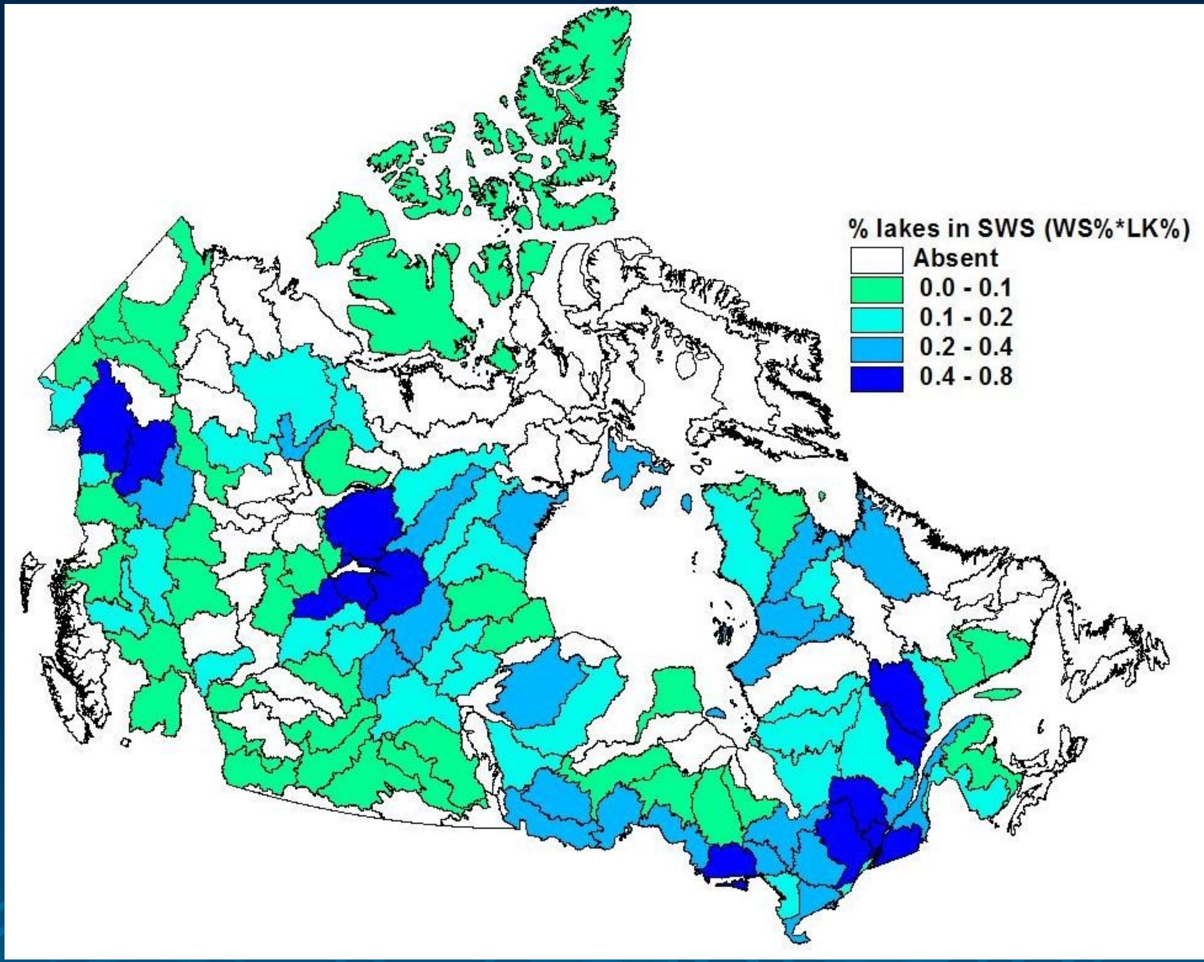
- Canadian Lakes Assessment Model
- Integrated modelling framework of populations of lakes by size class and secondary watershed (SWS)
- Characteristics of lake trout lakes by size class and SWS
- Midsummer thermal profile models
- Climate scenarios by SWS

Estimation Steps

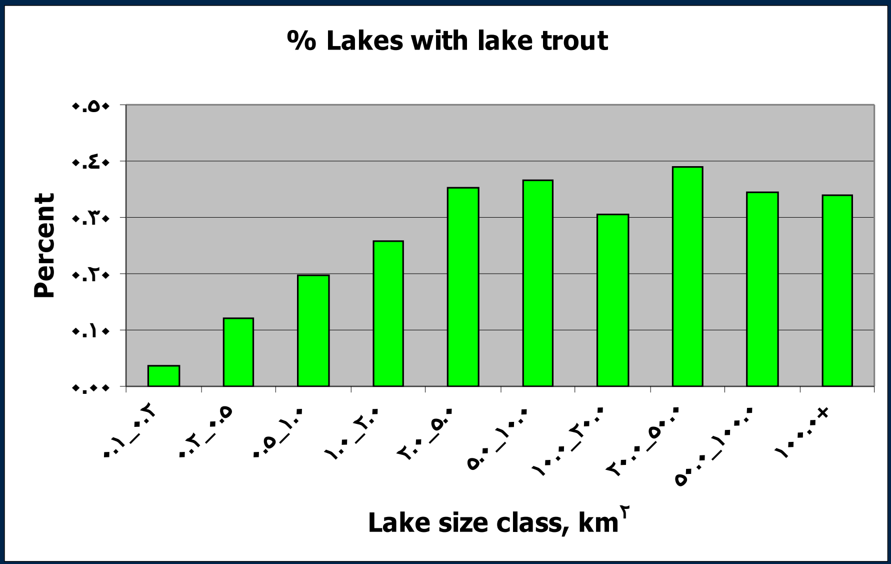
- Number and characteristics of lake trout lakes by secondary watershed
- Characterize lake thermal regimes in relation to lake and climate features
- Specify lake trout thermal ecology

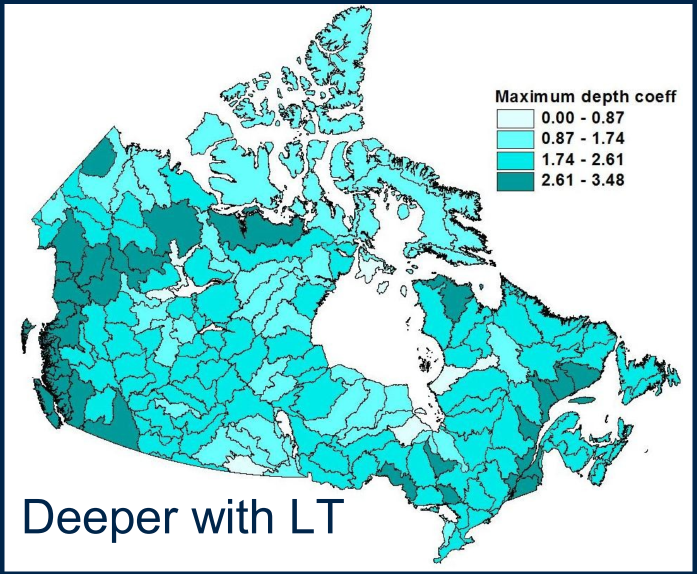
Percent of Lakes with Lake Trout by SWS

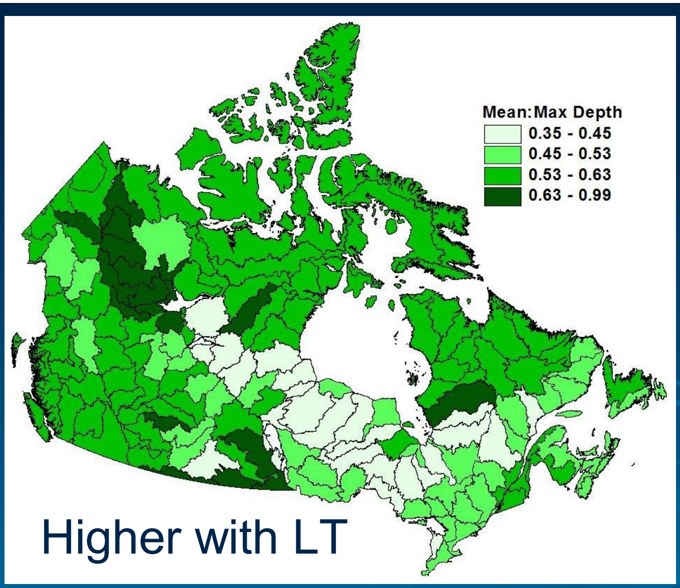
- Estimated 66,500 lakes covering 351,000 km2 with a volume of 22,400 km3
- Most on the boreal and taiga shields (# 79%, area 65%, volume 75%)

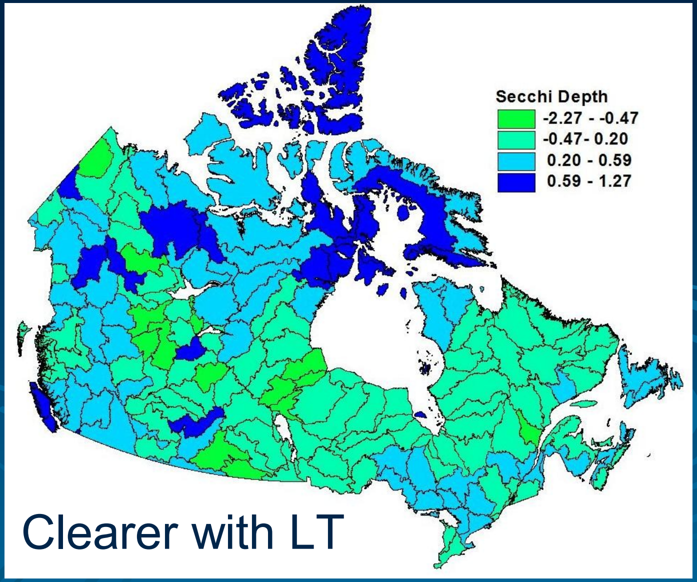


Regional Characteristics of Lakes









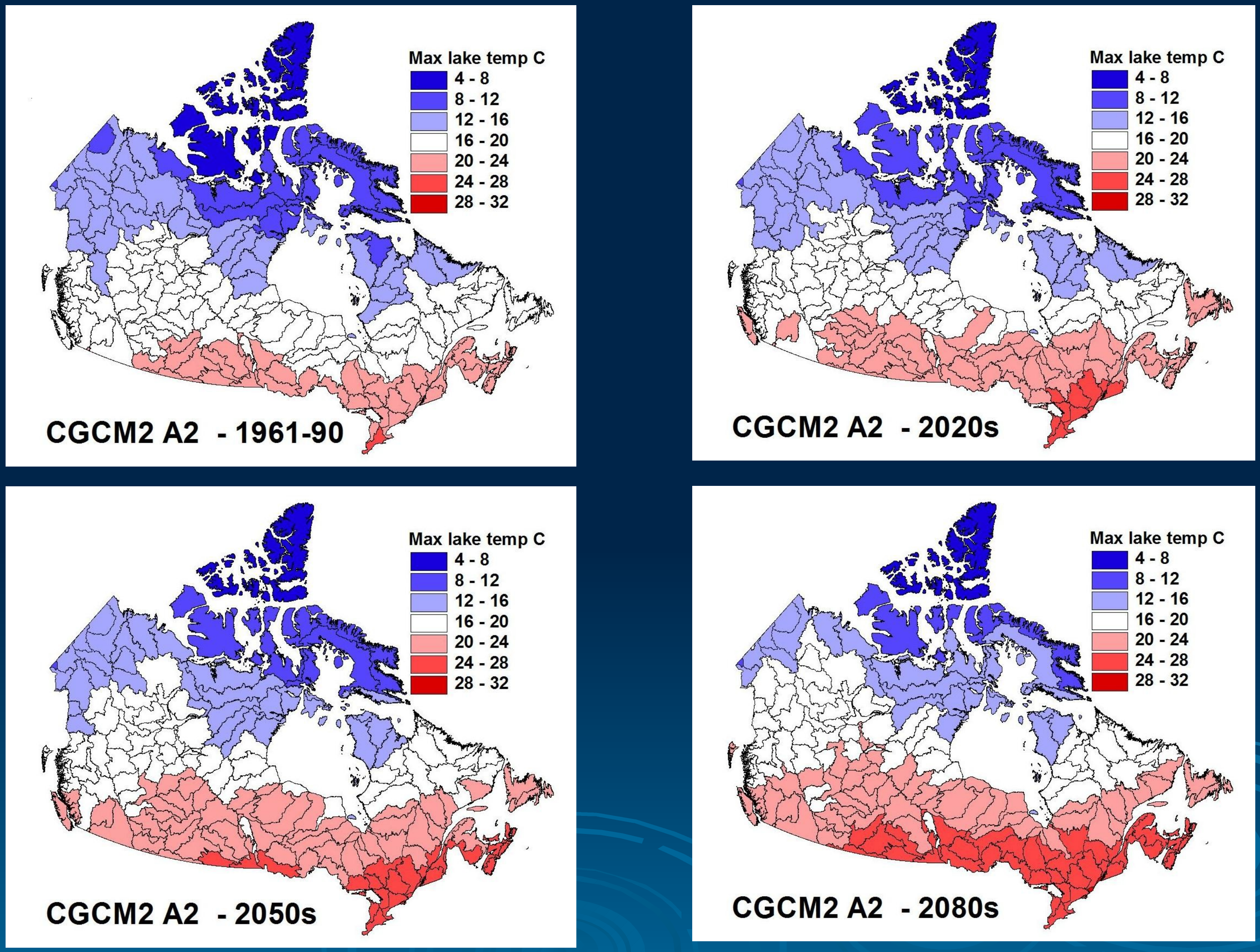
Modelling Lake Thermal Regimes

- Maximum summer surface temperature
  - Used remote sensing of large lakes and in situ data from other lakes to model
- Is the lake stratified?
  - Used 1953 *in situ* lake profiles from 1931-2002 (mainly ON, AB, BC)
- If not stratified:
  - What is the temperature gradient from surface to bottom
- If stratified:
  - Bottom temperature at peak of stratification
  - Thermocline depth and steepness of transition

Maximum Summer Surface Temperature?

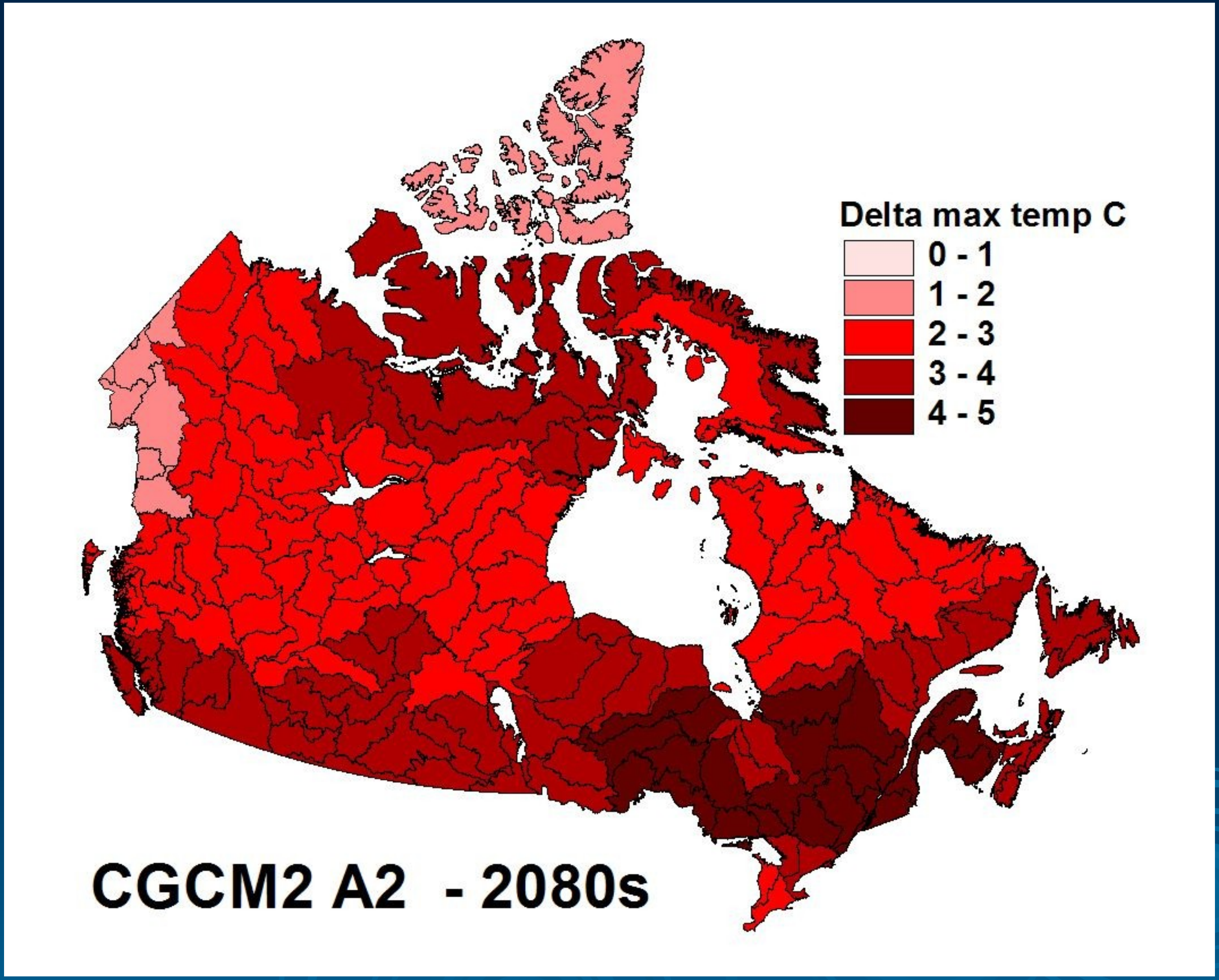
- Mixture of data with wide size range
  - ➔N=554 remotely sensed lakes (≥100 km2) for 2001-2003
  - ➔N=1953 *in situ* lake observations from 1931-2002 (mainly ON, AB, and BC)
- Tmax = 24.67 – 0.25•Latitude° - 0.26•Ln(Lake area km^2) + 0.56•MSAT(JJA) °C
- R^2 (obs. vs pred.) = 0.538

Maximum Summer Lake Temperature

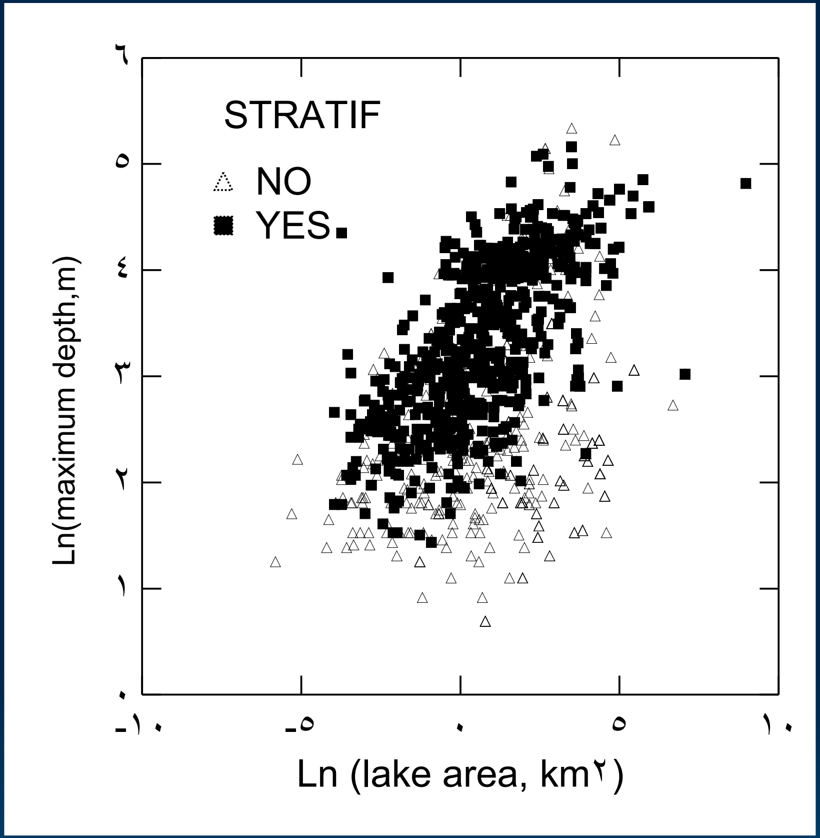


Estimated for lakes with area 10 km2 (1000 ha)

Increases of Tmax in 2080s



Is A Lake Stratified?

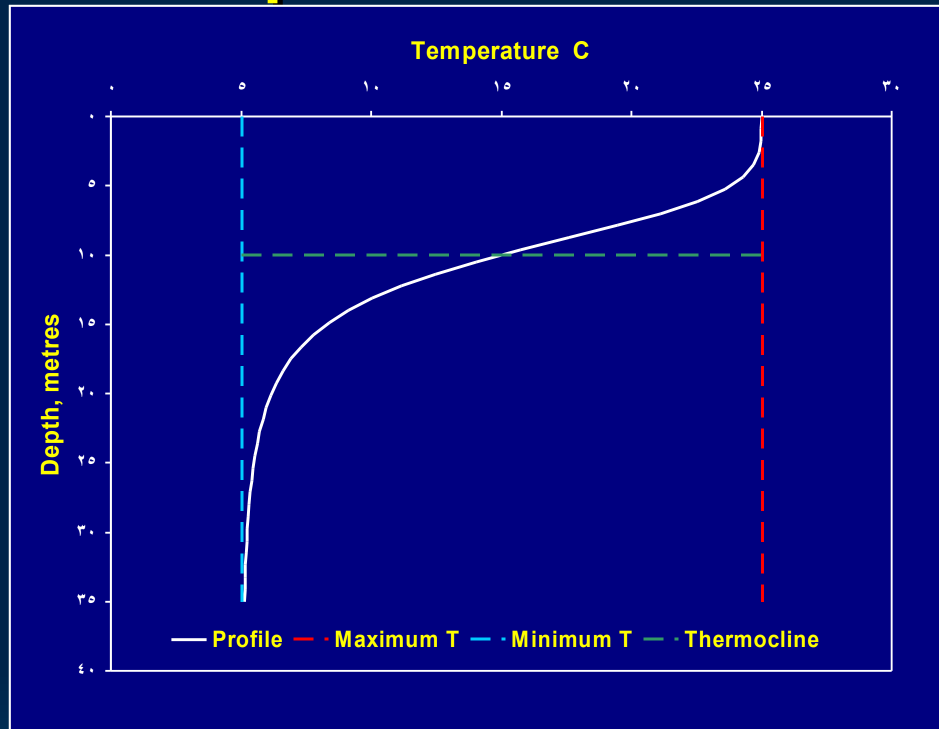


- Logistic Regression (LR) with N=1953
- LR = -5.89 – 0.63*Ln (Area) +2.22*Ln (Zmax)
- Probability (Strat =Yes) = Exp(LR)/(1+Exp(LR))
- Prediction success = 70.1%

Temperature Profiles in Unstratified Lakes

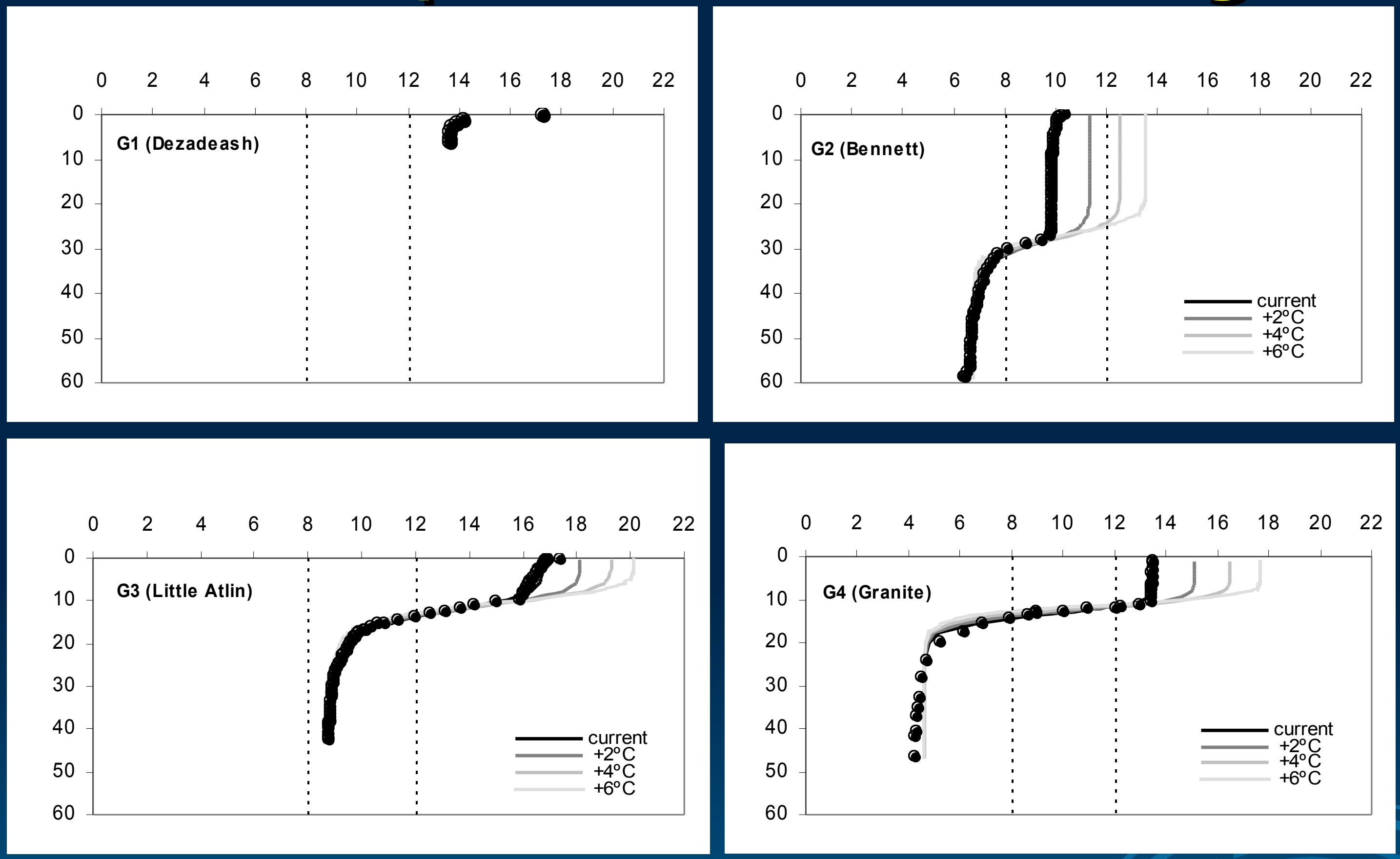
- Temp (Z) = Tmax – Tgrade*Z
- Tgrade C/m = 0.929 -0.114*Ln(Area) +0.056*Ln(Zmax) +0.037*MSAT +0.038*Tmax +0.055*MSPRECIP
- R2 = 0.471
- As climate warms both the surface temperature and the temperature gradient with depth increases

Vertical Temperature Profile Model



- For stratified lakes:
- $T(Z) = Tmin+(Tmax-Tmin)*Ztherm^{C}/(Ztherm^{C}+Z^{C})$
- Where Ztherm is the thermocline depth and C a steepness parameter
- Used by Mackenzie-Grieve/Post CJFAS 63:788-797 (2006)

Temperature Profiles Change In Response to Warming

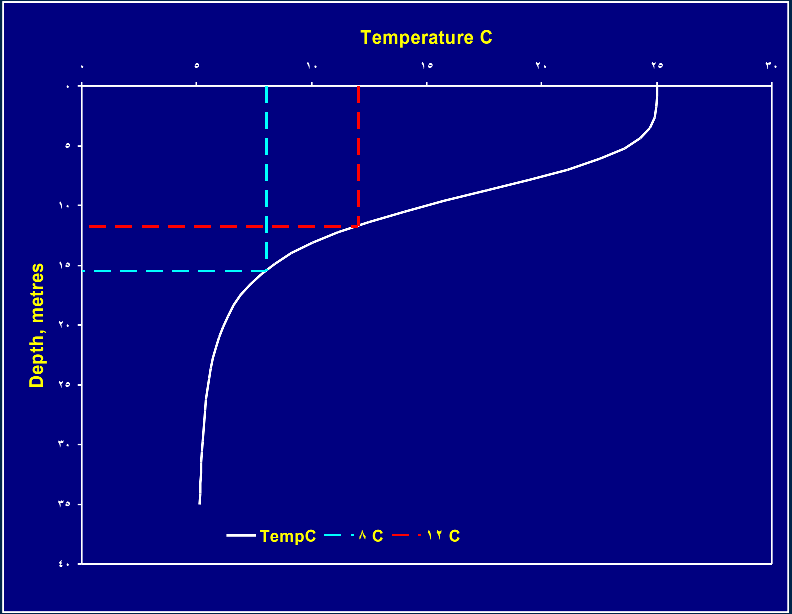


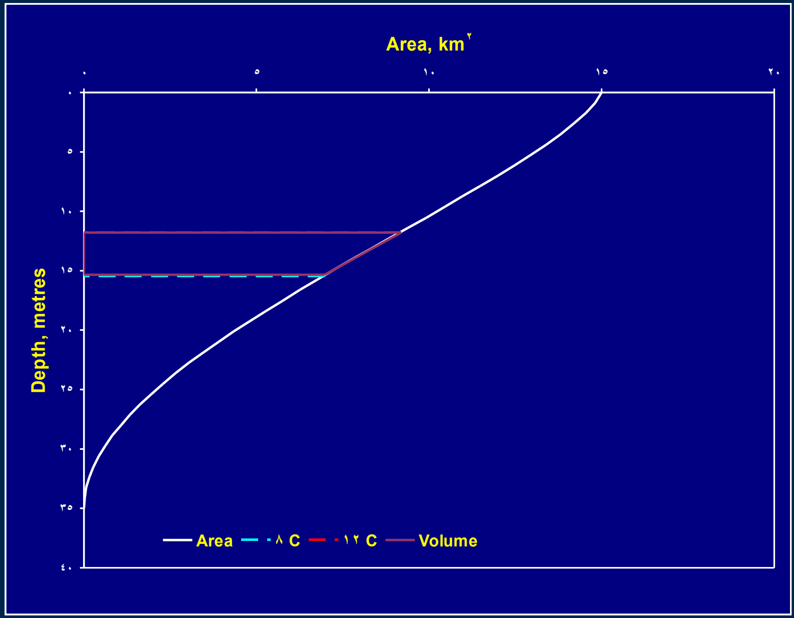
- In selected BC/YK lakes Mackenzie-Grieve and Post identified groups of lakes
- This was generalized via regression models over many lakes

Temperature Profile Coefficients

	Tmin	Ln(Ztherm)	C(Steep)
Ln Area	+ve	+ve	
Ln Zmax	-ve	+ve	-ve
Ln Secchi		+ve	
Ztherm			+ve
Tmax			-ve
MAWind	+ve		
MSAT			+ve
R^2	0.272	0.449	0.141

Thermal Volume Calculation





- Find depths of temperature interval and integrate area over depth to give volume
- If interval thermal suitability (S) is < 1, multiply by S, and
- Sum over all temperature intervals
- Preliminary modelling confined to binary models with S= 0 or 1

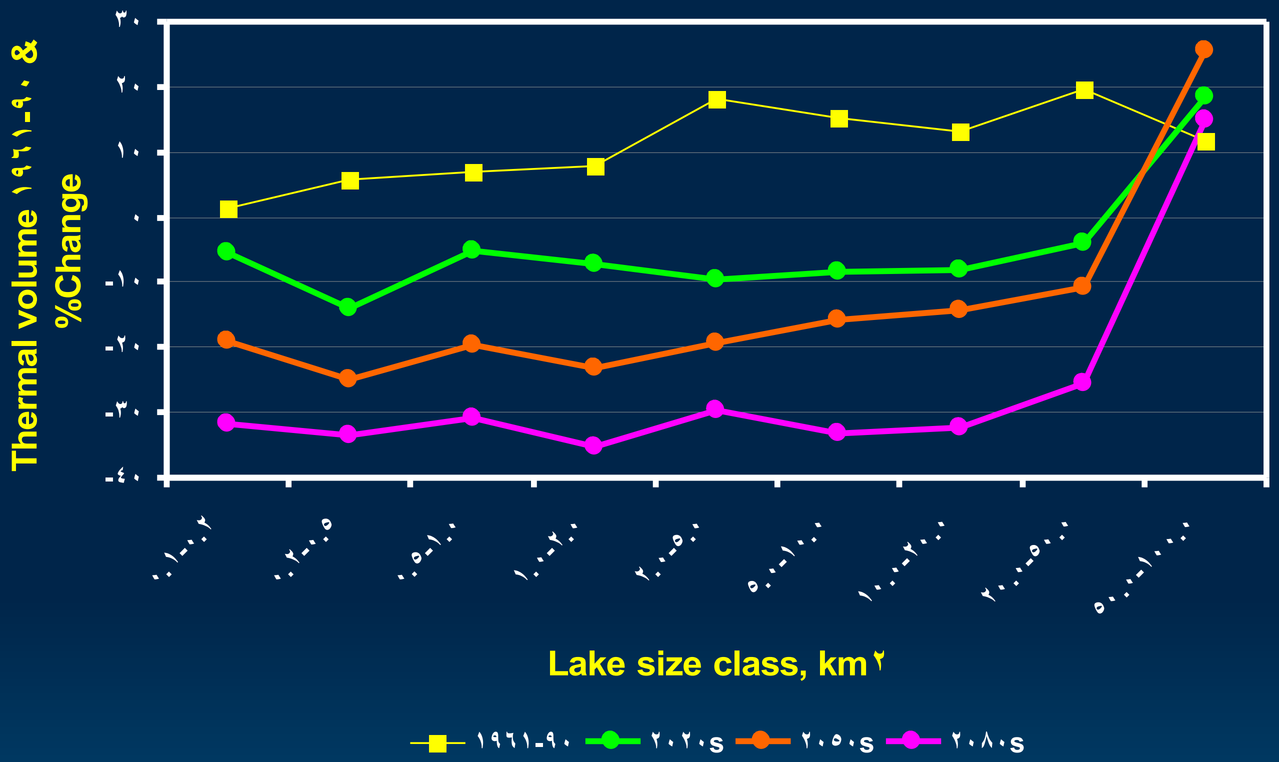
Lake Trout Thermal Ecology

- Lake trout prefer lower temperatures and are usually found below the thermocline in lakes
- Optimal thermal niche is usually defined as 8-12 C with final preferendum at 10 C
- In late summer lake trout faces a thermal habitat bottleneck as the warming of the epilimnion and the steepness of stratification reduces available habitat to a minimum
- CLAM was used to estimate total supply of midsummer thermal habitat across all lake trout lakes

Lake Trout Resources and Climate Change

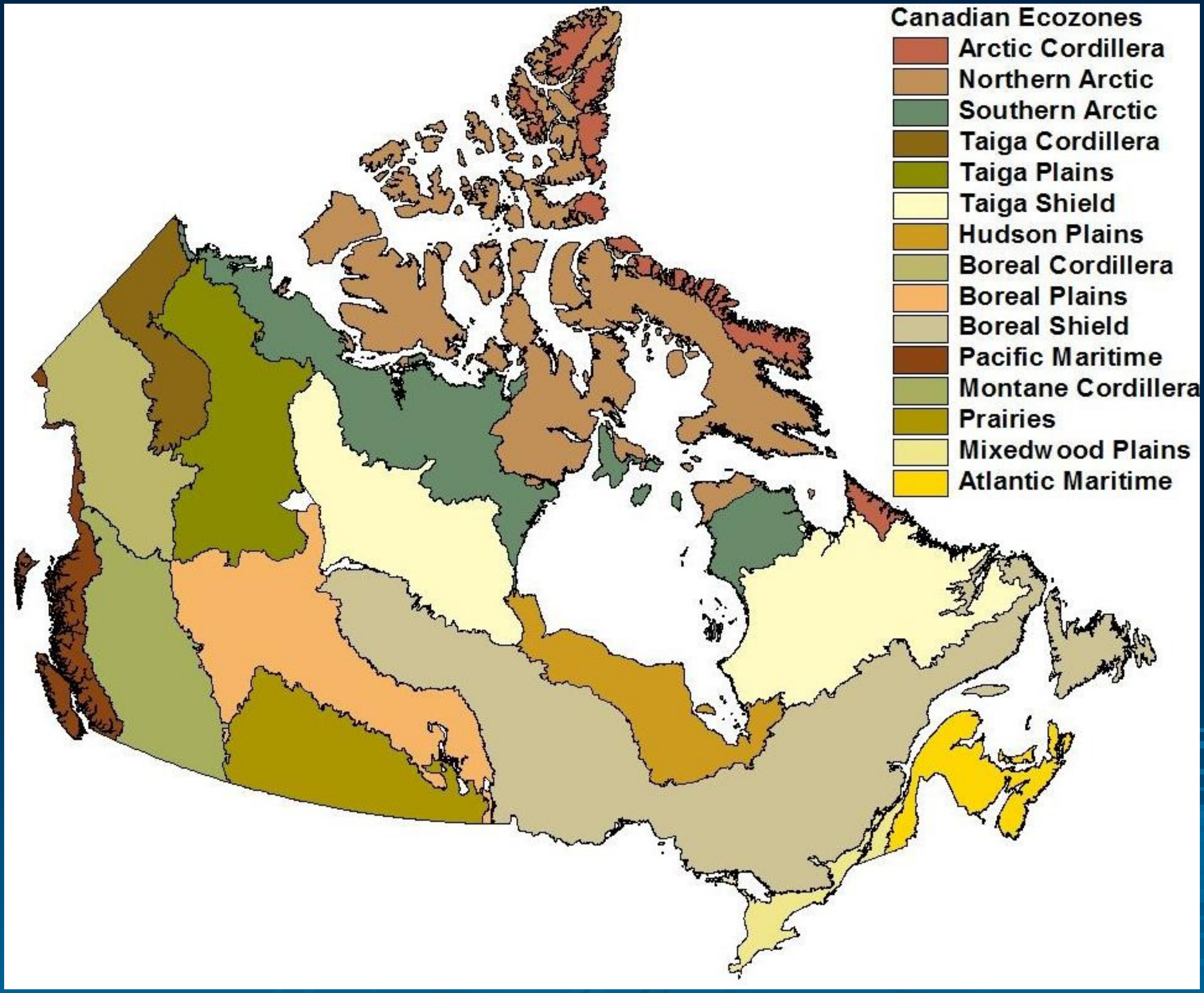
Lake trout	Small	<100>	Large
# lakes	66360		119
Area, km2	82221		269056
Volume, km^3	997.0		21433.1
Thermal volume, km^3			
1961-90	100.0		1563.8
2020s	95.4		1093.1
2050s	88.1		926.6
2080s	74.6		788.1
% Decrease from 61-90			
2020s	-4.6		-30.1
2050s	-11.9		-40.7
2080s	-25.3		-49.6

Thermal Volume in Small Lakes



- Among smaller lakes, thermal volume increases with size
- Most classes show decreases except for 50-100 class

Terrestrial Ecozones



Lake Trout Habitat By Ecozone

	Volume	%Change from 61-90		
Ecozone	1961-90	2020s	2050s	2080s
Boreal Cordillera	11.9	34.8	32.8	-14.5
Boreal Plains	4.7	2.8	19.2	155.5
Boreal Shield	719.5	-25.4	-32.2	-43.9
Mixedwood Plains	95.6	-11.5	-13.7	-22.8
Montane Cordillera	11.2	-9.0	-13.2	-18.7
Northern Arctic	187.6	-15.1	-53.0	-69.5
Southern Arctic	66.8	33.2	36.0	34.7
Taiga Plains	445.0	-60.6	-70.3	-73.0
Taiga Shield	120.3	-7.4	-16.3	-29.7
Total	1663.8	-28.6	-39.0	-48.1

Ecozones with < $1km^3$ not shown

Alternate Habitat (2C Intervals)

	4-6	6-8	8-10	10-12	12-14	14-16
Small Lakes						
1961-90	270.9	105.7	58.3	41.7	68.9	125.0
2020s	271.1	100.8	46.7	48.7	50.7	89.5
2050s	279.0	95.8	43.2	44.9	45.0	65.7
2080s	291.5	87.5	39.7	34.9	46.6	49.0
Large Lakes						
1961-90	16390.3	2910.5	673.6	890.2	1484.0	830.7
2020s	16511.9	2663.5	572.8	520.3	704.8	1703.4
2050s	16569.6	2544.5	527.5	399.1	744.9	763.3
2080s	16686.8	2415.2	435.1	353.0	382.2	812.1

- Lowest thermal volumes 8-10 and 10-12C
- More cooler volume and warmer volume will decrease

Lake Trout's Ecological Trap

- There is evidence of variation in the preferred temperature range but no clear explanation as yet
  - ➔ May be lower in clearer less productive lakes and higher in larger lakes with fewer competitors
- If lake trout move to lower temperatures there is less light, maybe less oxygen, and certainly less access to preferred prey (pelagic fishes like cisco)
  - ➔ Climate change is likely to further decrease light as DOC increases and decrease oxygen as lake productivity rises
- If lake trout move to higher temperatures, they face higher metabolic costs and increased competition for prey with species like walleye and smallmouth bass
  - ➔ Climate change is likely to enhance opportunities for competitors
- Limited scope for lake trout to adapt to climate change

Management Challenges

- Conservation of lake trout resources may require directing fisheries to reduce competitive pressures and certainly will require efforts to reduce invasions by new species like bass
- Important to identify areas where lake trout resources are most likely to be conservable given the combined stresses from humans and climate change

Future Steps With CLAM

- Assess proportional suitability models
- Assess additional species
  - ➔ Walleye, Smallmouth Bass, …
- Add further environmental factors
  - ➔ Light, Oxygen, Nutrients, DOC, …
- Extend to seasonal coverage from ice-out to ice-in
- Assess inter-specific patterns of competition for overlapping habitat space
- Assess production and exploitation effects

Acknowledgements

- Climate Change Action Fund
- Fisheries and Oceans Canada
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