Stratification and salinity changes in Alberta lakes

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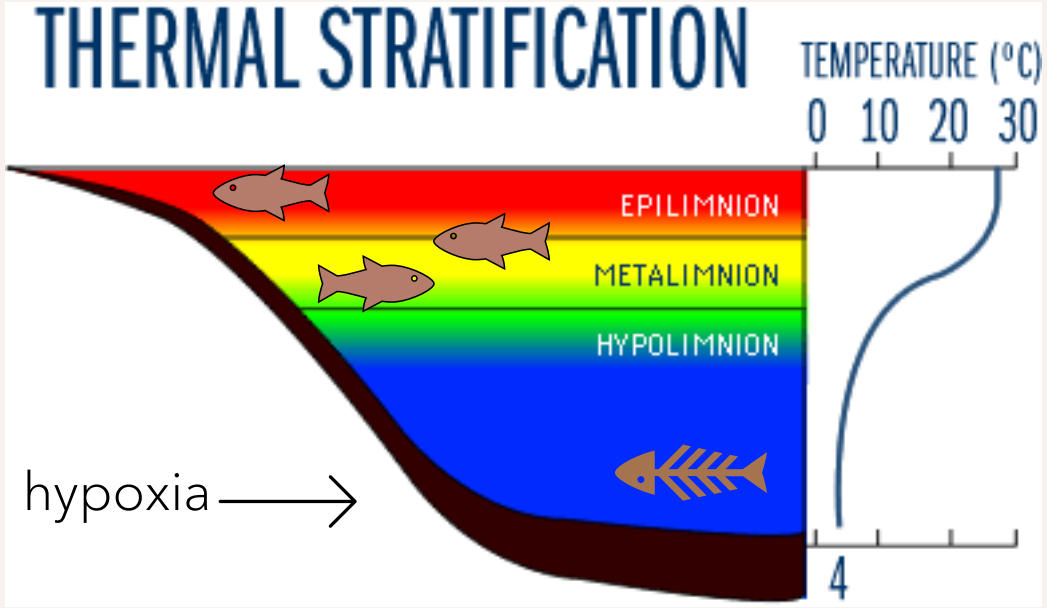
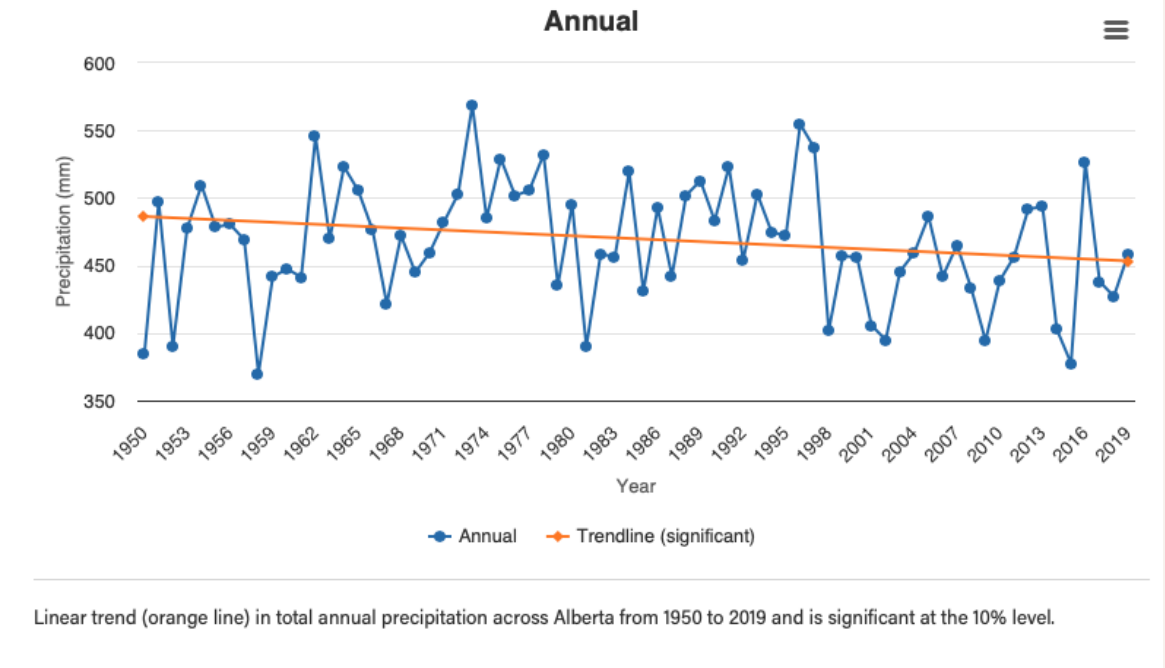
Lake Stratification

- Lakes stratify into distinct layers due to density differences
- Density is a function of
  - Temperature
  - Salinity
- Stratification has implications for oxygen availability



Changing Climate in Alberta

- Alberta is experiencing:
  - Decreased precipitation (↓10%,1950-2019)
  - Increased temperatures (↑1.89°C, 1950-2019)
  - Declining lake levels
- Potential impacts on lakes:
  - Increasing temperatures
  - Increasing salinity
  - Changing stratification patterns

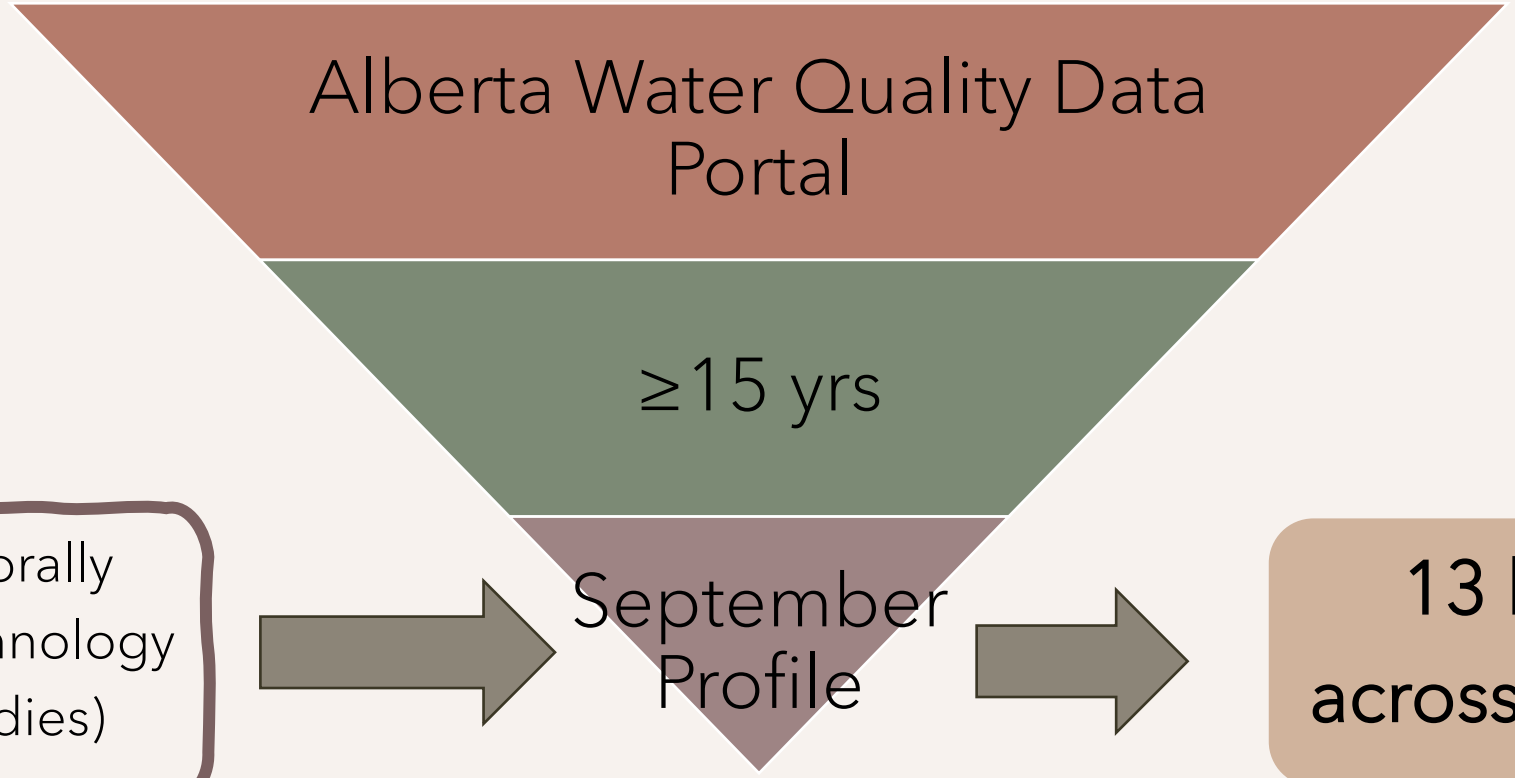


Source: Alberta Ministry of Environment and Protected Areas

Which raises the question…

Have there been long-term changes in the physical structure (temperature, salinity, & stratification regimes) of lakes Alberta?

Methods: Selection Criteria



Autumn is temporally understudied in limnology (only 10% of studies)

13 basins across 10 lakes

Methods: Study Sites

Deep (>20m)

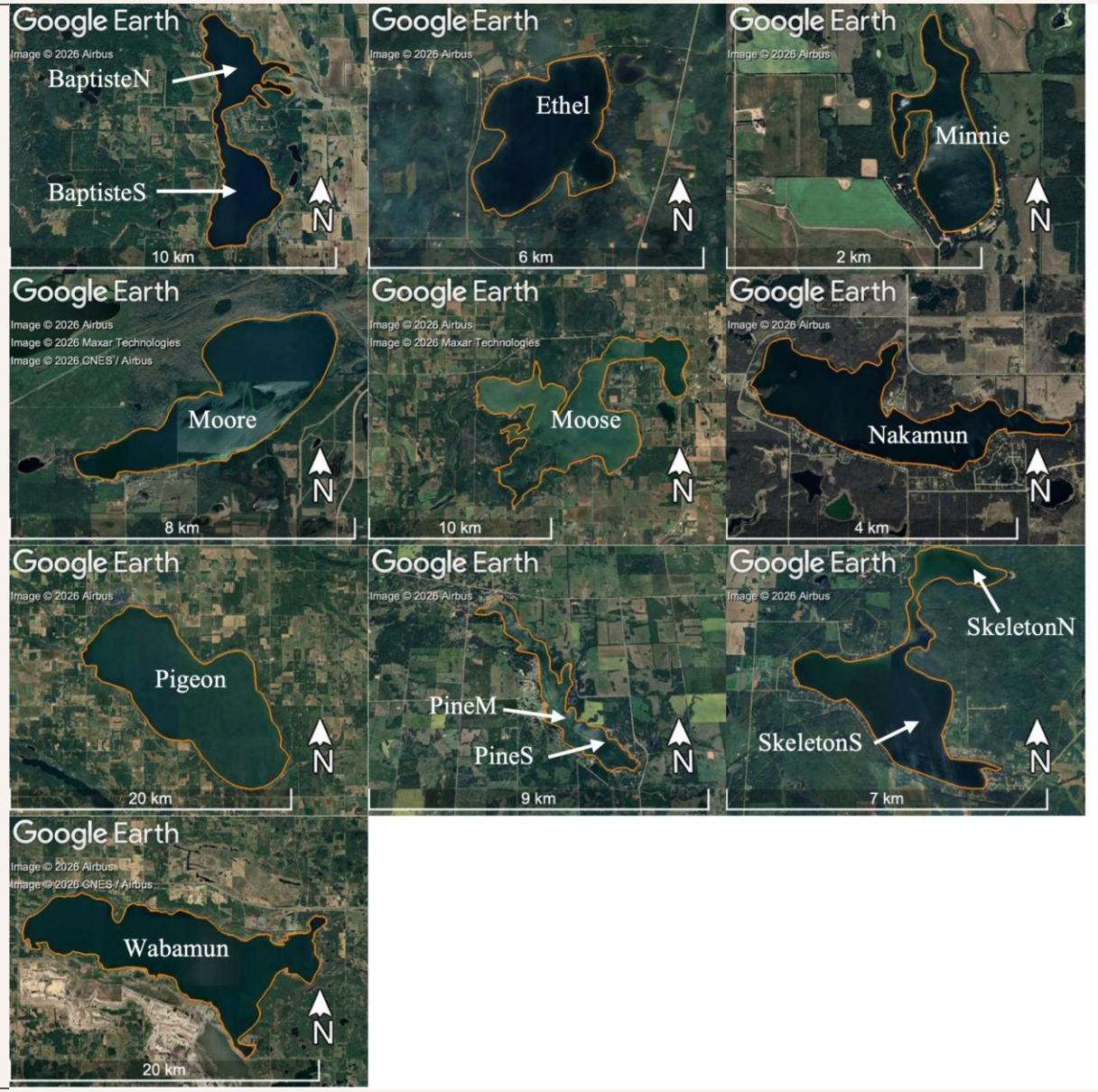
- Ethel
- Minnie
- Moore
- BaptisteS

Mid (13-20m)

- BaptisteN
- Moose
- SkeletonN

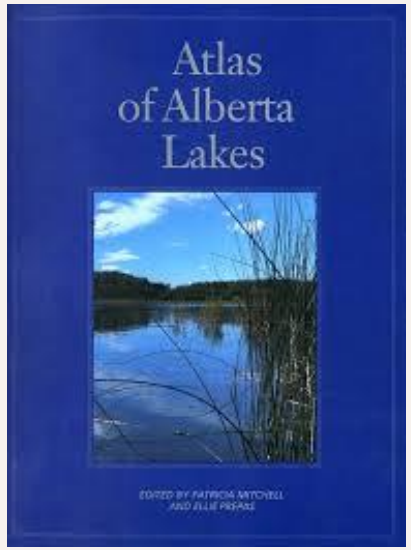
Shallow (<13m)

- SkeletonS
- Pigeon
- Nakamun
- PineM
- PineS
- Wabamun



Methods: Additional Data

- Water chemistry from the Atlas of Alberta Lakes and government reports
  - Major ions and related SC
  - Morphometry
    - Maximum depth (z_{max})
    - Mean depth (z_{mean})
    - Catchment drainage area
    - Drainage ratio = $\frac{Drainage\ Area}{Surface\ Area}$
    - Surface area (SA)
    - Relative depth (z_r) = $f(z_{max}, SA)$



Methods: Profile Data & Calculations

- Water profile data:
  - Temperature (T)
  - SC
  - Dissolved oxygen (DO)
- Calculations:
  - Density (ρ)
  - Buoyancy frequency (*N*)
  - Relative contribution of salinity compared to temperature in the density structure (fS)
- Analysis: Mann-Kendall tests, Sen's slope, Wilcoxon rank sum tests

$$\Delta\rho_{st} = \rho_o - \rho_{st}$$

$$\Delta\rho_t = \rho_o - \rho_t$$

$$\Delta\rho_s = \rho_t - \rho_{st}$$

$$fS = \frac{|\Delta\rho_s|}{|\Delta\rho_s| + |\Delta\rho_t|}$$

ρ_o: density of freshwater @ 4°C

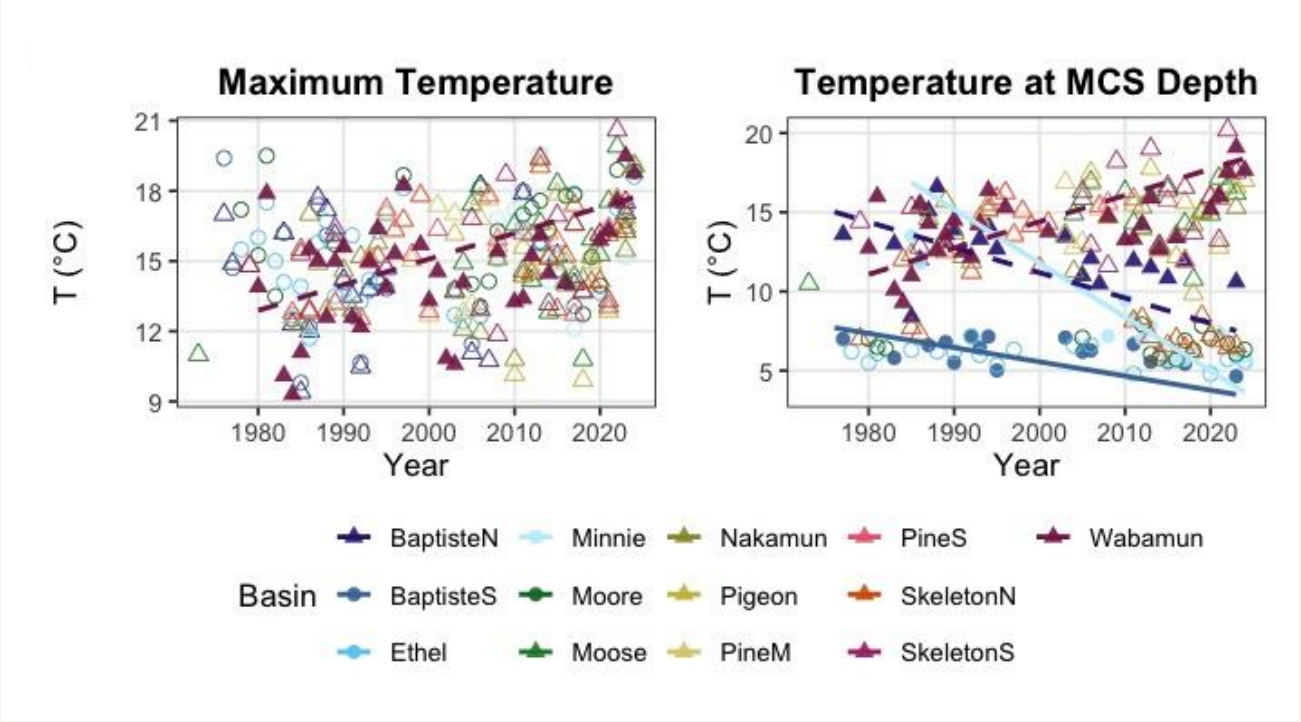
ρ_{st}: density from T and salinity

ρ_t: density from T alone

ρ_s: density from salinity alone

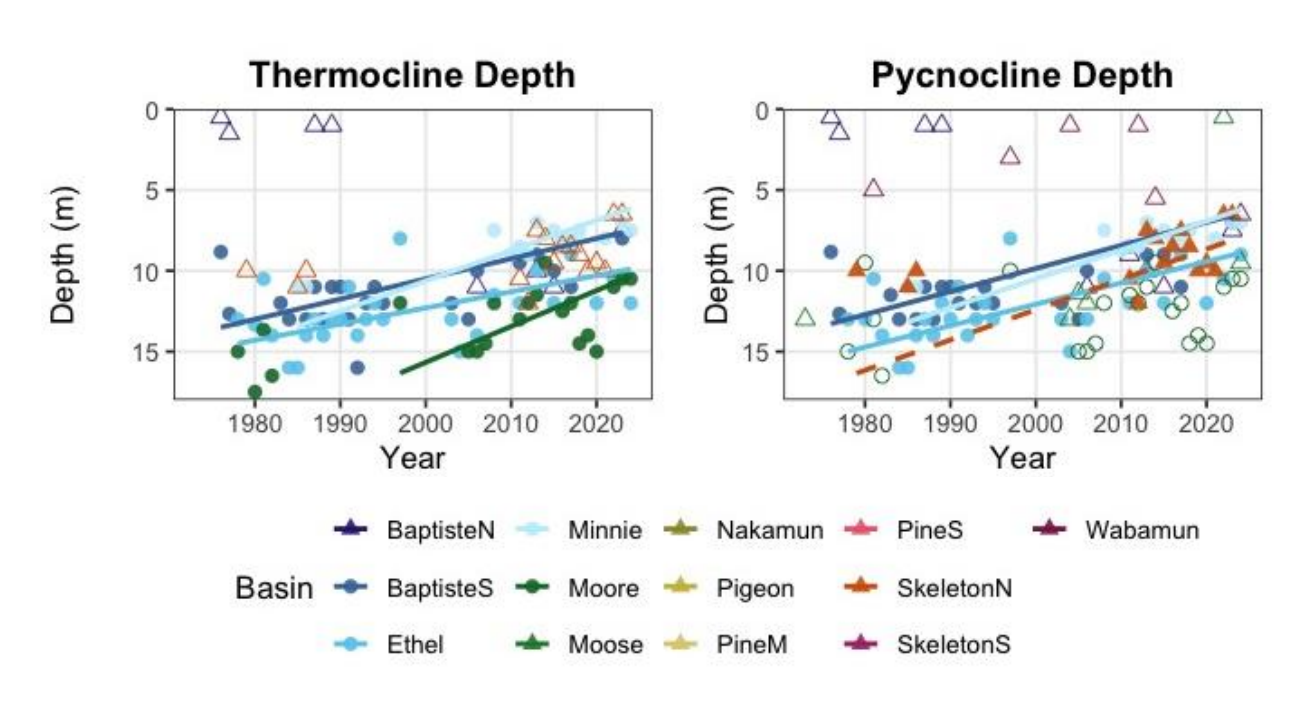
Results: Thermal Trends

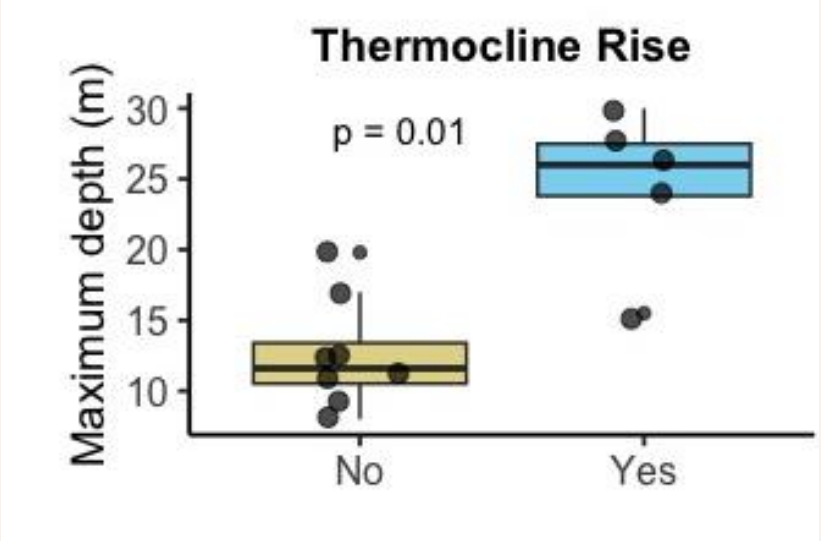
- No change in:
  - Maximum T
  - Average water column T
- T at MCS decreased in 3 out of 4 of the deep basins
  - from -0.9 to -3.4°C per decade



Results: Thermal Trends

- Thermocline depth rose in the deep basins by 1 – 2.22 m per decade



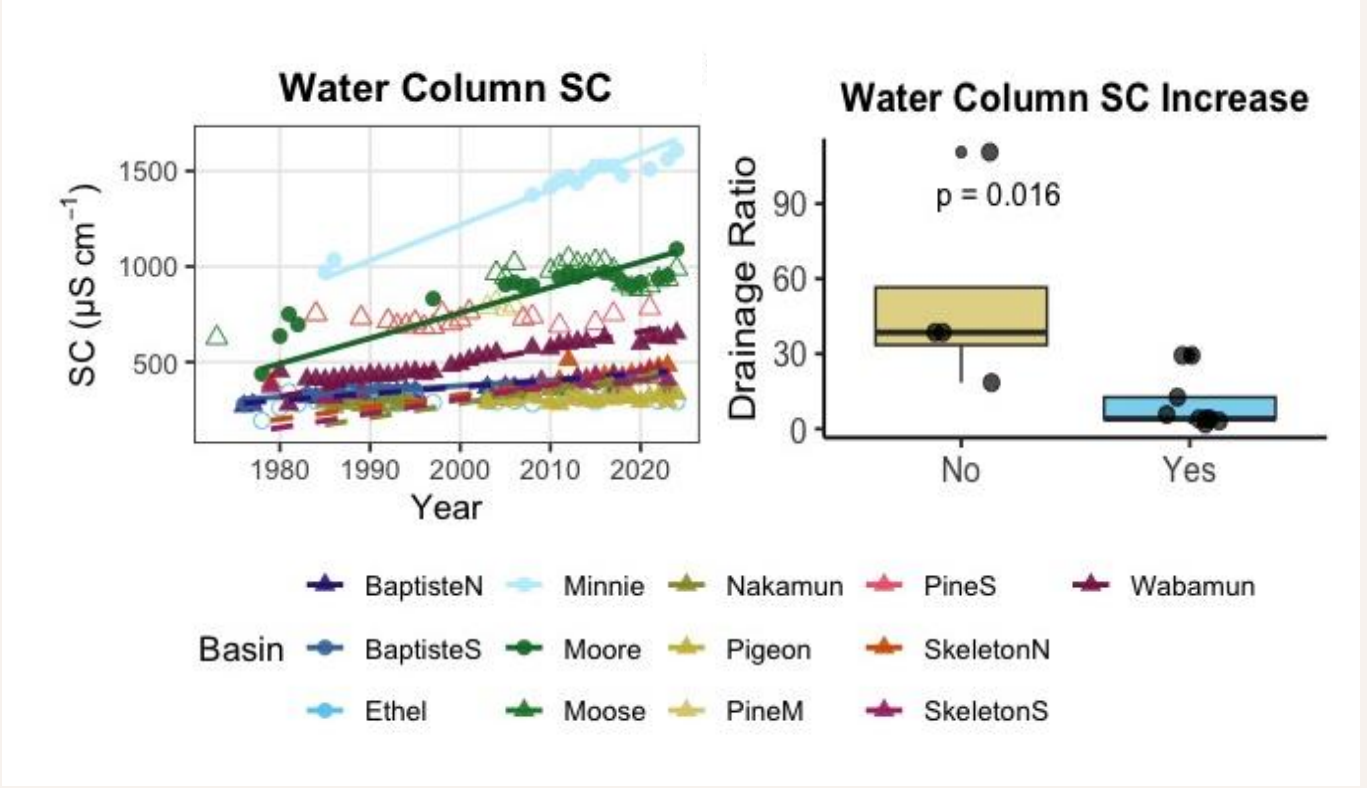


Significant change in deep basin

Significant change in mid/shallow basin

Results: Salinity (SC) Trends

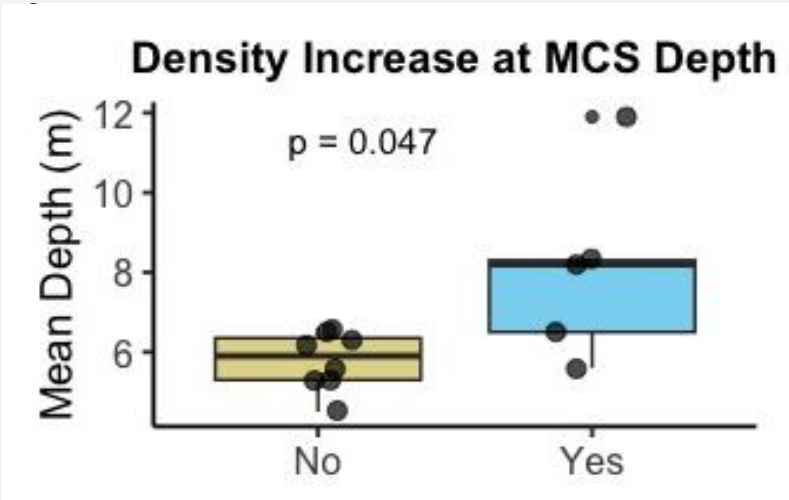
- Water column SC increased all basins except Ethel, Moose, PineM, and PineS
- Surface SC increased in ~60% of the basins
  - Surface and WC SC increases occurred at similar rates, at 2.1 – 18.67 µS cm^{-1} yr^{-1}

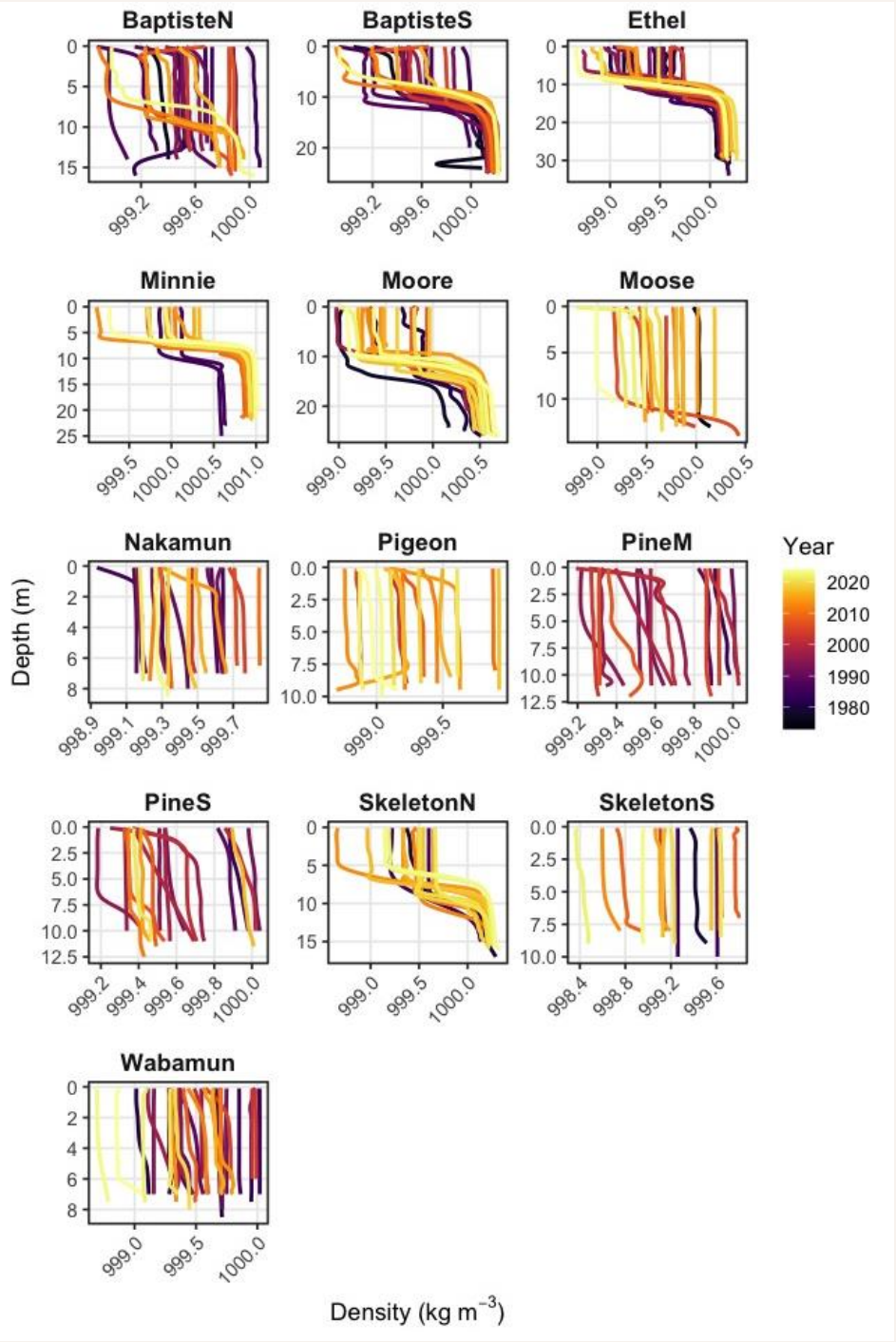


Significant change in deep basin Significant change in mid/shallow basin

Results: Density Trends

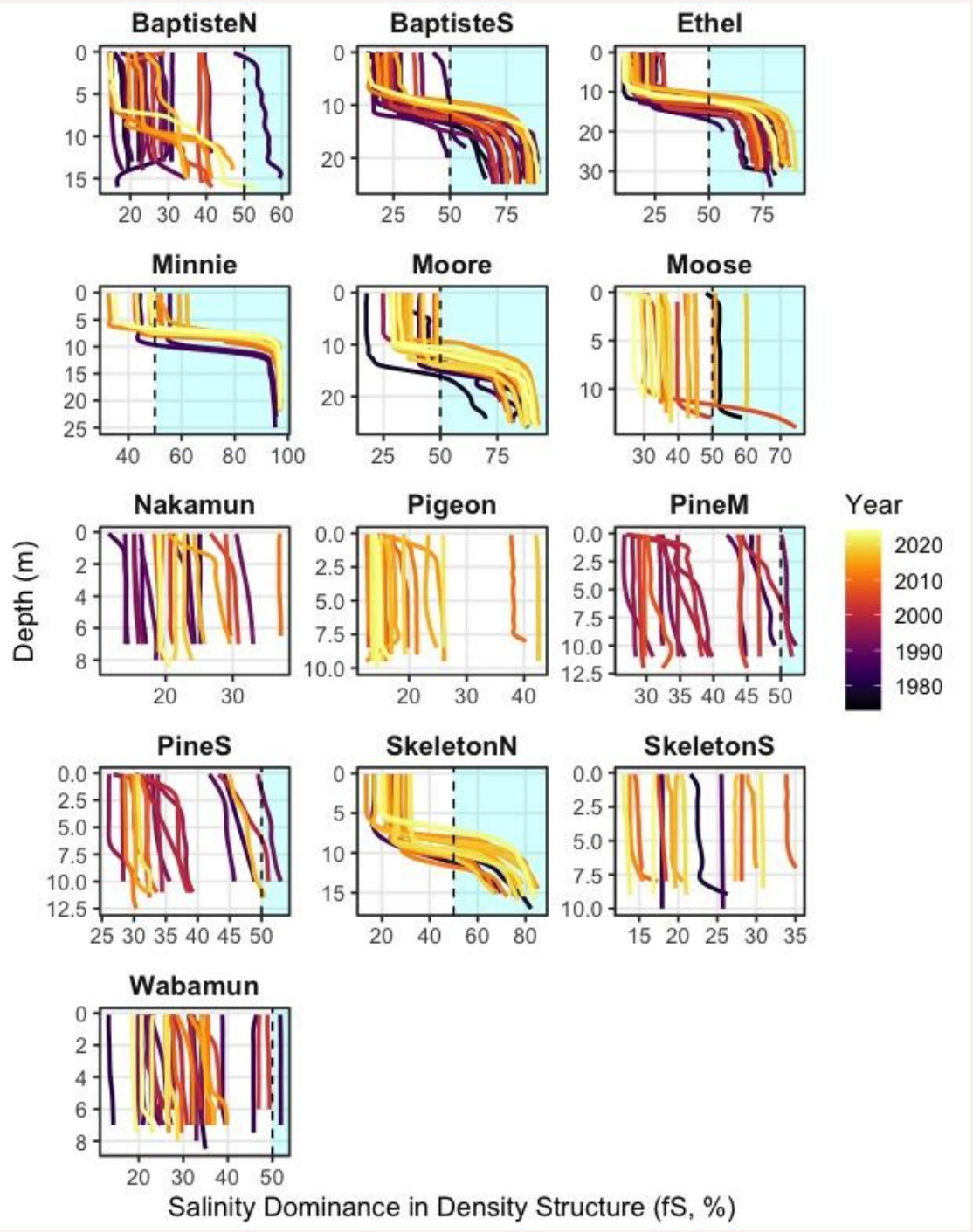
- Stratification was consistently present in the 4 deep basins & SkeletonN
- MCS density increased in most deep and mid-depth basins (from 0.05 to 0.28 kg m^{-3} per decade)





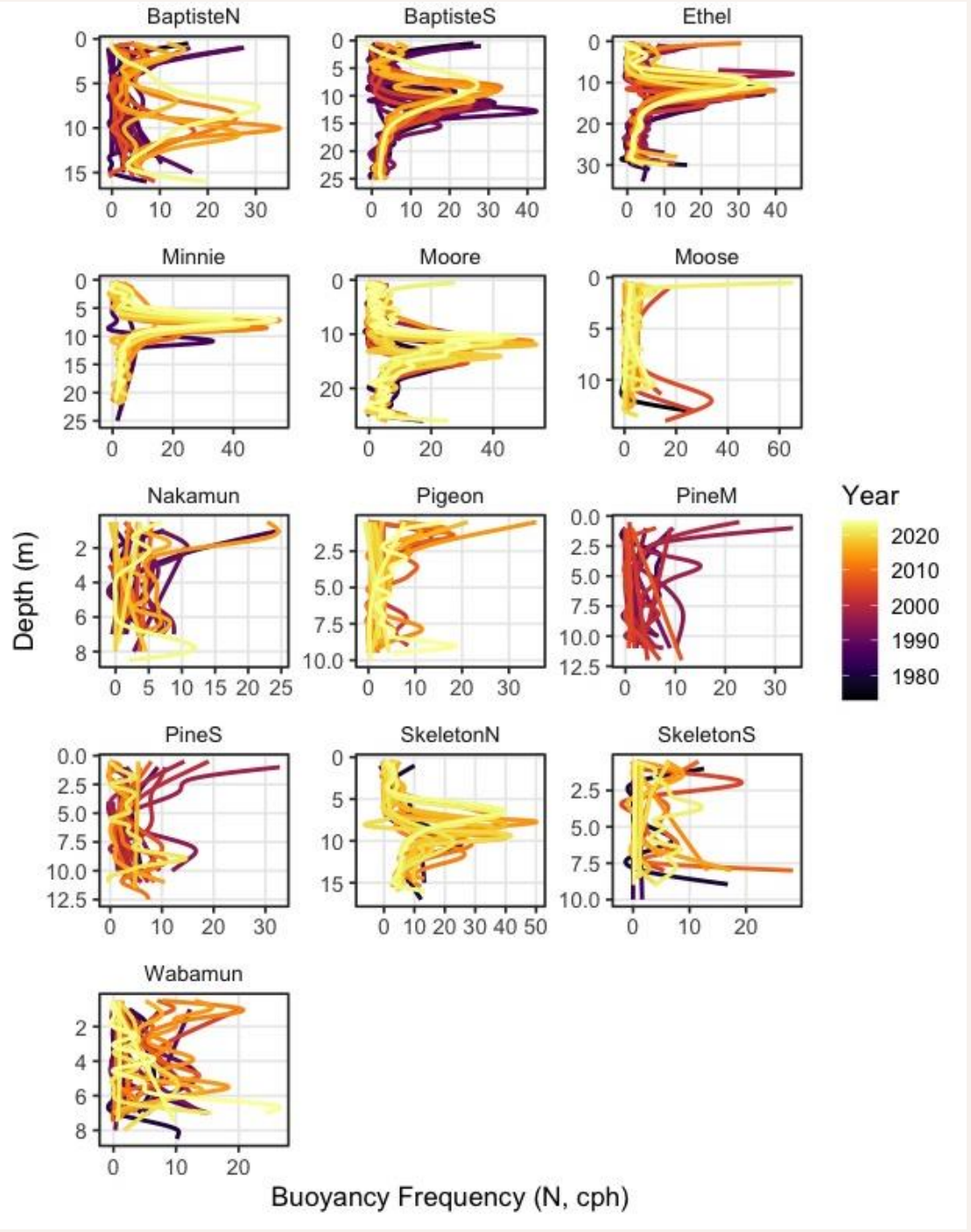
Results: Density Trends

- In salt-dominated lakes (except Minnie), depth of fS = 50% rose upward at rates of 0.7 to 1.7 m per decade



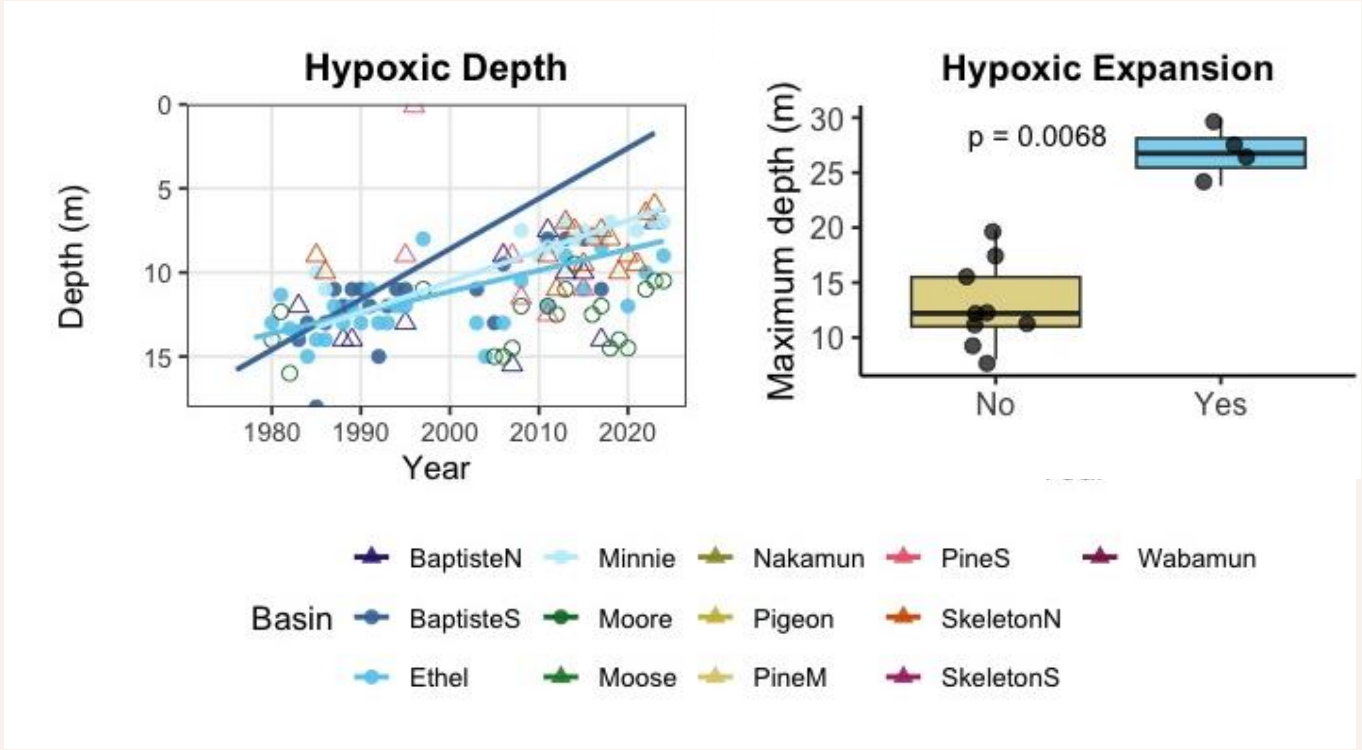
Results: Density Trends

- Strength of buoyancy frequency did not change, but depth of max *N* rose in all deep basins & SkeletonN



Results: Oxygen Trends

- Hypoxic zone has expanded in deep basins
- Vertical extent of oxygenated water column lost since 1980s:
  - BaptisteS = 48%
  - Ethel = 24%
  - Minnie = 22%
  - Moore = 20%



Significant change in deep basin

Significant change in mid/shallow basin

Changing Lake Structures in Autumn in Alberta

- Surface temperatures haven't changed, but stratification structure has shifted in stratified lakes
  - Rising thermoclines
  - Cooling bottom waters
- Many lakes in Alberta are undergoing salinization
  - In stratified lakes, salinity is dominating the density structure in greater proportions of the water column
- Hypoxic zones are expanding in stratified lakes

→ implications for fish habitat & winter O_2 availability