Climate Change, Water Resources, Fish and Fisheries: Driving Environmental Factors and Shifting Baselines

What to expect, how to adapt

Resiliency and Adaptation

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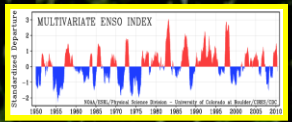


October 2012

Fish as Indicators

Fish and fisheries have been important indicators of the aquatic ecosystems of the Great Lakes Basin

Fish and fish communities have led the way in revealing many things and have signalled:

- **Habitat changes and loss**
- **Eutrophication and changes in water quality**
- **Aquatic contamination**
- **Aquatic acidification**
- **And now, changing climatic conditions**

Let's examine climate change, shifting baselines, and fish and fisheries

Background

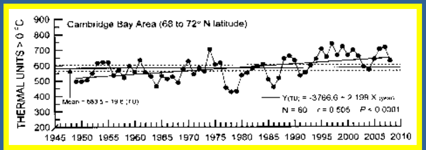
- Changing climate is already affecting aquatic resources, fish, and fisheries; environmental conditions are changing and becoming more variable, creating different conditions and shifting baselines

- Fish and fisheries can be very sensitive to these environment influences, which can create relatively obscure and somewhat insidious changes

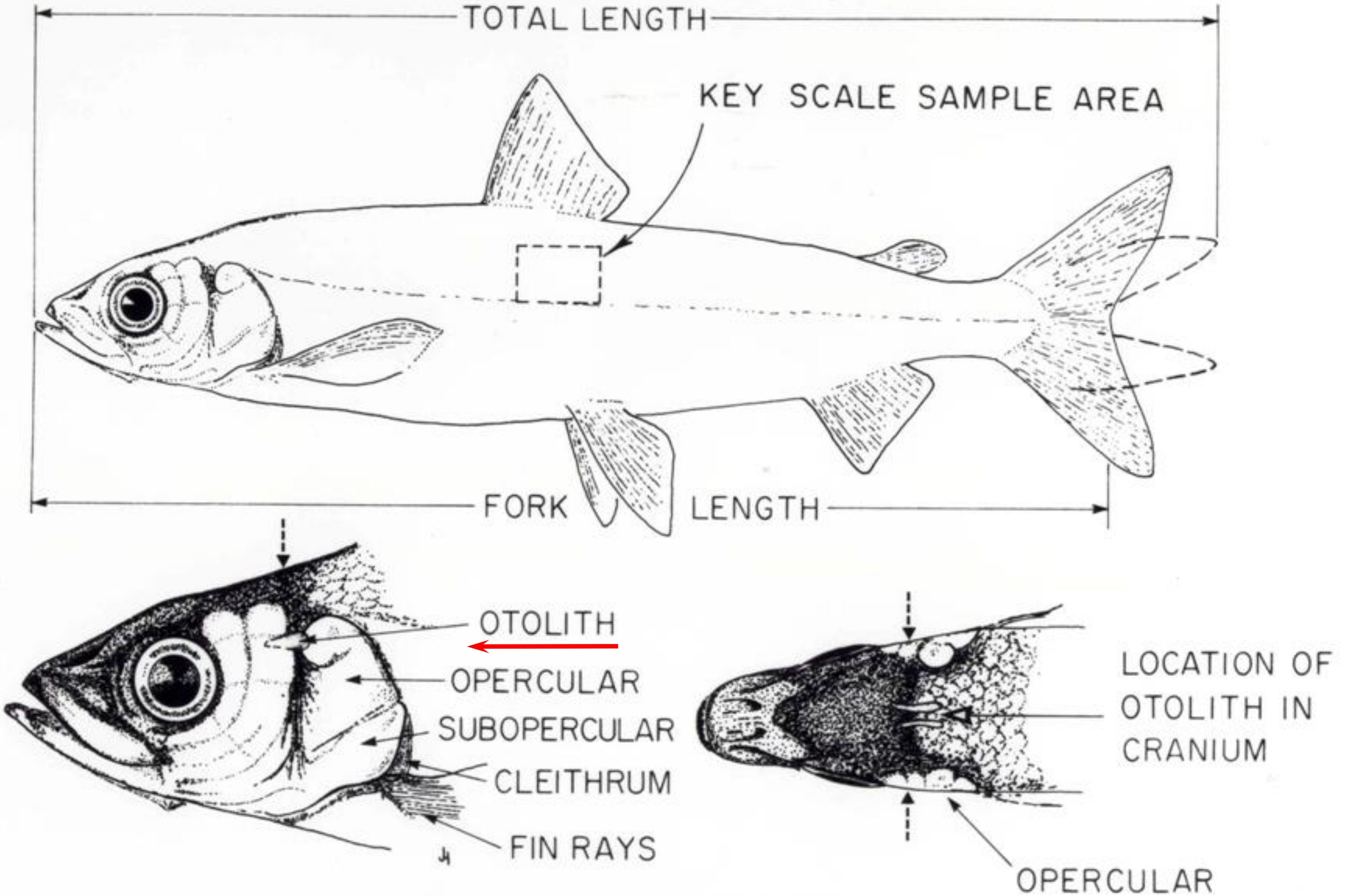
- Are we assessing these changes and managing for them? Will we adapt? Will climate change create a new and "unexpected" crisis? *It shouldn't*

Climate Effects on Fish and Fisheries Are Global in Scope

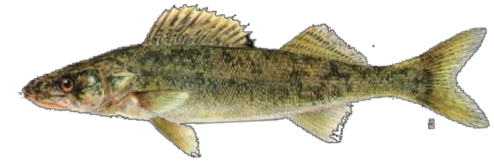
Calcified structures in fish confirm global influences across broad geographic areas

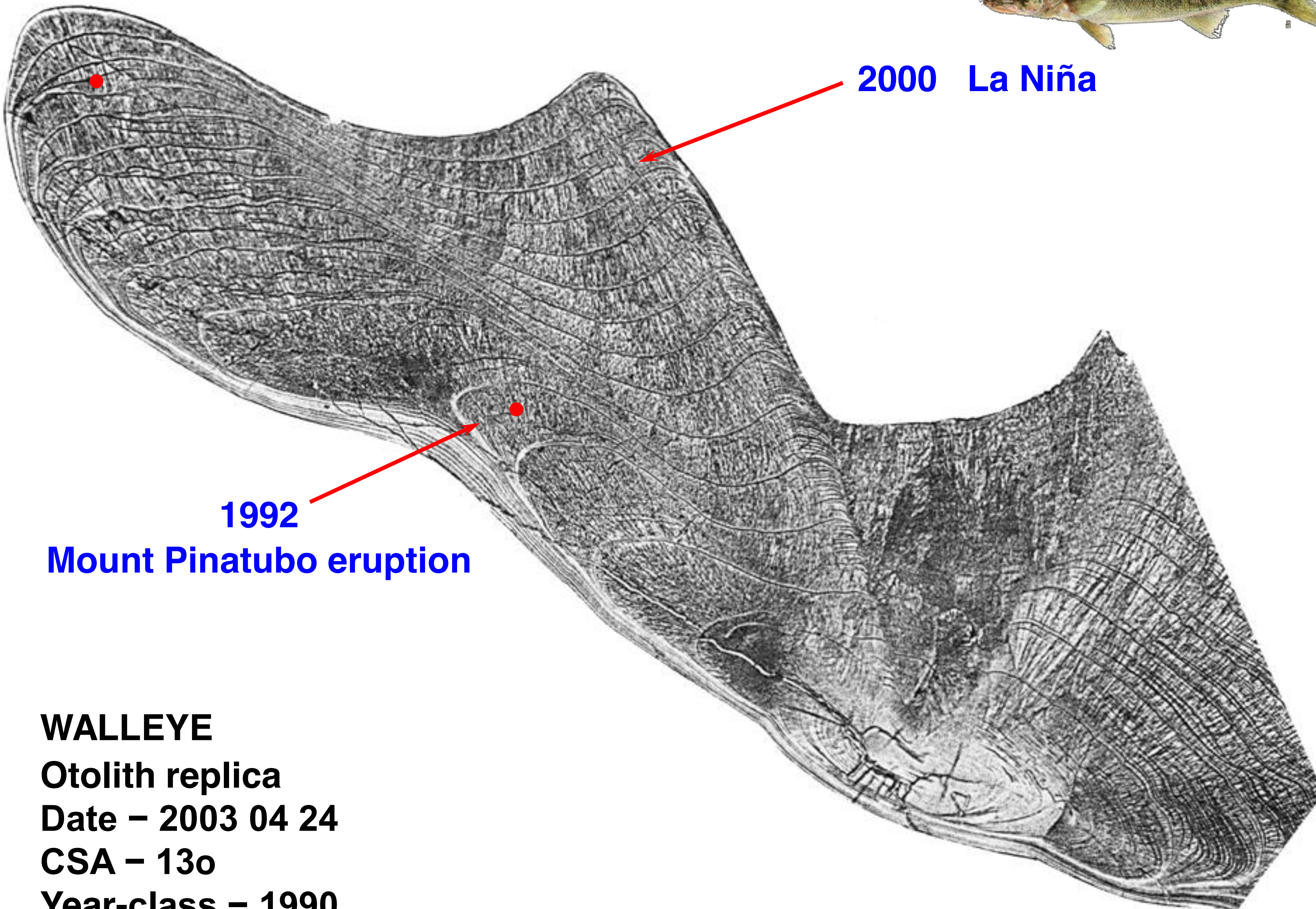


Calcified Structures of Fish



LAKE HERRING *Coregonus artedii Lesueur*

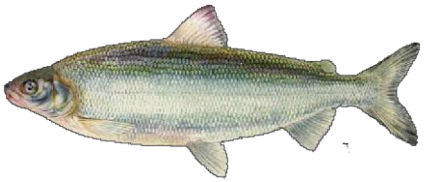


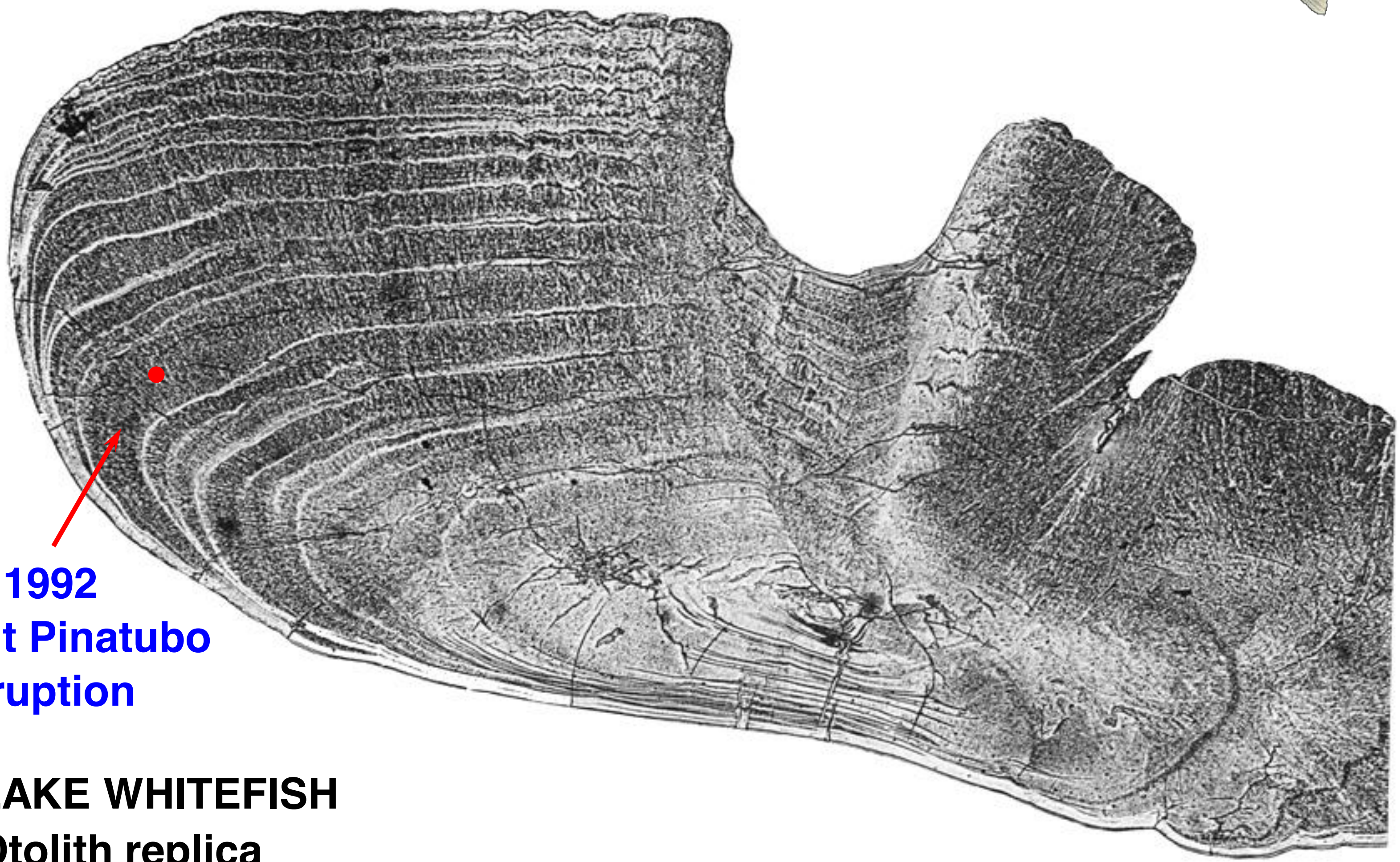


WALLEYE
Otolith replica
Date – 2003 04 24
CSA – 13o
Year-class – 1990
Lake Ontario

Image from Otolith Section

A



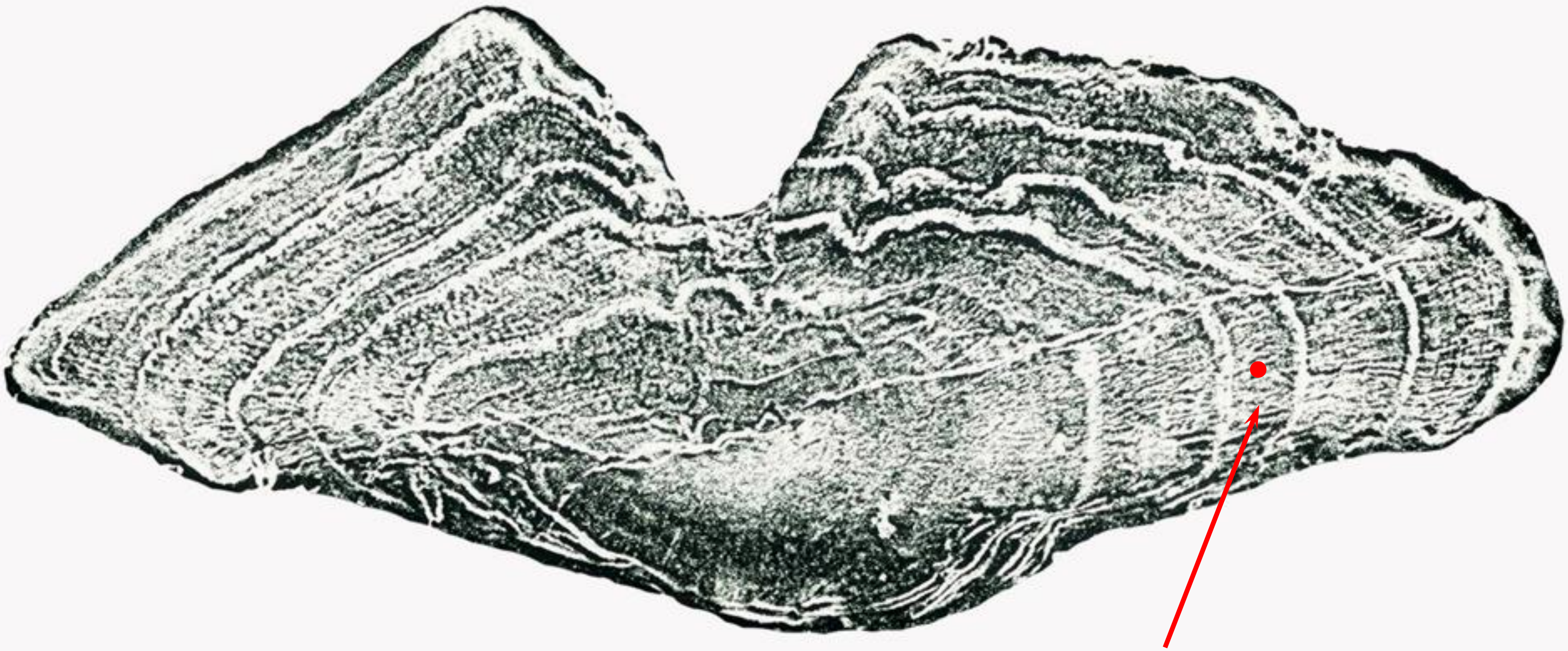


LAKE WHITEFISH
Otolith replica
Date – 2002 10 17
CSA – 15o
Year-class – 1988
Lake Ontario

Image from Otolith Section

B

LAKE TROUT
Otolith replica
Raglan Lake
Arctic Quebec



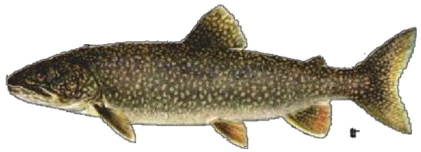
1992
Mount Pinatubo eruption

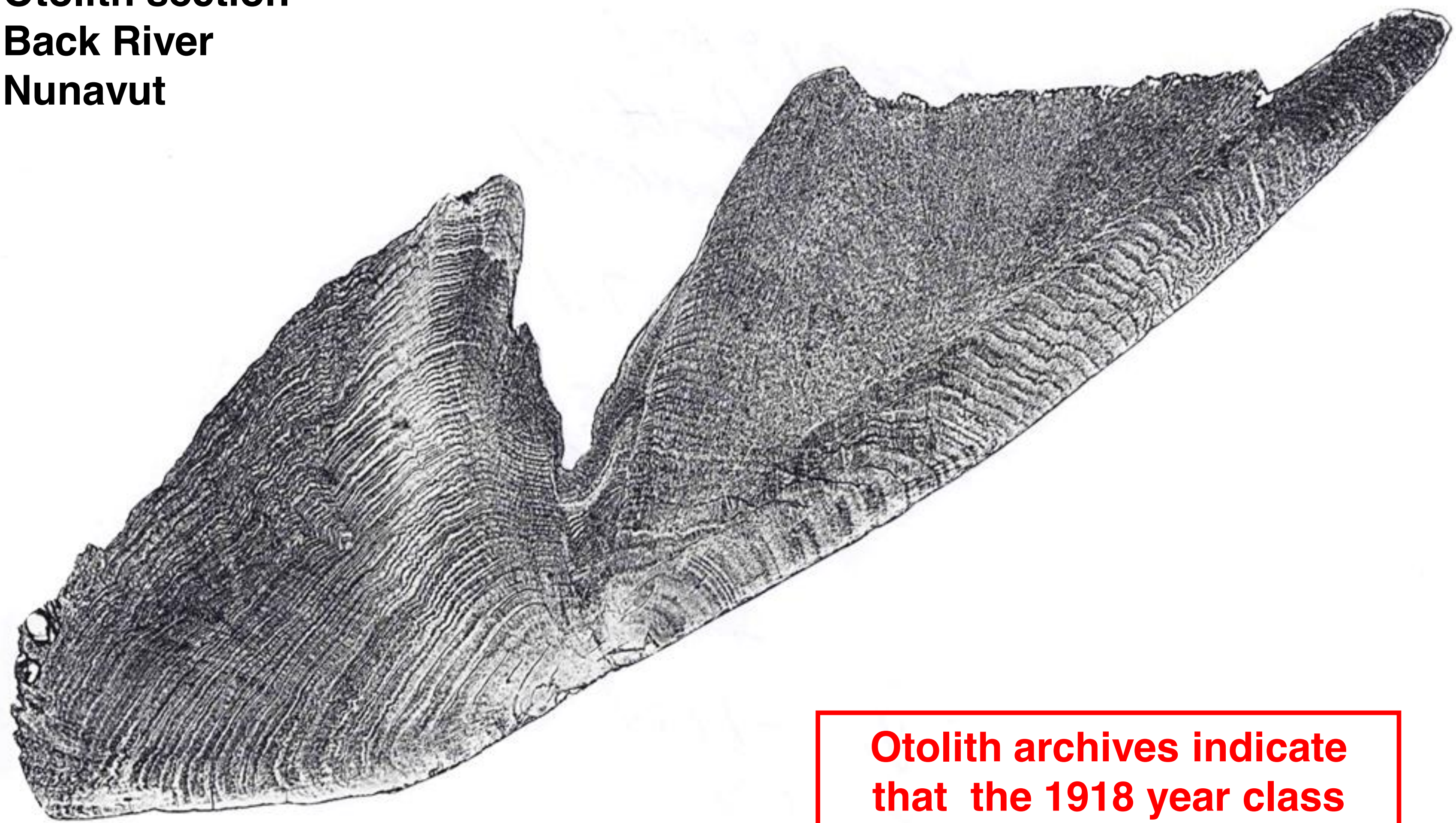
Date – 1995 07 24
CSA – 5+
Year-class – 1990

Image from Otolith Section

C

LAKE TROUT
Otolith section
Back River
Nunavut





Otolith archives indicate that the 1918 year class was universally strong across the Canadian Arctic

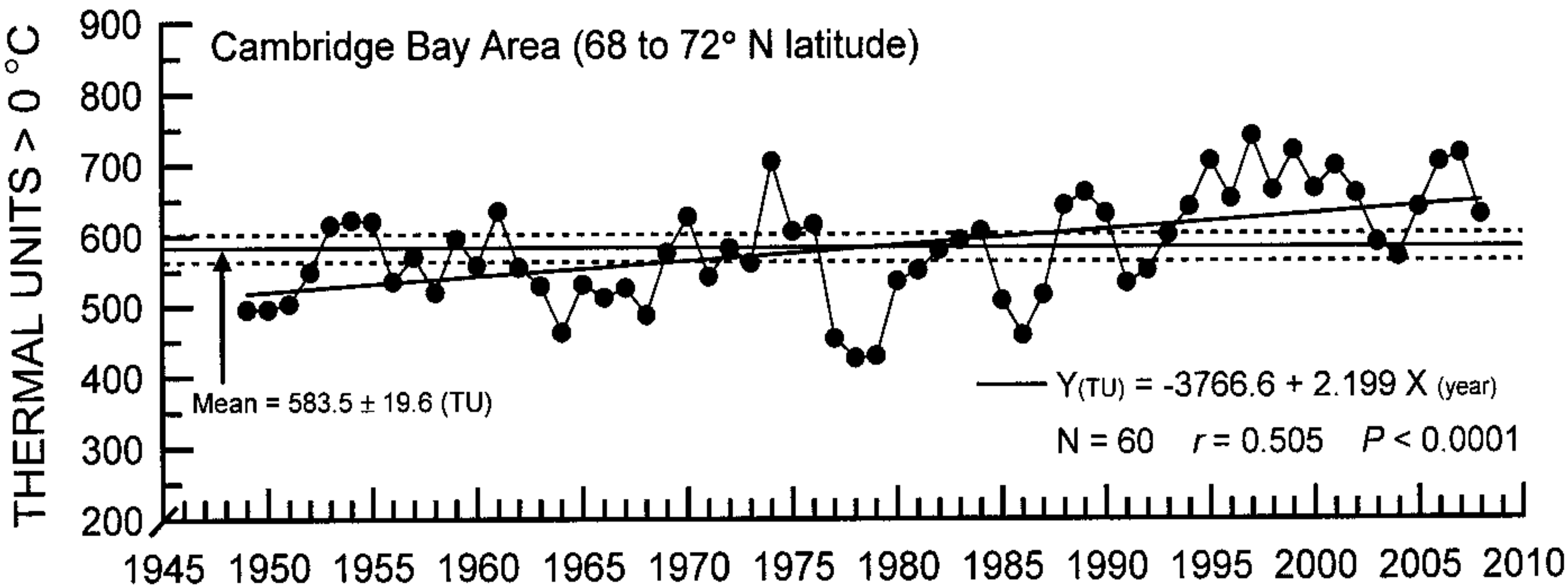
Date – 1990 07 24
CSA – 72+
Year-class – 1918

Image from Otolith Section

D

CLIMATE CHANGE IN THE CANADIAN ARCTIC

Accumulated thermal units (degree days >0), frost-free period



The average annual increase in thermal units for the period was 134 degree days, or 26%

Objectives

1. Examine changing environmental conditions and baselines in eastern Ontario water bodies, considering trends and variability

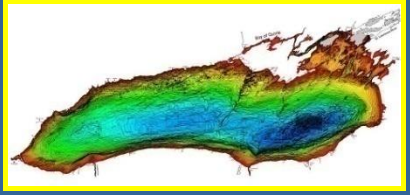
2. Examine responses of freshwater fish and fish communities using long-term data; examine effects and change and also consider predictability and adaptation

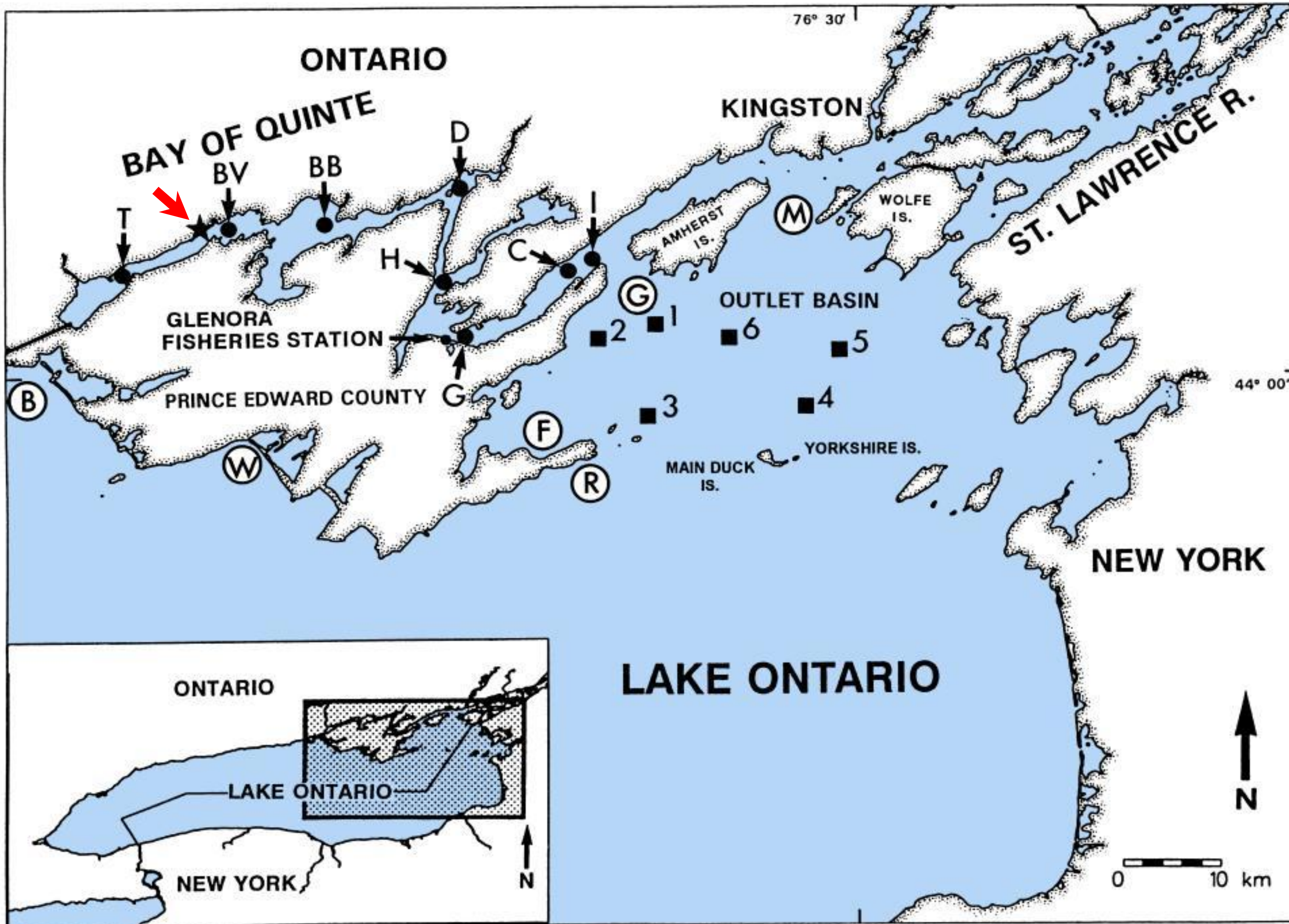
3. Consider how we might manage and adapt to help sustain fish resources and human endeavours in a changing and more variable climate

Change is underway – are we detecting and managing for it ?

Long-Term Sampling

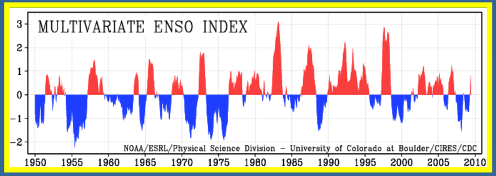
Provides valuable quantitative indices for assessing environmental conditions and fish populations and communities




76° 30′
ONTARIO
BAY OF QUINTE
KINGSTON
ST. LAWRENCE R.
T
BV
BB
D
I
H
C
AMHERST IS.
WOLFE IS.
M
G
OUTLET BASIN
1
2
6
5
GLENORA FISHERIES STATION
G
B
PRINCE EDWARD COUNTY
44° 00′
3
4
F
W
R
MAIN DUCK IS.
YORKSHIRE IS.
NEW YORK
LAKE ONTARIO
ONTARIO
LAKE ONTARIO
NEW YORK
N
N
0
10 km

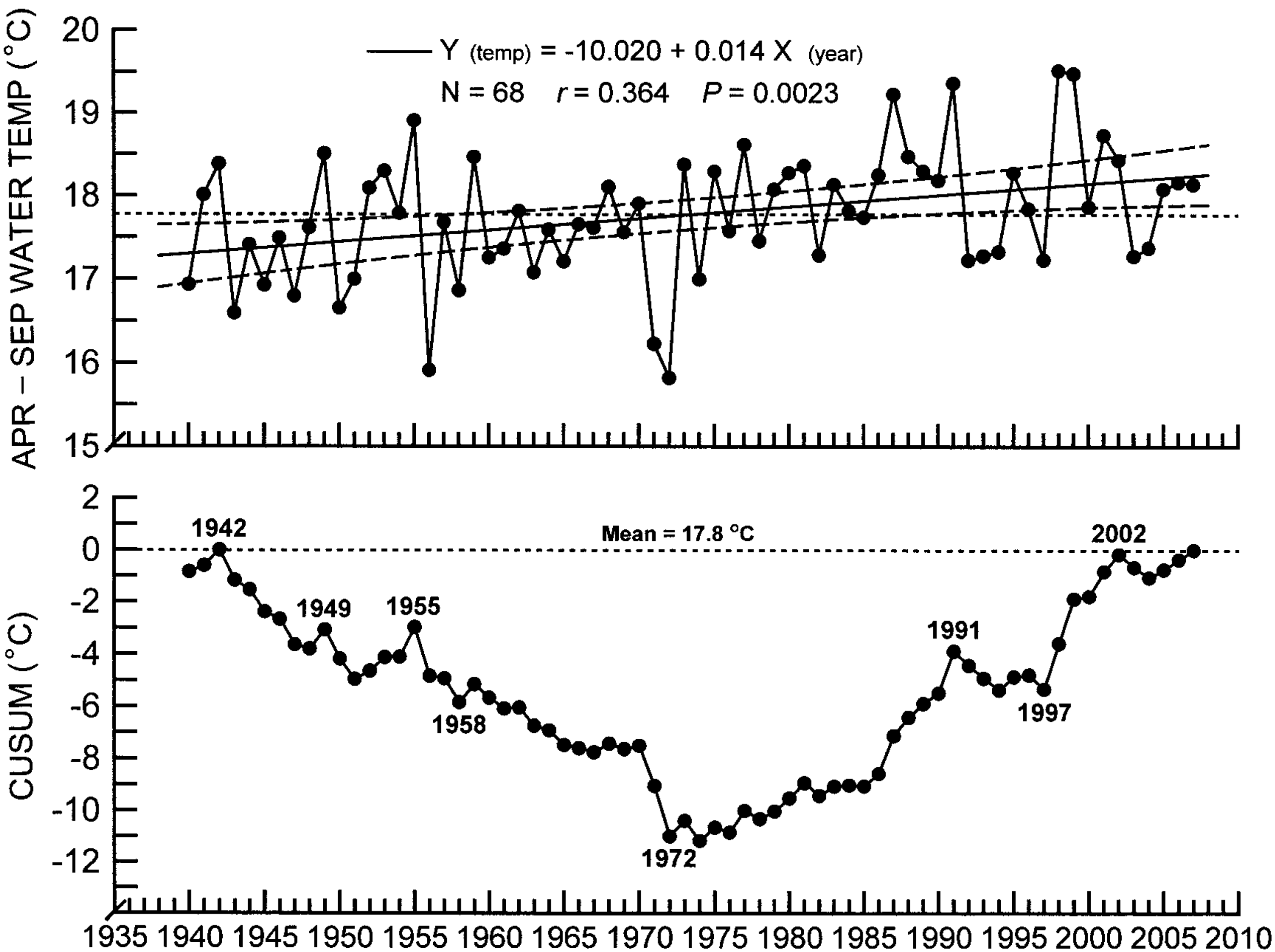
Global Warming, Changing Thermal Conditions, and Shifting Baselines

Bay of Quinte and nearshore waters of Lake Ontario



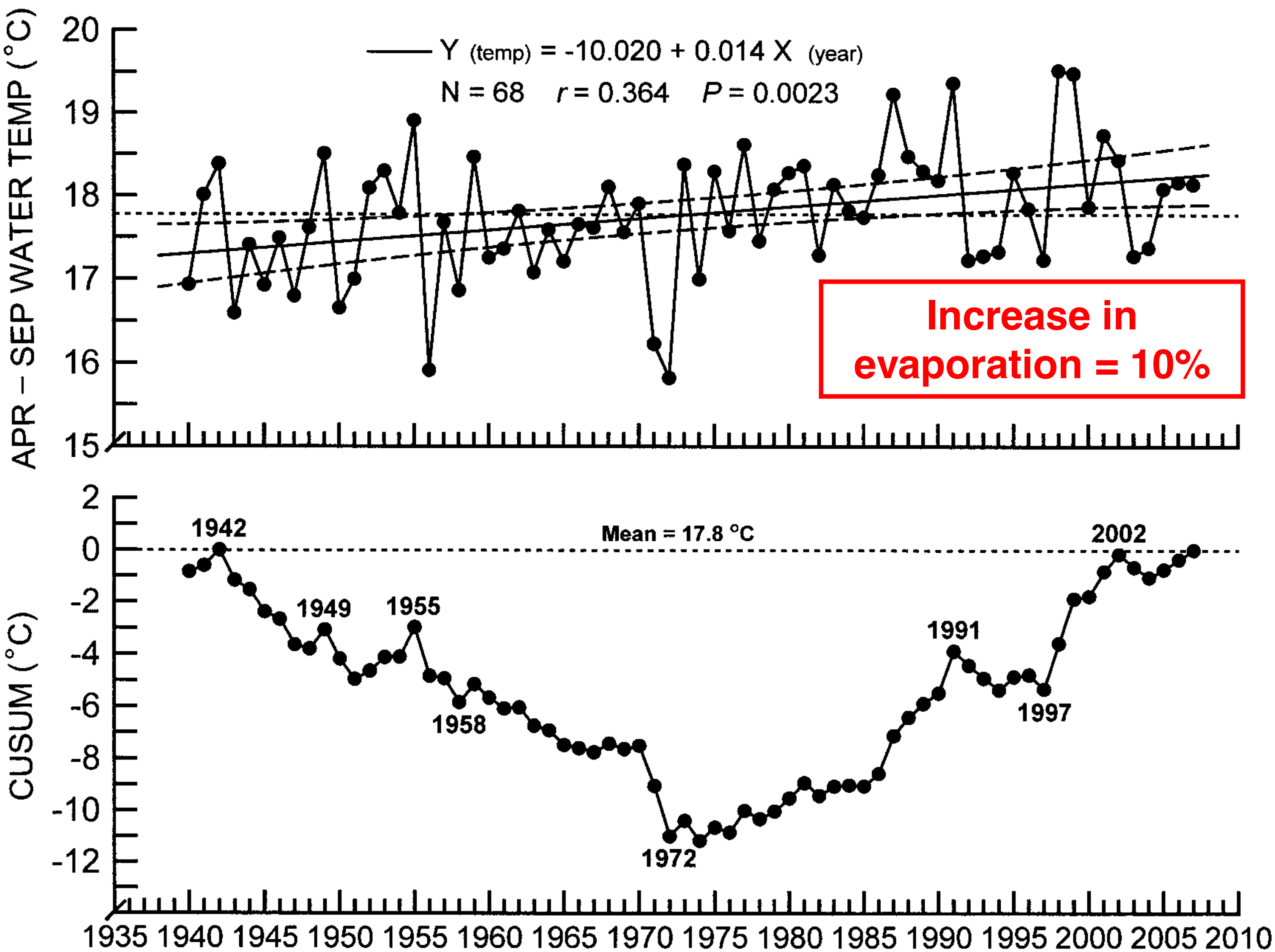
APRIL TO SEPTEMBER WATER TEMPERATURE

Lake Ontario, inshore waters, Bay of Quinte



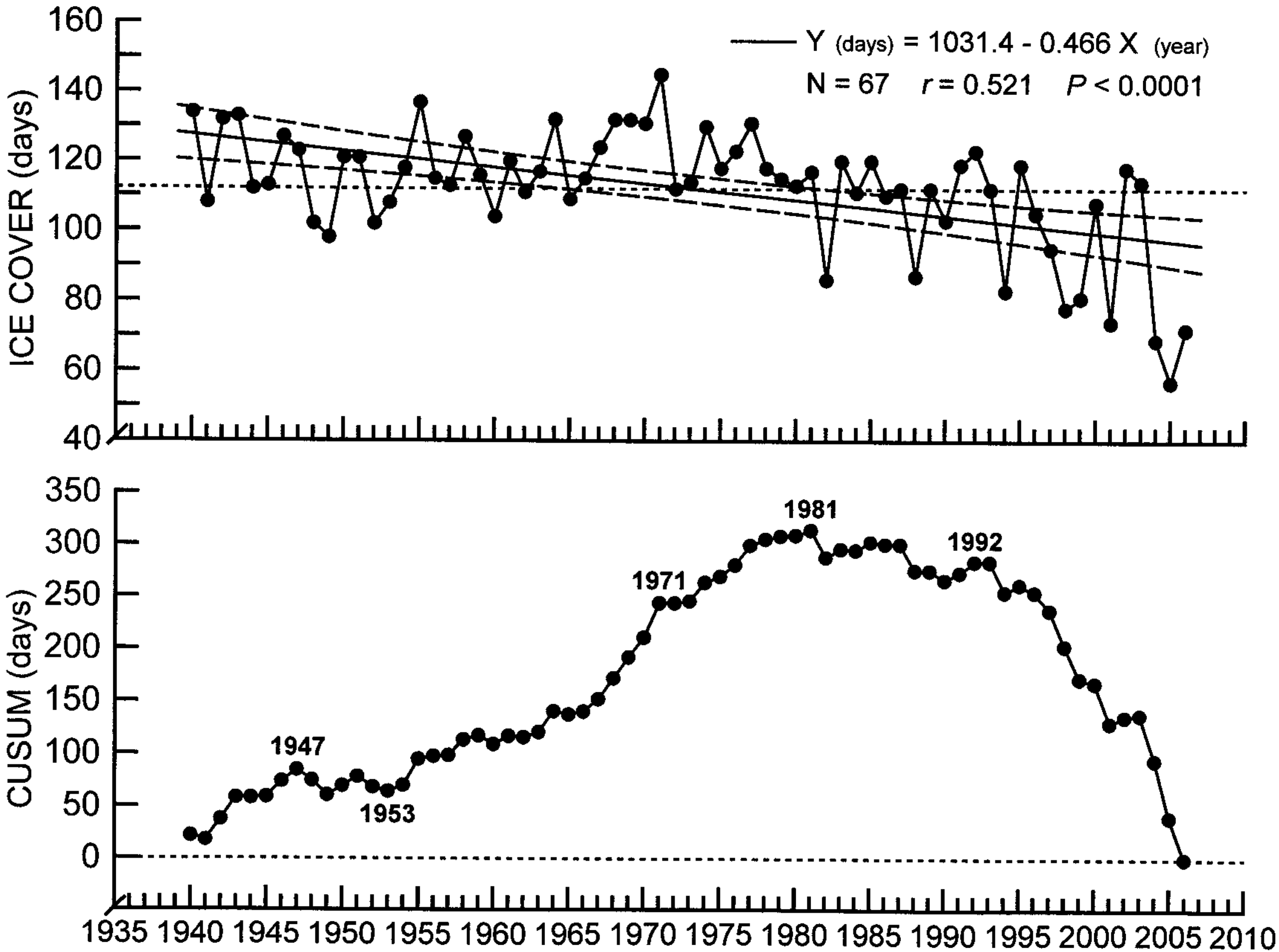
APRIL TO SEPTEMBER WATER TEMPERATURE

Lake Ontario, inshore waters, Bay of Quinte

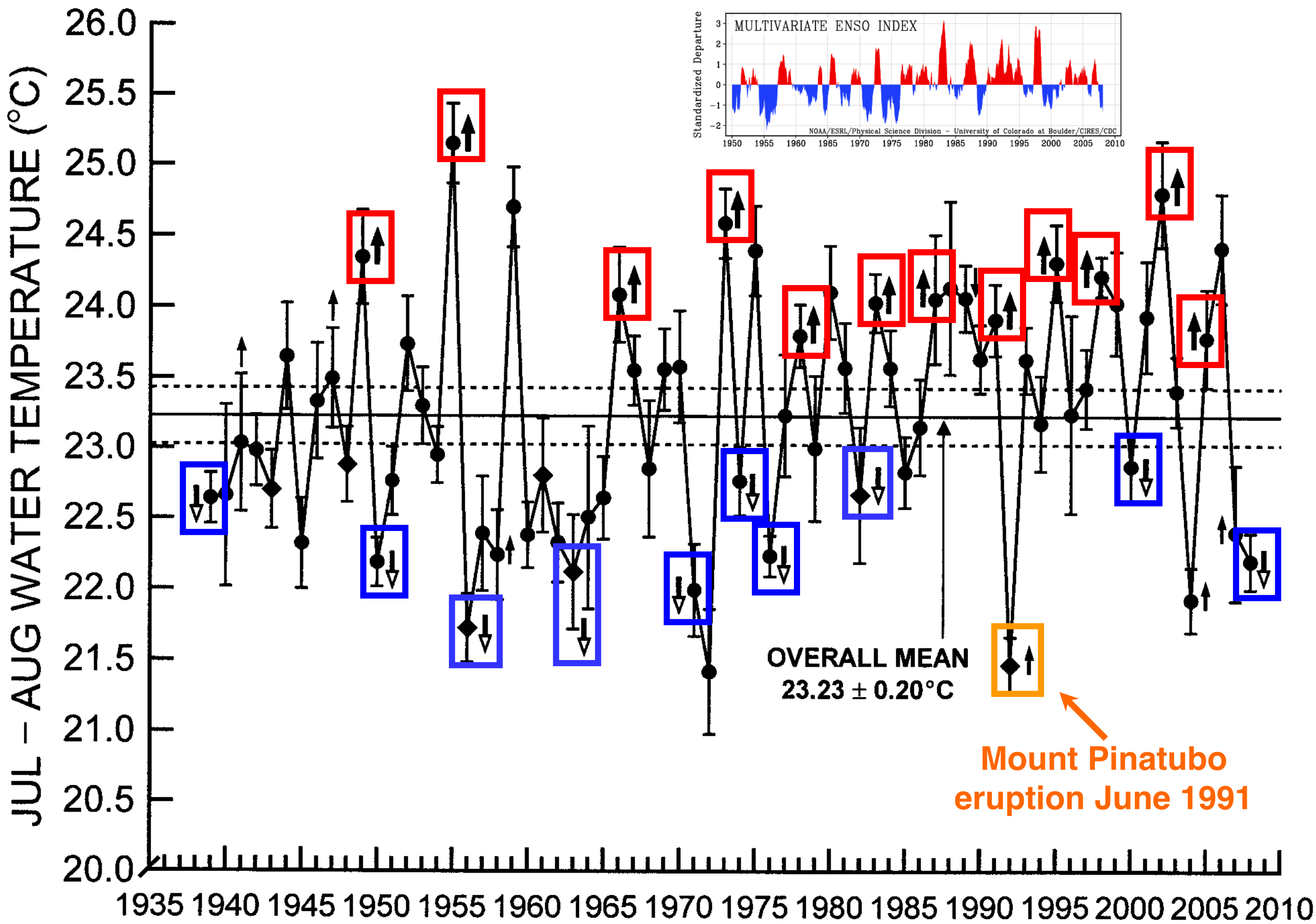


DURATION OF ICE-COVER PERIOD

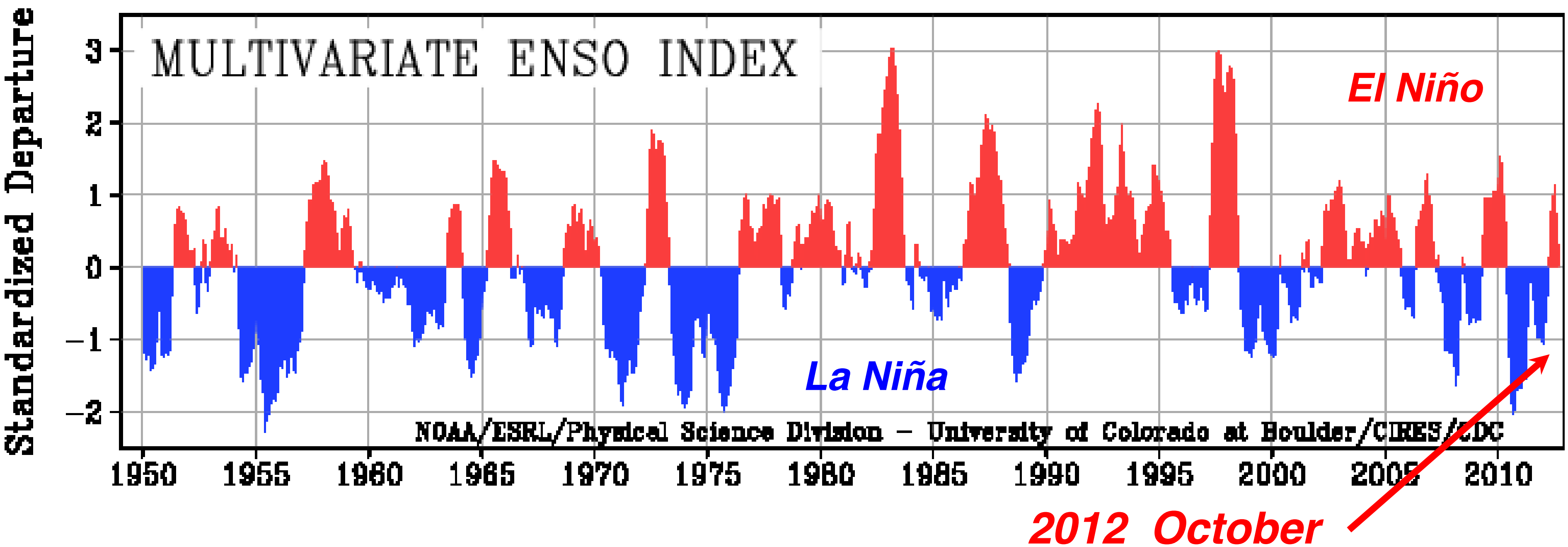
Bay of Quinte – temperature < 1.5°C, 112 ± 4d



MIDSUMMER WATER TEMPERATURE CONDITIONS



El Niño and La Niña conditions in tropical Pacific can predict conditions in Great Lakes Basin; 70 to 90% of temperature extremes in Great Lakes Basin are predicted by tropical Pacific conditions 2 to 8 months earlier.



La Niña, which occurred in the tropical Pacific in 2008 and winter, spring 2009, created conditions in the Great Lakes Basin that were entirely predictable and followed by El Niño in 2010, but a very strong La Niña appeared again in 2011 **– now we're in another** ***El Niño***

Water – Air Temperature Comparison

Water temperature is much less variable than air temperature; it traps radiant energy

Comparison of water and air temperatures Bay of Quinte watershed, Ontario, 1950-2006.

Month and season	Water temperature (°C)			Air temperature (°C)			Water to air difference
	Mean	95% C.I.	CV	Mean	95% C.I.	CV	
Jan	0.7	0.08	43.7	-7.3	0.74	38.1	8.0
Feb	0.7	0.08	47.6	-6.1	0.68	41.8	6.8
Mar	1.0	0.17	60.0	-0.9	0.58	234.3	1.9
Apr	6.4	0.48	27.8	6.4	0.43	25.5	0
May	14.3	0.41	10.9	12.6	0.47	14.0	1.7
Jun	20.2	0.29	5.5	17.7	0.35	7.4	2.5
Jul	23.5	0.26	4.2	20.6	0.28	5.0	2.9
Aug	23.1	0.29	4.7	19.7	0.32	6.2	3.4
Sep	19.3	0.29	5.6	15.2	0.40	9.9	4.1
Oct	12.3	0.31	9.4	9.0	0.40	16.8	3.3
Nov	5.7	0.32	21.1	2.9	0.43	55.1	2.8
Dec	1.3	0.21	61.9	-3.9	0.77	74.1	5.2
Spring (Mar-May)	7.3	0.26	13.7	6.0	0.38	23.7	1.3
Summer (Jun-Aug)	22.3	0.21	3.6	19.3	0.23	4.4	3.0
Fall (Sep-Nov)	12.4	0.20	6.0	9.0	0.29	12.2	3.4
Winter (Dec-Feb)	0.9	0.10	43.6	-5.8	0.44	28.4	6.7
Winter/spring (Dec-May)	4.1	0.15	13.9	0.1	0.32	800.8	4.0
Midsummer (Jul-Aug)	23.3	0.23	3.8	20.1	0.25	4.6	3.2
Open-water period (Apr-Nov)	15.6	0.18	4.3	13.0	0.17	4.8	2.6
Closed-water period (Dec-Mar)	0.9	0.11	43.9	-4.6	0.39	31.9	5.5
Annual (mean monthly)	10.7	0.14	4.8	7.1	0.19	9.9	3.6

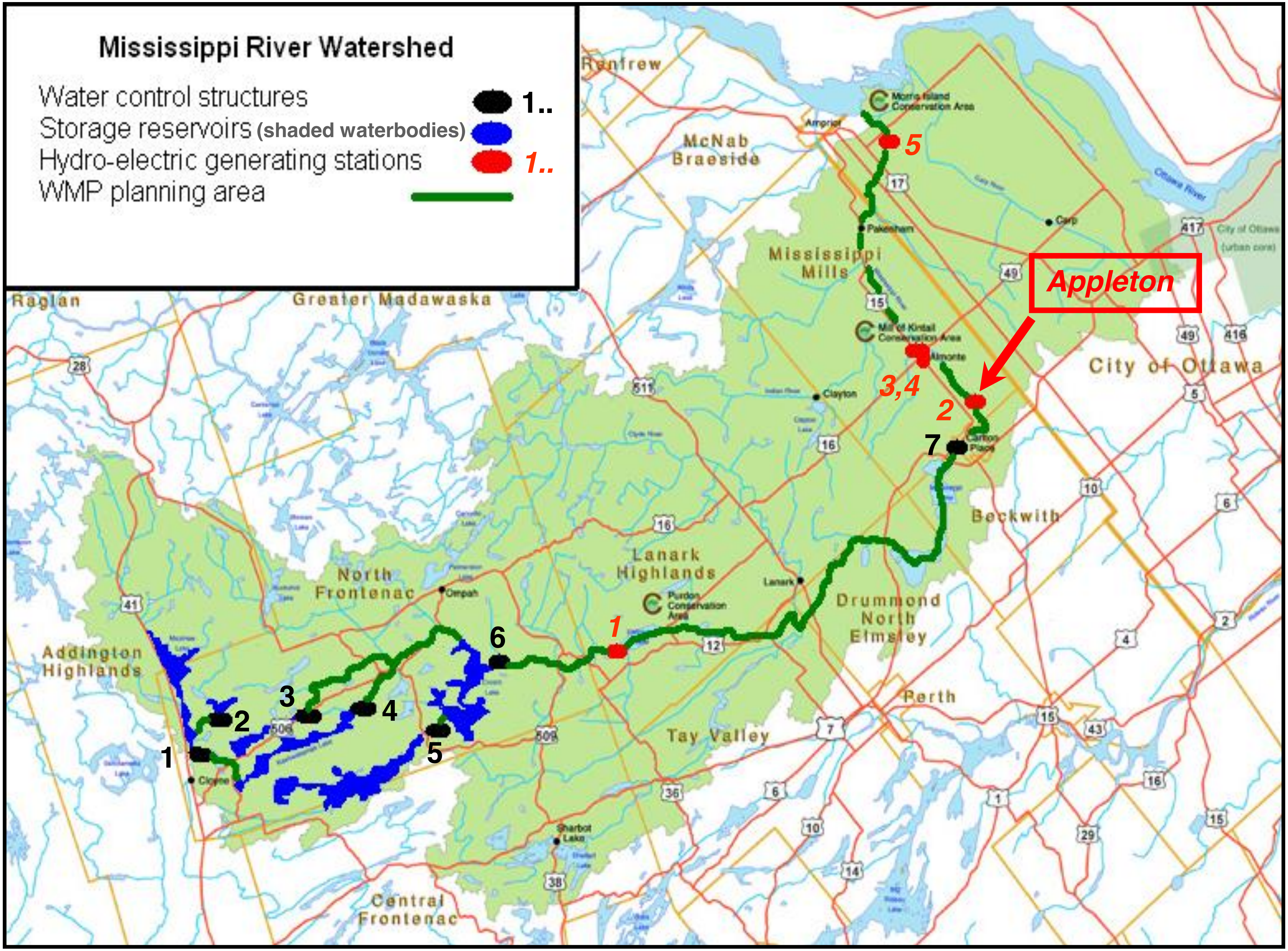
Water Resources and management implications

Global Warming and Water Dynamics

Ontario's Mississippi R. watershed and discharge at Appleton

Modelling Conducted by Paul Lehman and Sobhalatha Kunjikutty,

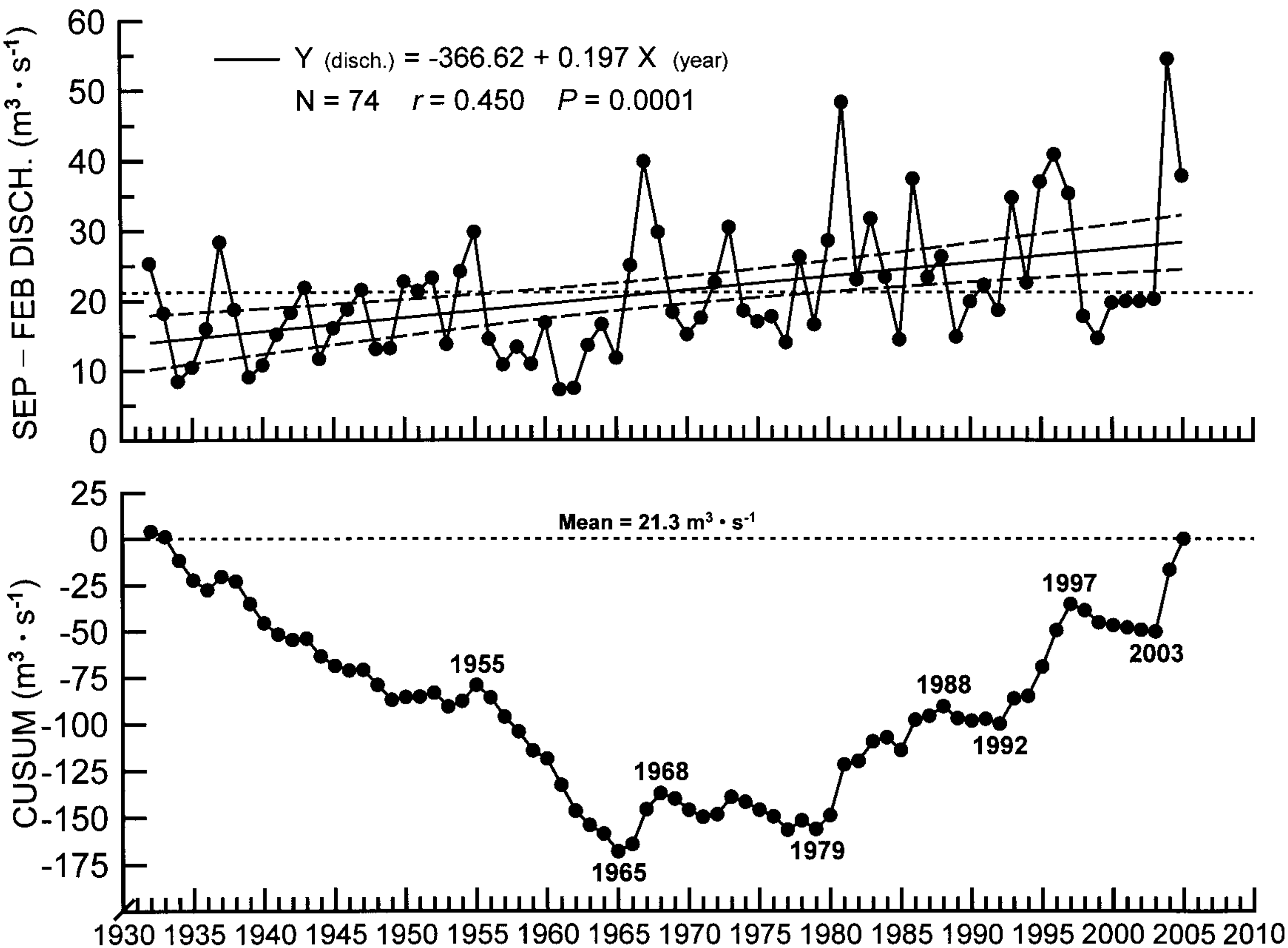
Mississippi Valley Conservation, 2008



Mississippi River Watershed
Water control structures 1..
Storage reservoirs (shaded waterbodies)
Hydro-electric generating stations 1..
WMP planning area
Appleton
Renfrew
McNab Braeside
Mississippi Mills
City of Ottawa
Raglan
Greater Madawaska
Beckwith
Lanark Highlands
North Frontenac
Addington Highlands
Drummond North Elmsley
Perth
Tay Valley
Central Frontenac
Morris Island Conservation Area
Mill of Kintail Conservation Area
Purdon Conservation Area
Almonte
Clayton
Carp
Lanark
Ompah
Sharbot Lake
Carleton Place
Pakenham
Arnprior
Cloyne
Ottawa River
1
2
3
4
5
6
7
1
2
3,4
5

FALL AND WINTER DISCHARGE

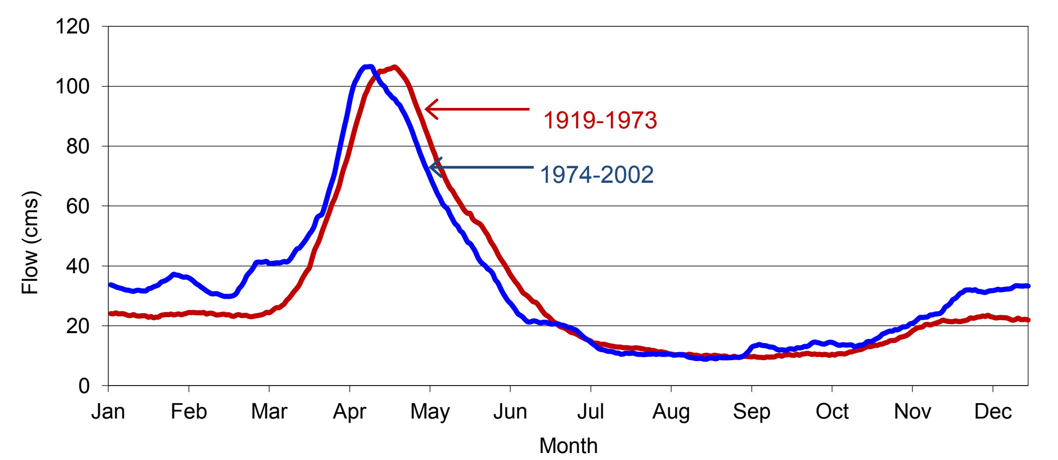
Mississippi River, Appleton – Sep to Feb

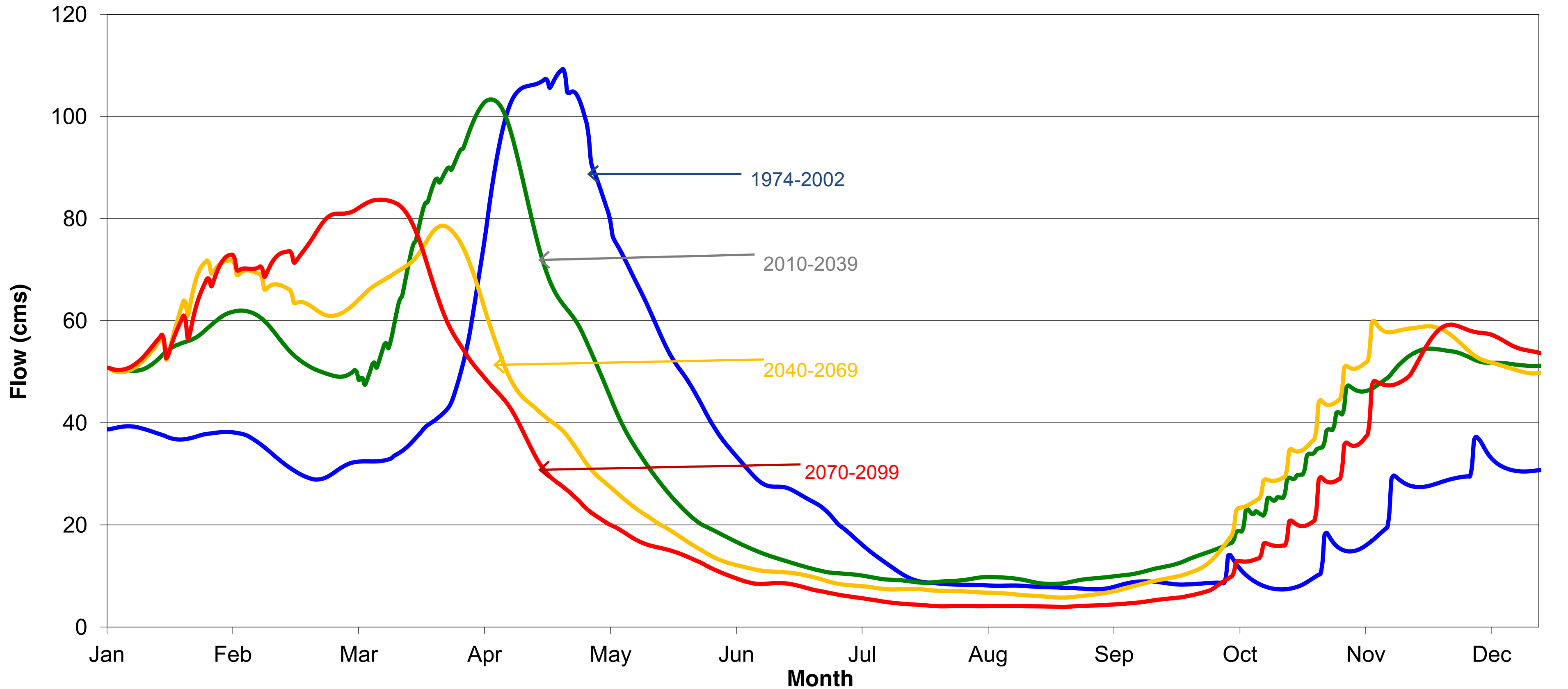


Mean Daily Stream Flow Comparison

Modelling Change

Mississippi River at Appleton (WSC 02KF006)





Mean Daily Stream Flow Comparison

Modelling Change

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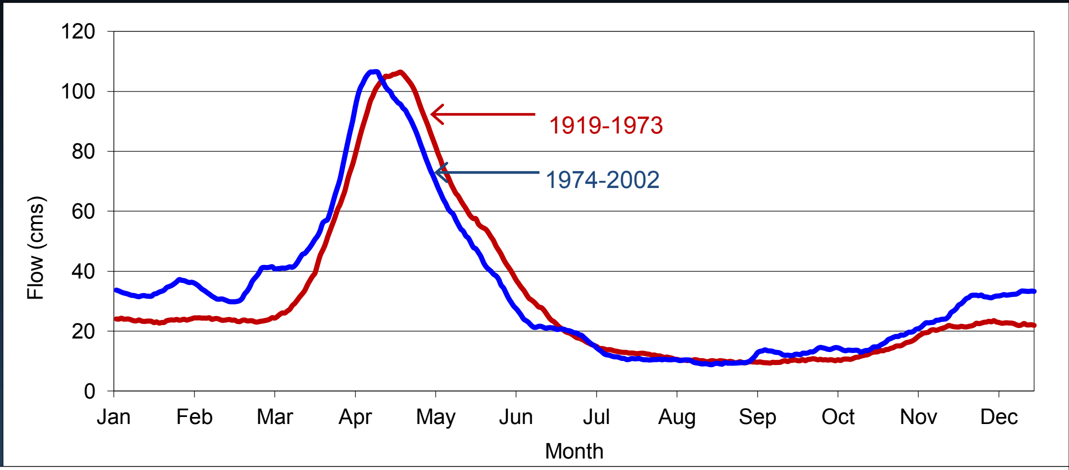
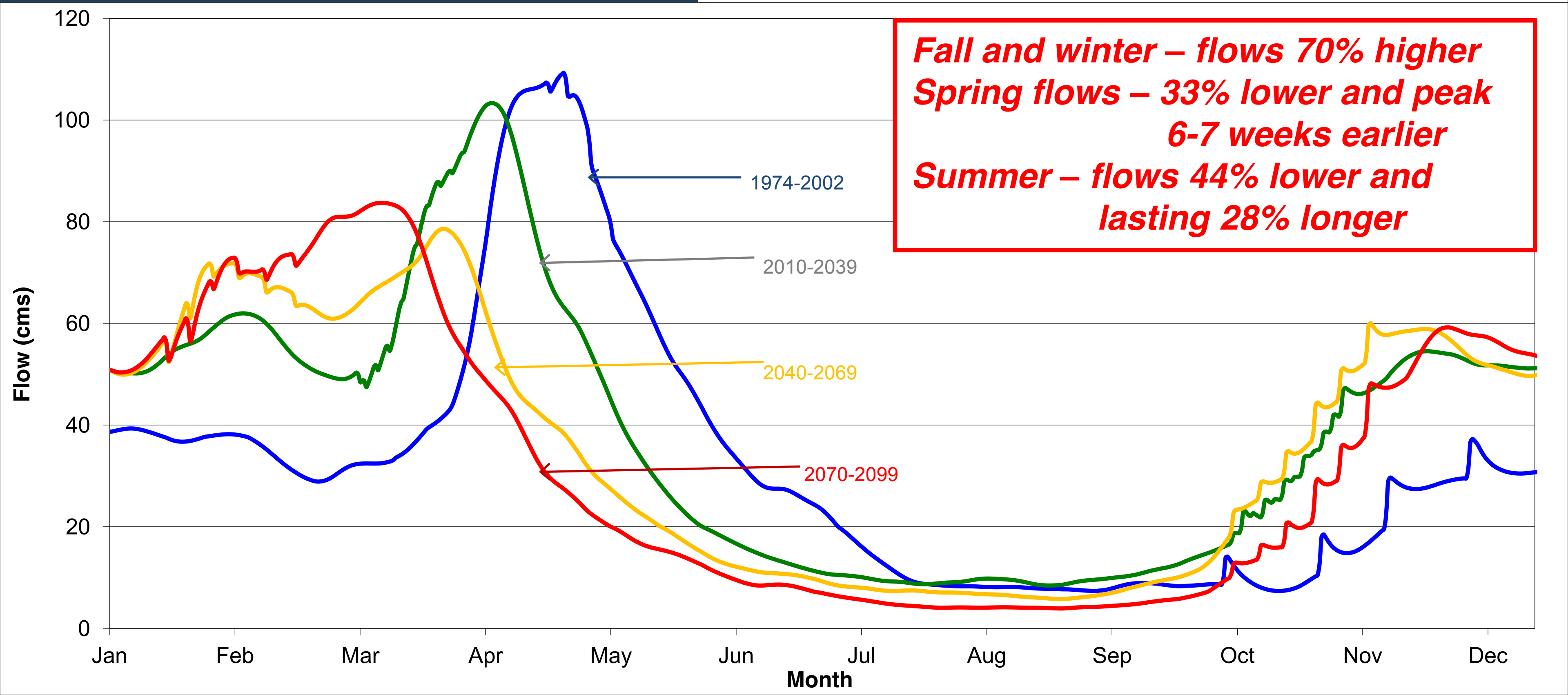




Populations, Communities, and Fish Response to a Warming Climate

Thermal requirements, recruitment, and growth

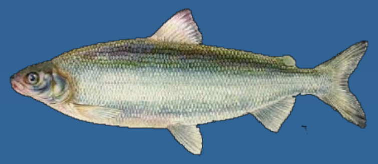
Thermal Requirements

and

Thermal Groupings

Typical warm-water, cool-water, and cold-water species





Temperature requirements of typical freshwater fish of the three major thermal groupings. ***Essential for understanding thermal response !***

Thermal grouping	Species	Spawning	Thermal habitat		
			Optimum	Preferred	Mean
Warm-water	bluegill	23.7	30.2	31.3	30.8
	white perch	20.1	28.8	29.8	29.0
	smallmouth bass	18.0	27.0	27.4	27.2
	Mean	20.6	28.7	29.5	29.0
Cool-water	yellow perch	9.3	22.5	23.3	22.9
	walleye	8.0	22.6	21.7	22.2
	northern pike	6.9	20.0	23.5	21.8
	Mean	8.1	21.7	22.8	22.3
Cold-water	brook trout	8.7	15.0	13.0	14.0
	lake whitefish	5.7	15.2	11.1	13.2
	lake trout	10.6	11.7	11.2	11.5
	Mean	8.3	14.0	11.8	12.9

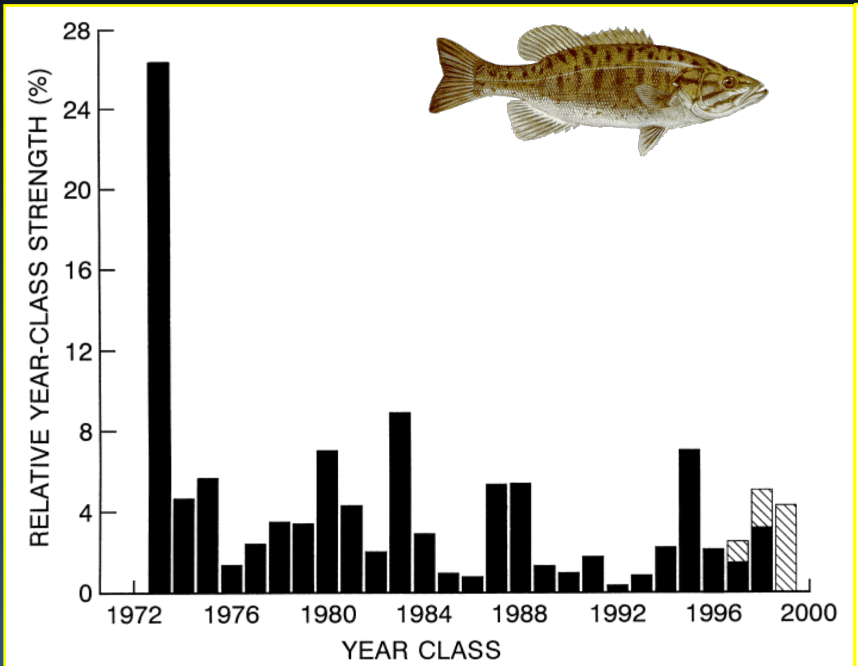
Recruitment, Temperature, and Global Warming

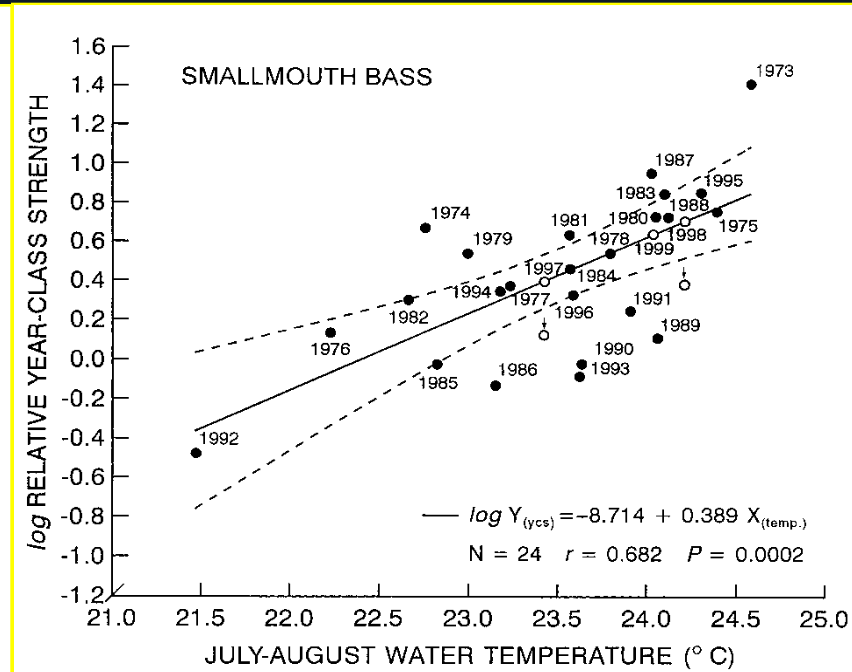
Population dynamics, community structure, species interactions



WARM-WATER SPECIES

Optimum Temperature for Growth >25^{o}C (Smallmouth bass)

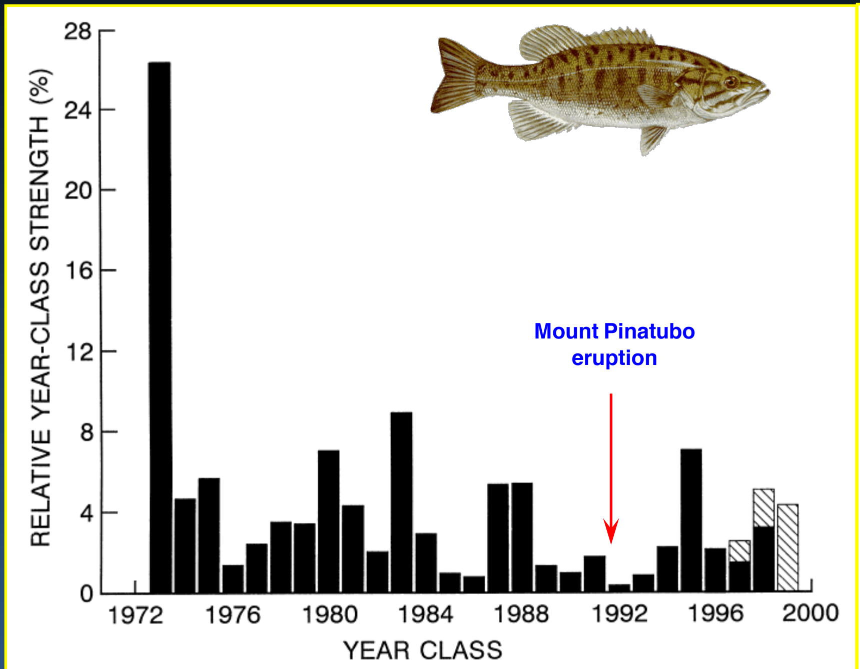


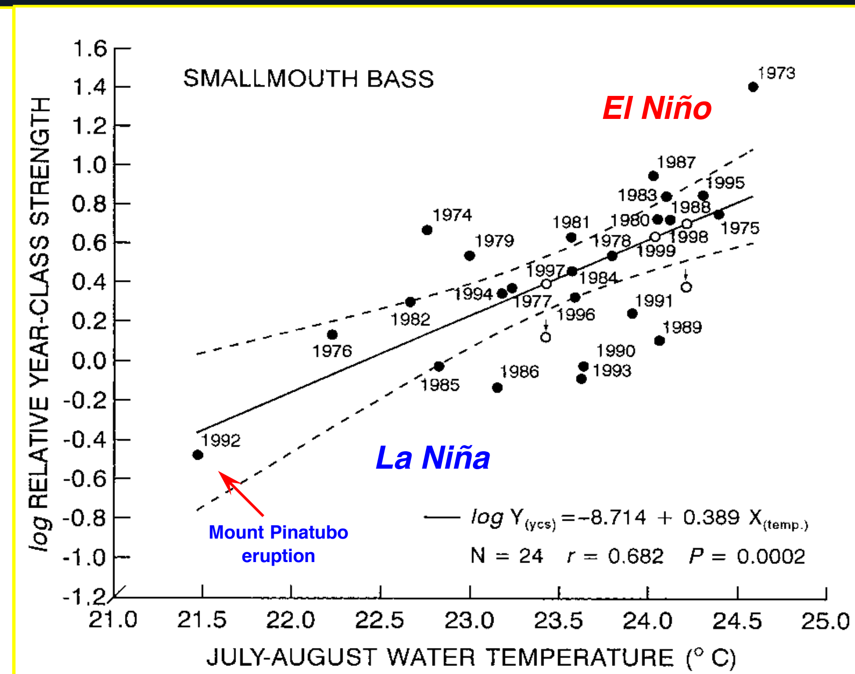


July-August water temperature		Year-class strength	
Mean	Deviation	Relative	Fold change
23.42	0	2.49	0
24.42	+1.00	6.10	+2.45
25.42	+2.00	14.94	+6.00
26.42	+3.00	36.59	+14.69

WARM-WATER SPECIES

Optimum Temperature for Growth >25°C (Smallmouth bass)





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Mean	**Deviation**	**Relative**	**Fold change**
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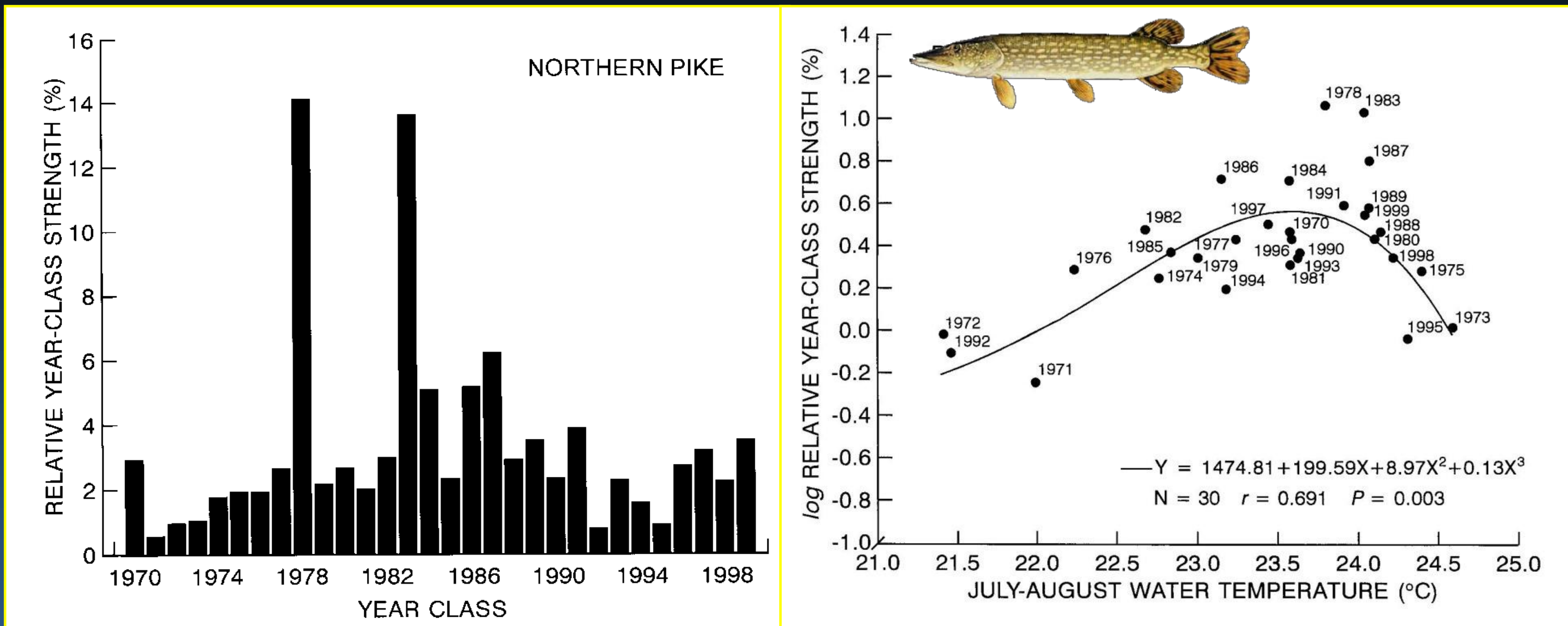
25.42	+2.00	14.94	+6.00
26.42	+3.00	36.59	+14.69

COOL-WATER SPECIES

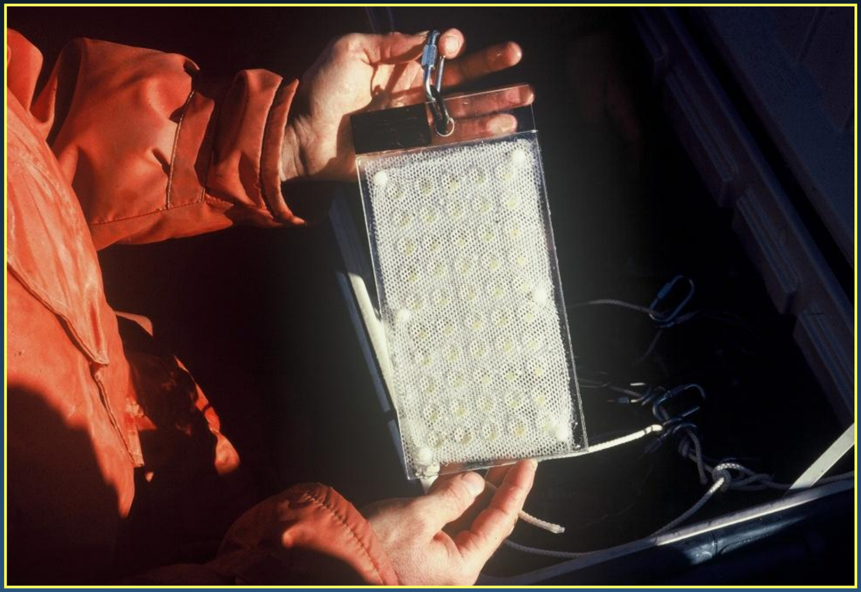
Optimum Temperature for Growth 15 – 25°C (Northern pike)

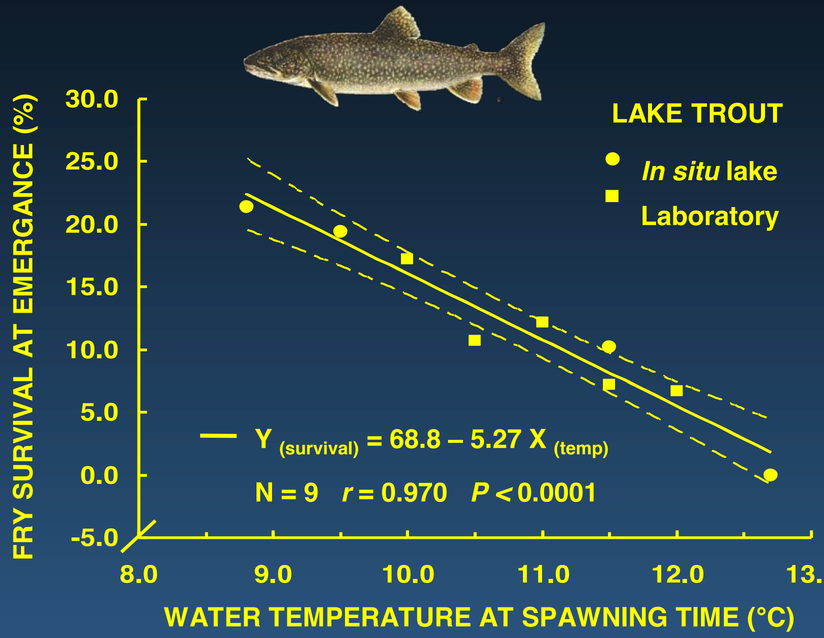


July-August water temperature		Year-class strength	
Mean	Deviation	Relative	Fold change
23.42	0	3.58	0
24.42	+1.00	1.51	-2.37
25.42	+2.00	0.20	-17.90
26.42	+3.00		

COLD-WATER SPECIES

Optimum Temperature for Growth <15°C (Lake trout)

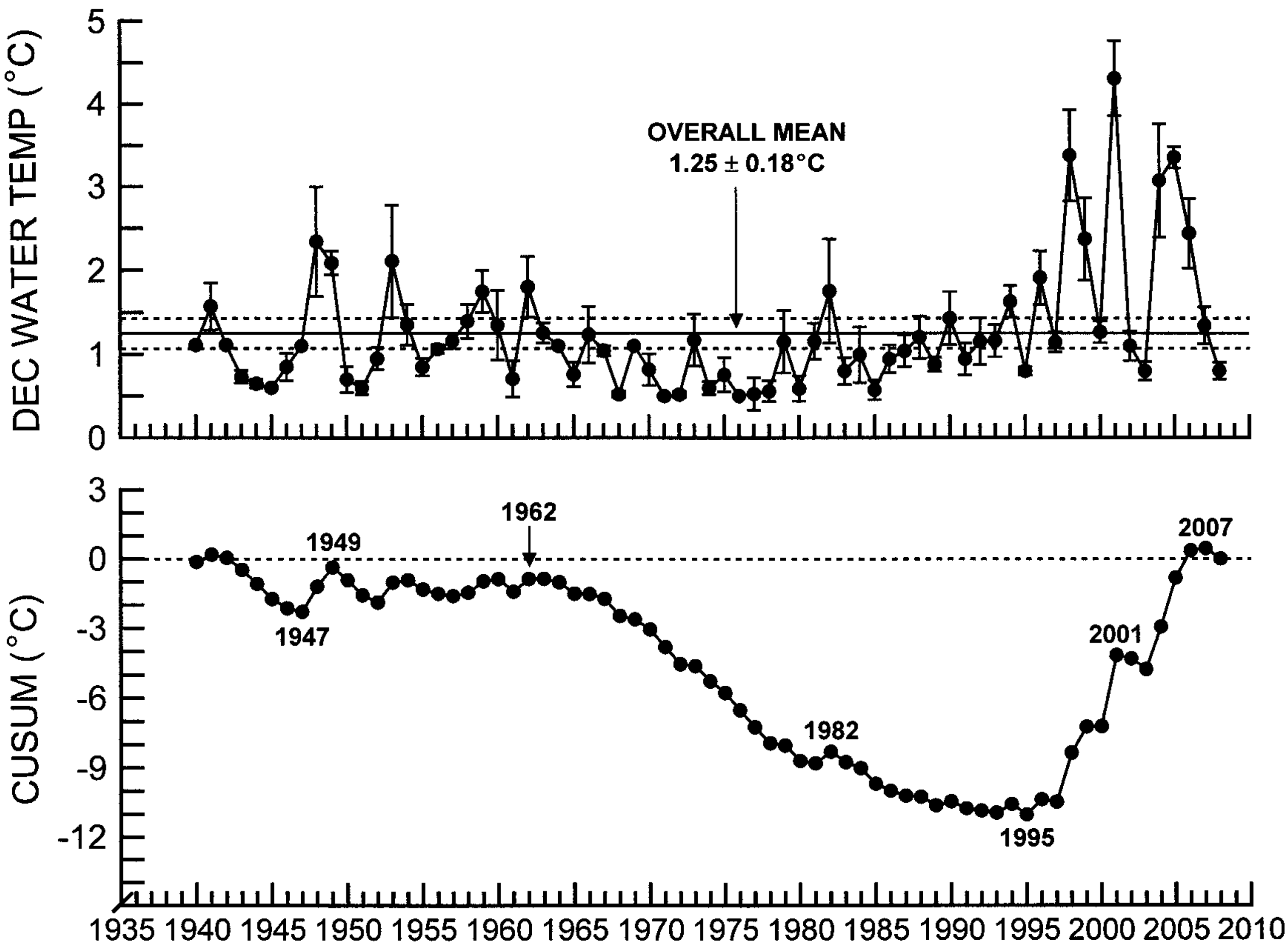




Water temperatures at spawning		Survival at emergence	
Mean	Deviation	Relative	Fold change
9.84	0	16.65	0
10.84	+1.00	11.37	-1.47
11.84	+2.00	6.93	-2.40
12.84	+3.00	0.83	-20.06

FALL WATER TEMPERATURES – DECEMBER

Lake Ontario, inshore waters of the Bay of Quinte

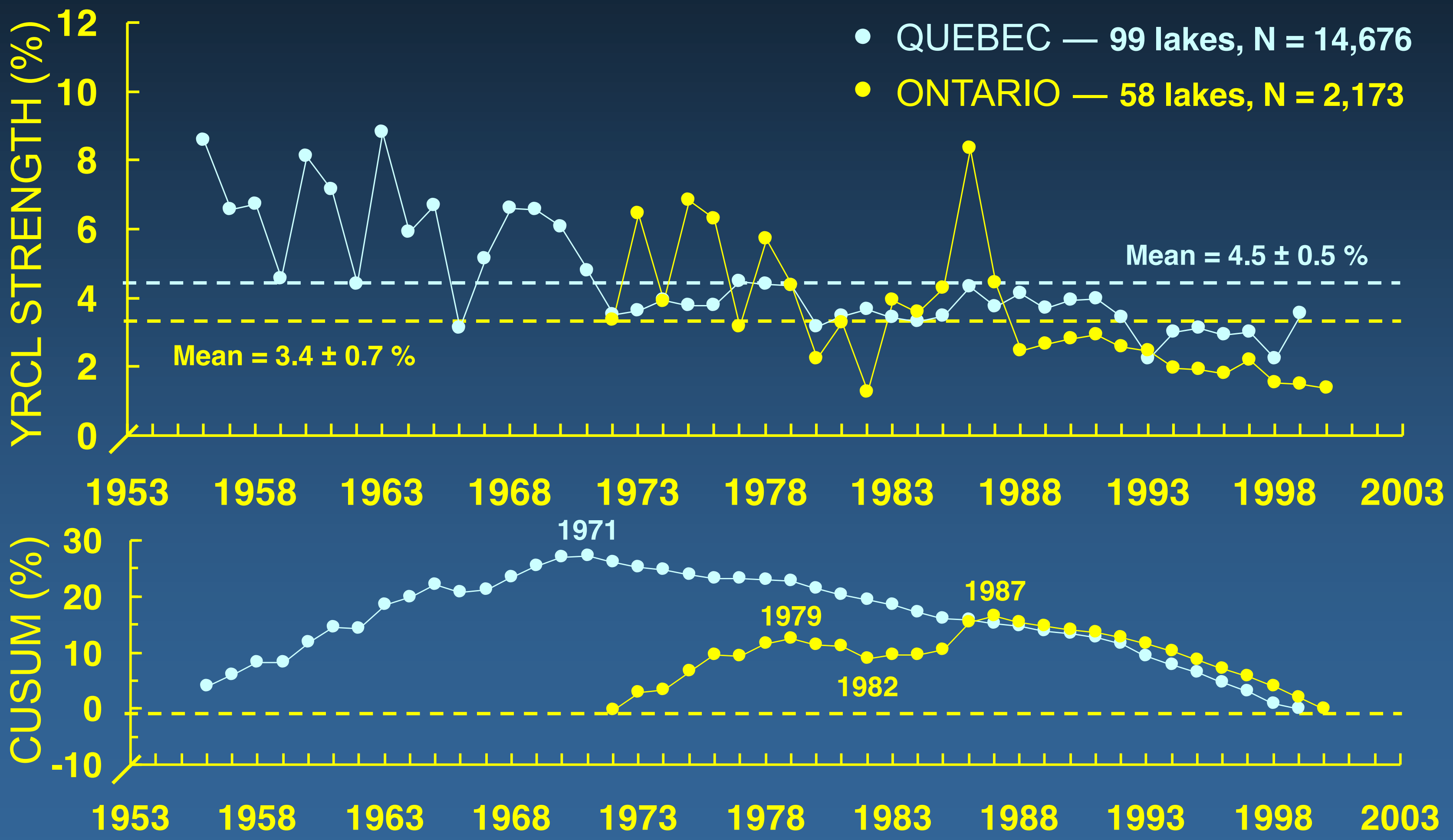


Long-Term Declining Recruitment in Lake Trout

Evidence of global warming in Quebec and Ontario lake trout populations

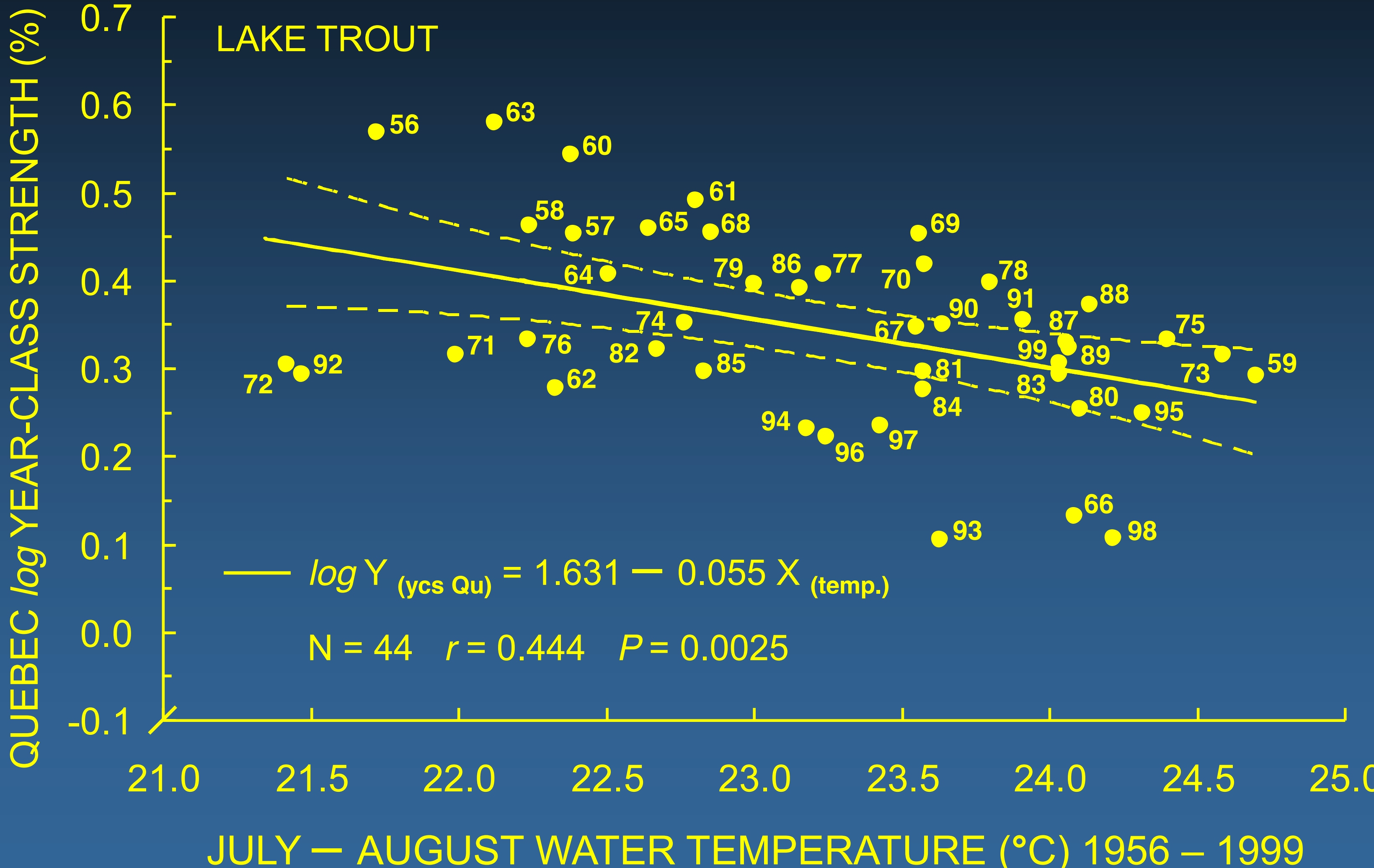
LONG-TERM YEAR-CLASS STRENGTH

Central Quebec – Ontario lake trout lakes



RECRUITMENT AND MIDSUMMER TEMPERATURE

Five decades of Quebec lake trout year-class strength



Lake Trout Spawning Adaptation, Timing, and Depth

Southern part of range spawn later (e.g., Oneida Lake) and new evidence for spawning deeper, below thermocline, Ontario lakes

SUMMARY: RECRUITMENT CHANGE AND COMMUNITY STRUCTURE

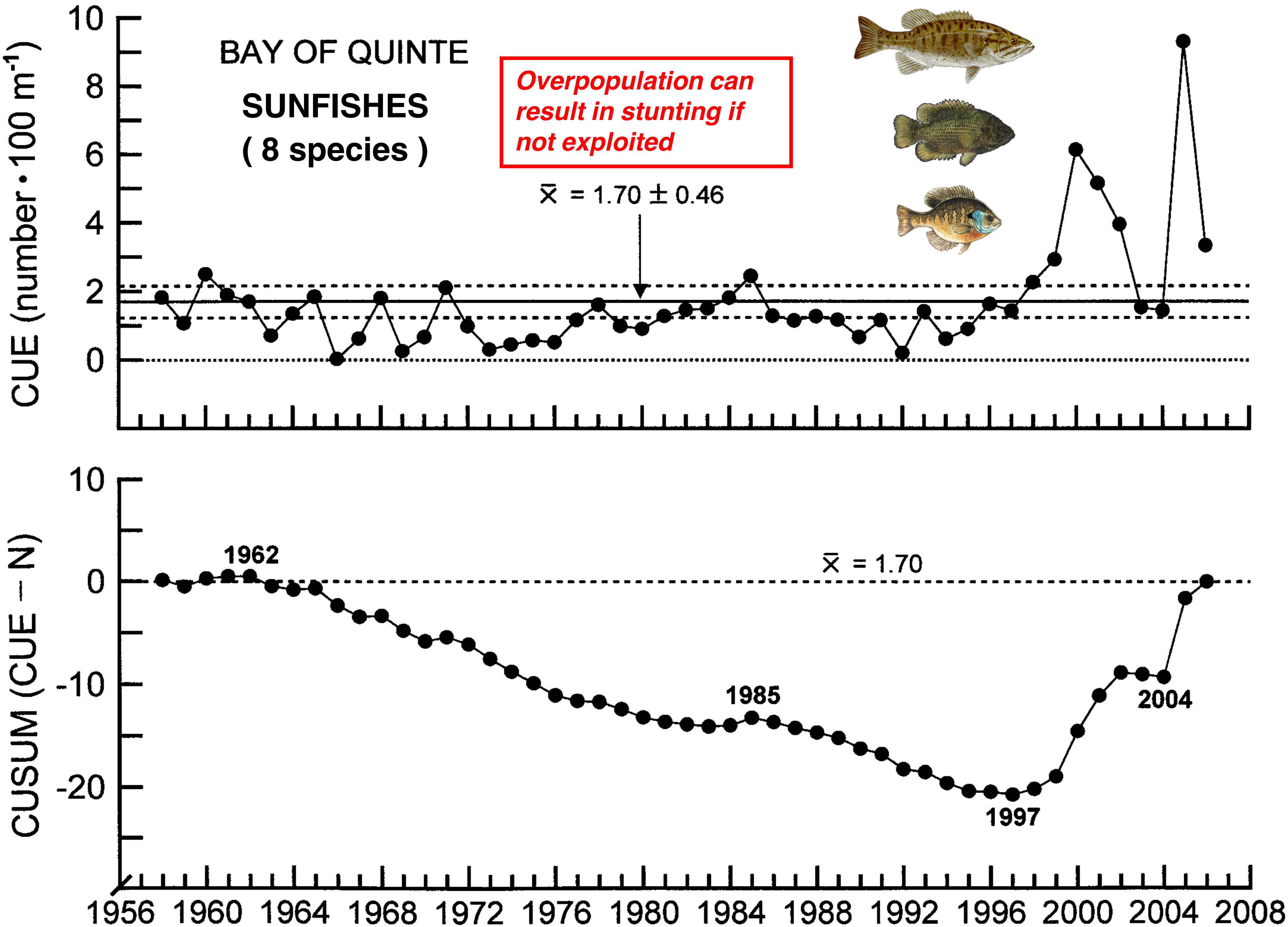
A summary of relative changes for typical warm-water, cool-water, and cold-water species in an increasing temperature regime of 1-3°C.

Thermal grouping Species	Recruitment change			Community structure (%)		
	+1°C	+2°C	+3°C [a]	0°C	+1°C	+2°C
Warm-water						
smallmouth bass	+2.5x	+6.0x	+14.7x	33	69[b]	93[c]
Cool-water						
northern pike	-2.4x	-17.9x		33	12	1
Cold-water						
lake trout	-1.5x	-2.4x	-20.1x	33	19	6

[a] Extrapolated

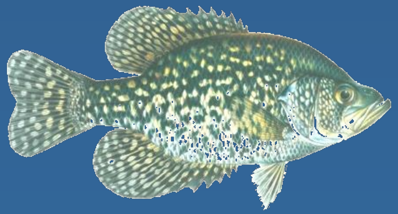
[b] Recruitment would increase by 2.1x with a 1°C increase

[c] Recruitment would increase by 2.8x with a 2°C increase


BAY OF QUINTE
SUNFISHES
(8 species)
Overpopulation can result in stunting if not exploited
X̄ = 1.70 ± 0.46
CUE (number • 100 m-1)
10
8
6
4
2
0
CUSUM (CUE − N)
10
0
-10
-20
1962
X̄ = 1.70
1985
2004
1997
1956
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
2008

Other Warm-Water Centrarchids Are Expanding and Invading

Black crappies, walleye predators, are increasing in abundance in Ontario (e.g., Bay of Quinte, Kawartha and Mississippi systems)

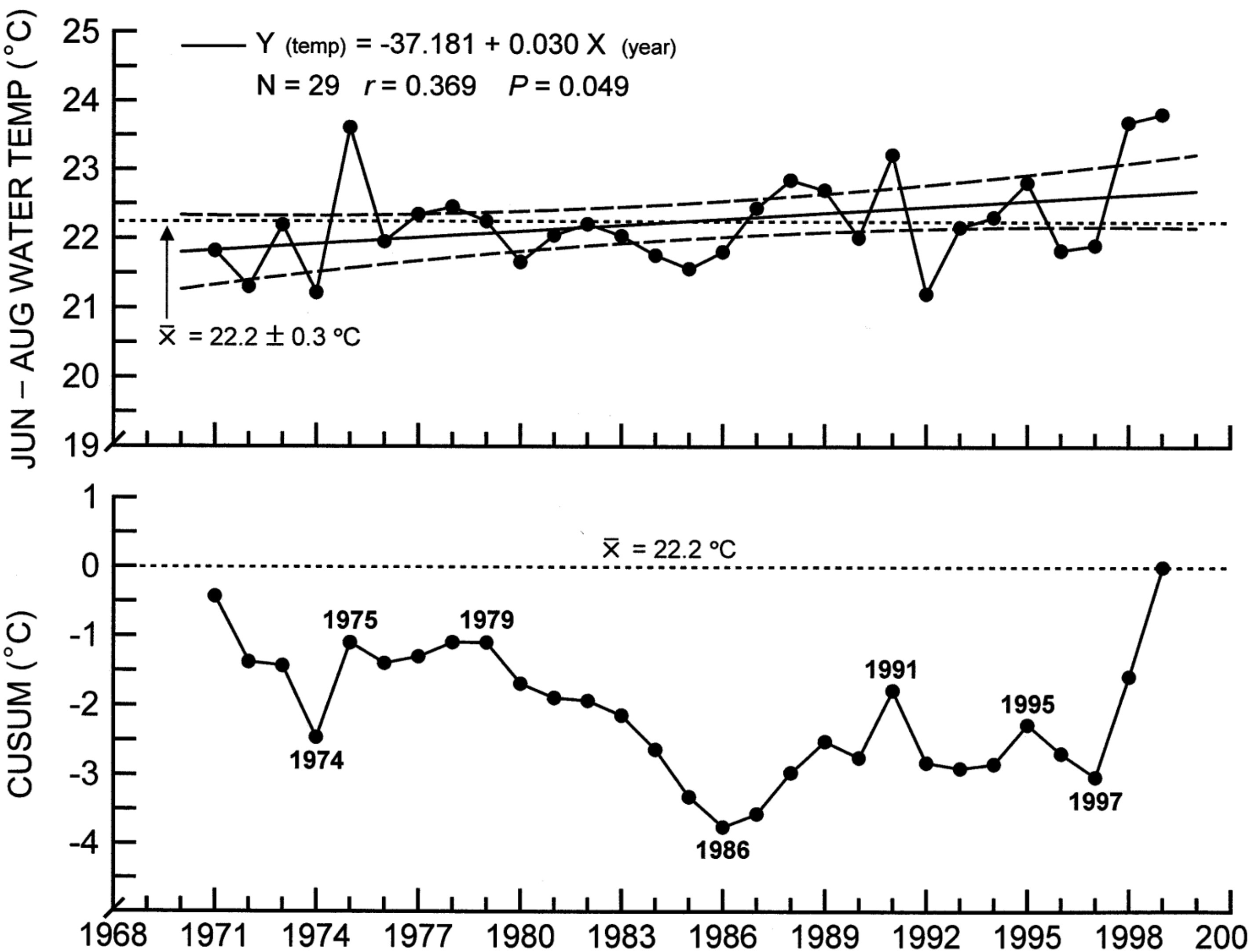


Relative Year-Class Strength and Summer Water Temperature

Warm- and cold-water fish recruitment in relation to June to August water temperature in the Mississippi River watershed

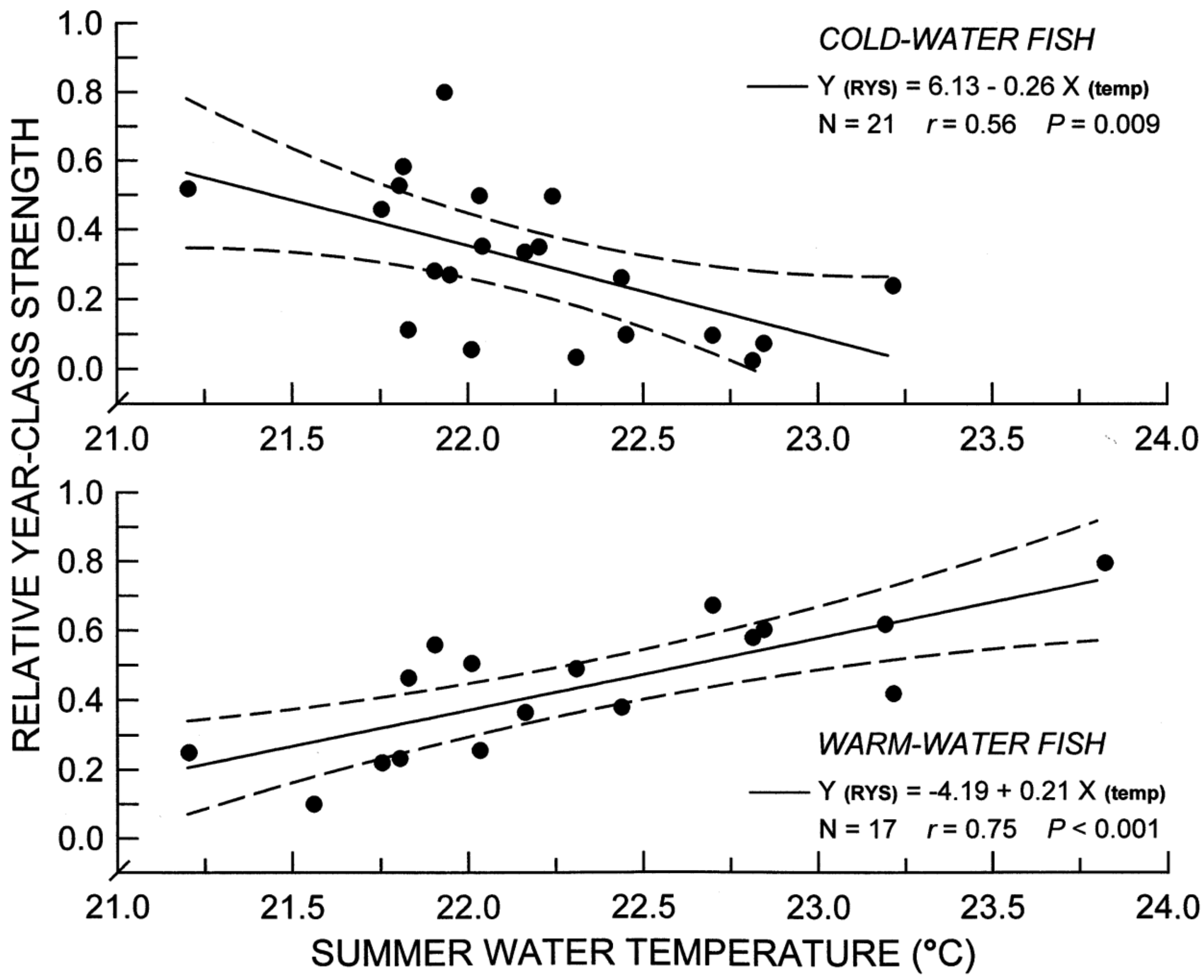
SUMMER WATER TEMPERATURE

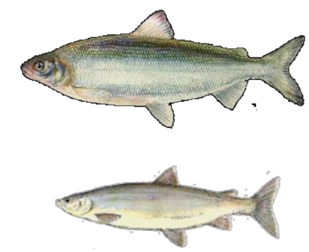
Ontario’s Mississippi watershed, Appleton – Carleton Place



YEAR-CLASS STRENGTH – SUMMER TEMPERATURE

Mississippi watershed, cold-water and warm-water fish





2 species

4 waterbodies

R^2=0.31

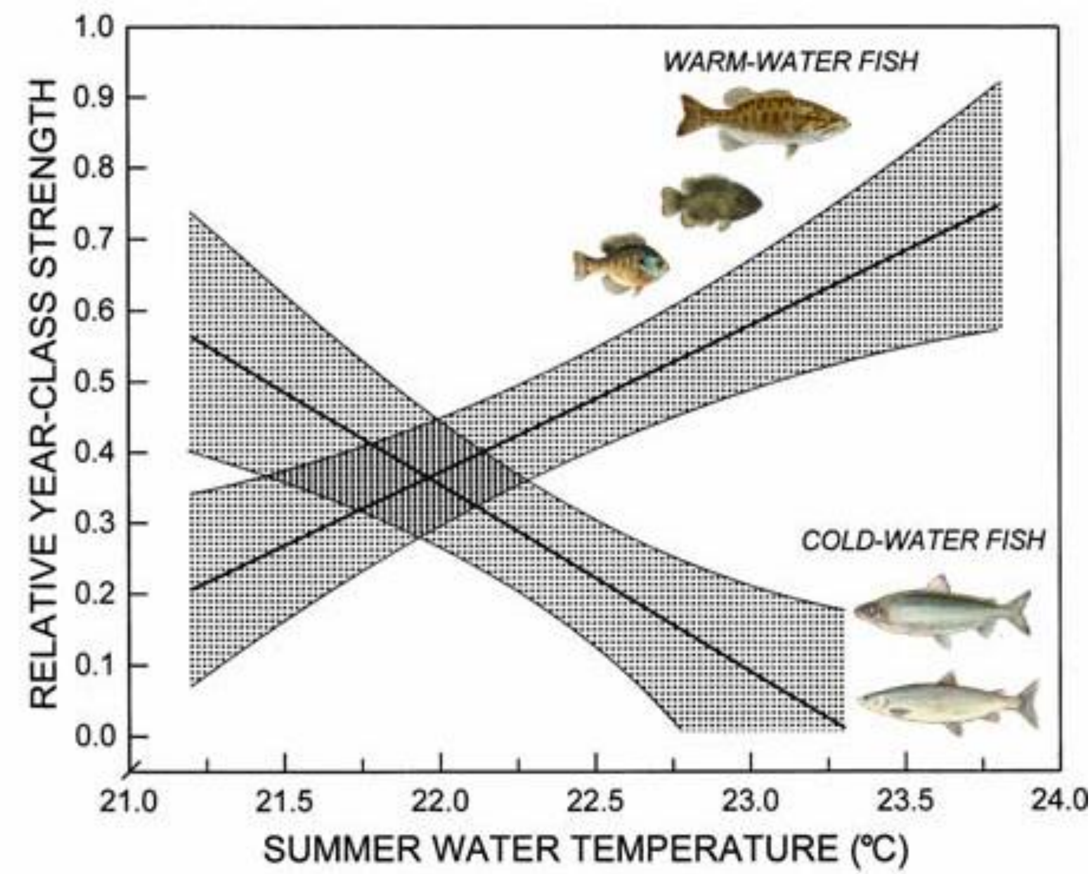
10 species

9 waterbodies

R^2=0.56

INVERSE RECRUITMENT – TEMPERATURE RELATIONS

Warm-water – positive; cold-water – negative



Over two decades a 60% increase; rate of increase–3.4% yearly

Over three decades a 60% decrease; rate of decrease–2.2% yearly

Minimal and maximal recruitment

Cold-water fish ≥ 23.3 and ≤ 19.5°C

Warm-water fish ≥ 20.2 and ≥ 25.1°C

Predicted changes in relative year-class strength of two centrarchids, smallmouth bass and rock bass, from mean, regressed, and model-predicted Mississippi River watershed summer surface water temperatures.

Time period		Water temperature			Year-class strength					
					Smallmouth bass		Rock bass		Combined	
Period	Median year	Summer	Deviation	Mid-summer	Relative	Fold change	Relative	Fold change	Relative	Fold change
1970-2000	1985[a]	22.2	0	23.2	2.05	0	1.56	0	1.75	0
	1970	21.8[b]	- 0.4	22.8	1.45	- 0.71	1.19	- 0.77	1.32[c]	- 0.73
	2000	22.7[b]	+0.5	23.7	3.15	+1.54	2.15	+1.39	2.65[c]	+1.47
2000-2009	2005[a]	23.2	+1.0	24.2	4.85	+2.36	2.98	+1.93	3.92	+2.18
2010-2039	2025[a]	24.2	+2.0	25.1	11.47	+5.59	5.74	+3.71	8.60	+4.78
2040-2069	2055[a]	25.2	+3.0	26.1	27.12	+13.23	11.05	+7.13	19.09	+10.61
2070-2099	2085[a]	26.2	+4.0	27.0	64.15	+31.28	21.27	+13.73	42.71	+23.73

[a] Median year for the period.

[b] Summer surface water temperatures increased from 1970 to 2000 by 0.9^{o}C.

[c] The predicted increase in recruitment for this increasing temperature would be 100%; however, the actual change in recruitment over this temperature range was 62%; the observed was slightly more half the predicted.

Fish and fisheries adaptation at its best!

G Bruce By H Robinson
Clayton Lake, Feb 2008

WALLEYE RECRUITMENT AND SPRING RIVER DISCHARGE

There is a well documented positive relationship between recruitment and spring discharge for some river-spawning walleye populations

For Moon River, Georgian Bay, 1955-1968, the relation between walleye year-class strength (RYS) and discharge (DISC) at spring spawning time was:

$$\log X_{\text{(walleye RYS)}} = 0.856 + 0.0034\, Y_{\text{(DISC cms)}}$$

$N = 14$ $r = 0.752$ $P = 0.0019$

Applying this recruitment - discharge relationship to Mississippi River Ontario discharge to estimate walleye recruitment:

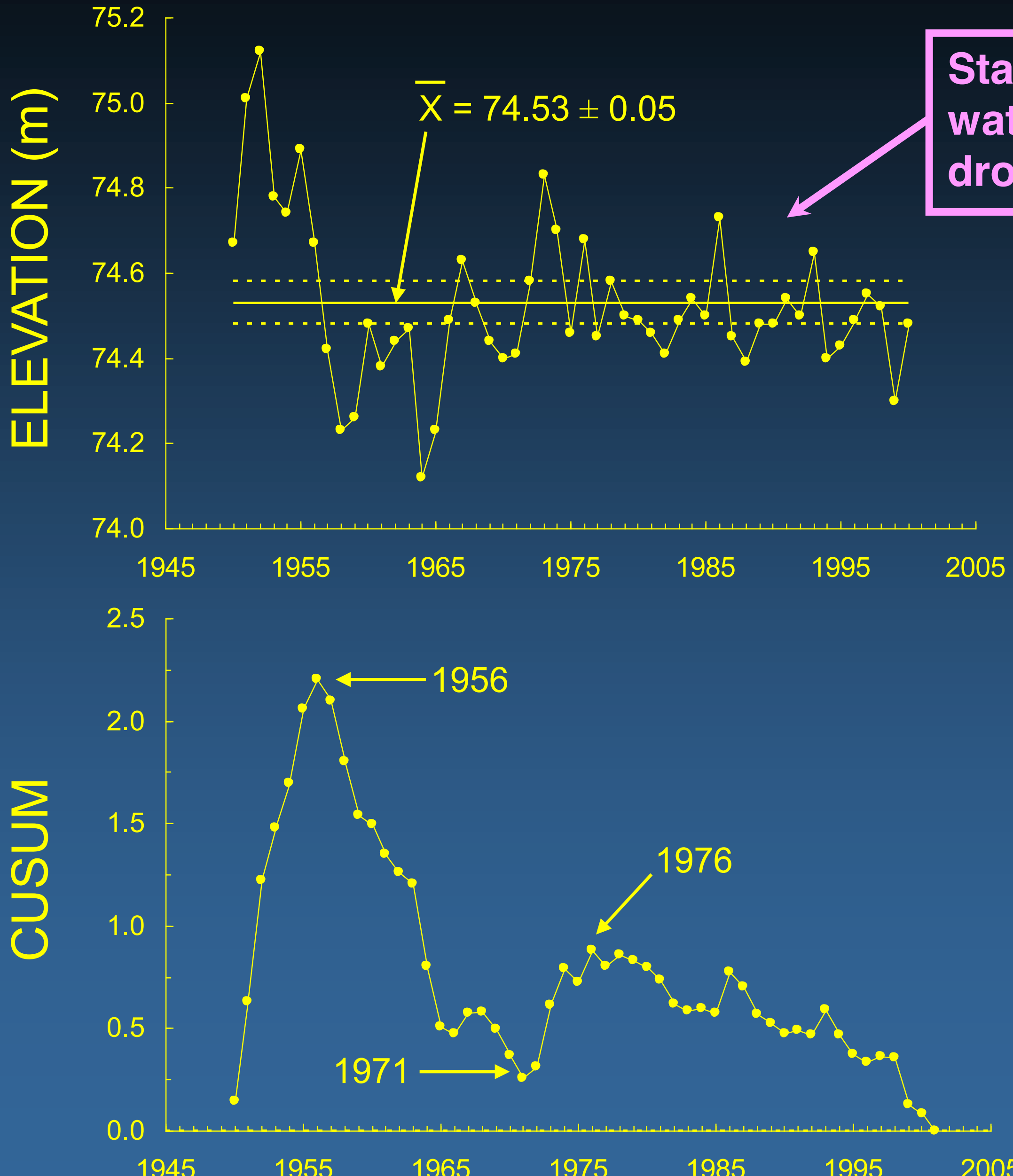
Time period		Peak discharge				Walleye recruitment	
Period	Median year	Date	Days earlier	Flow (cms)	% change	Relative year-class strength	% change
1974-2002	1985	Apr 27		107.4		1.00	
2010-2039	2025	Apr 8	19	103.3	- 3.8	0.97	-3
2040-2069	2055	Mar 27	31	78.6	- 26.8	0.80	- 20
2070-2099	2085	Mar 11	47	72.0	- 33.0	0.76	- 24

Water-Level Dynamics and Year-Class Strength of Pike

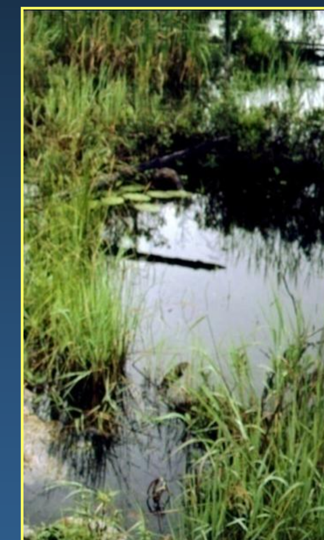
IJC study: water-level regulation, stabilization, drawdowns, and droughts

WATER LEVEL – UPPER ST. LAWRENCE RIVER

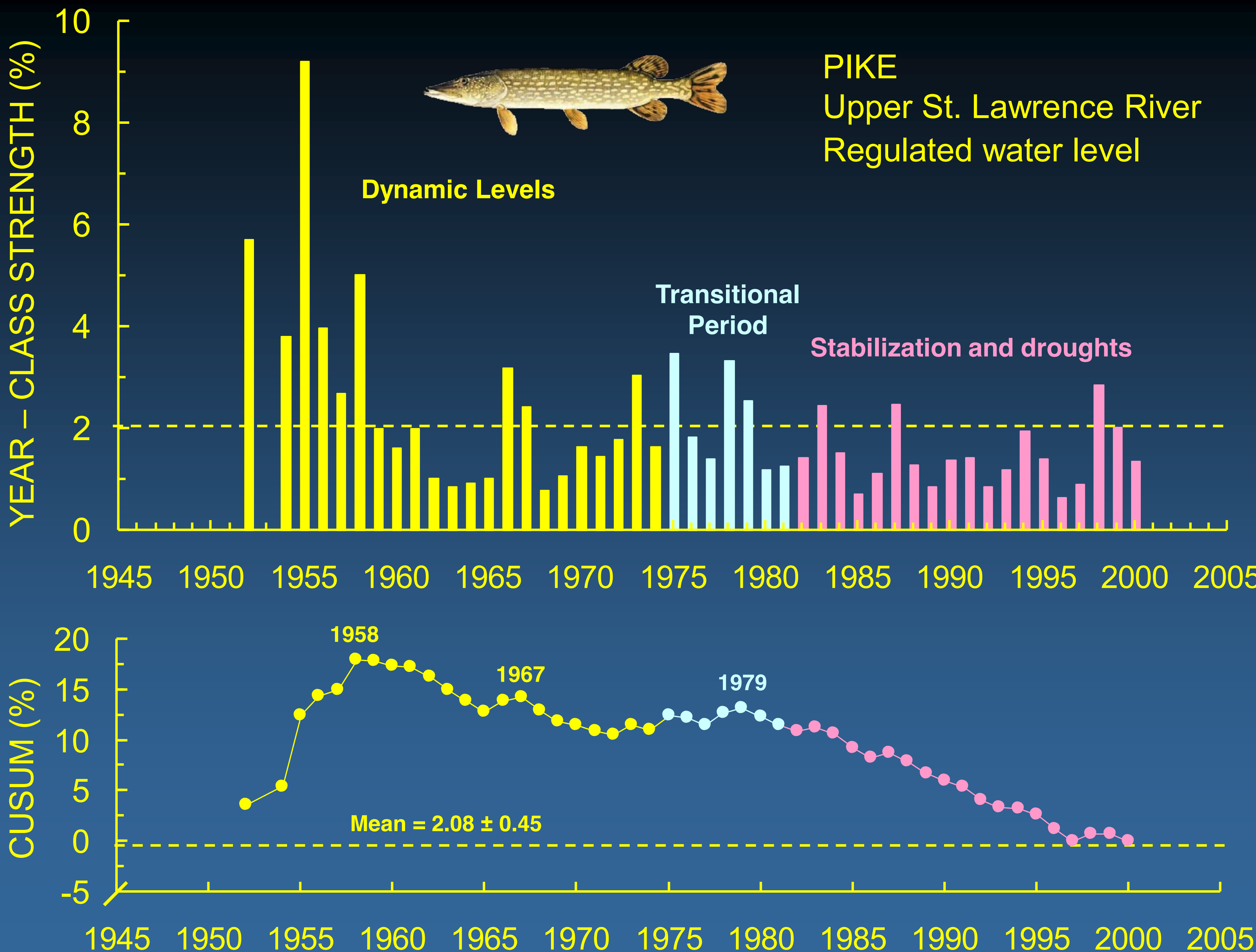
Pike Spawning Habitat

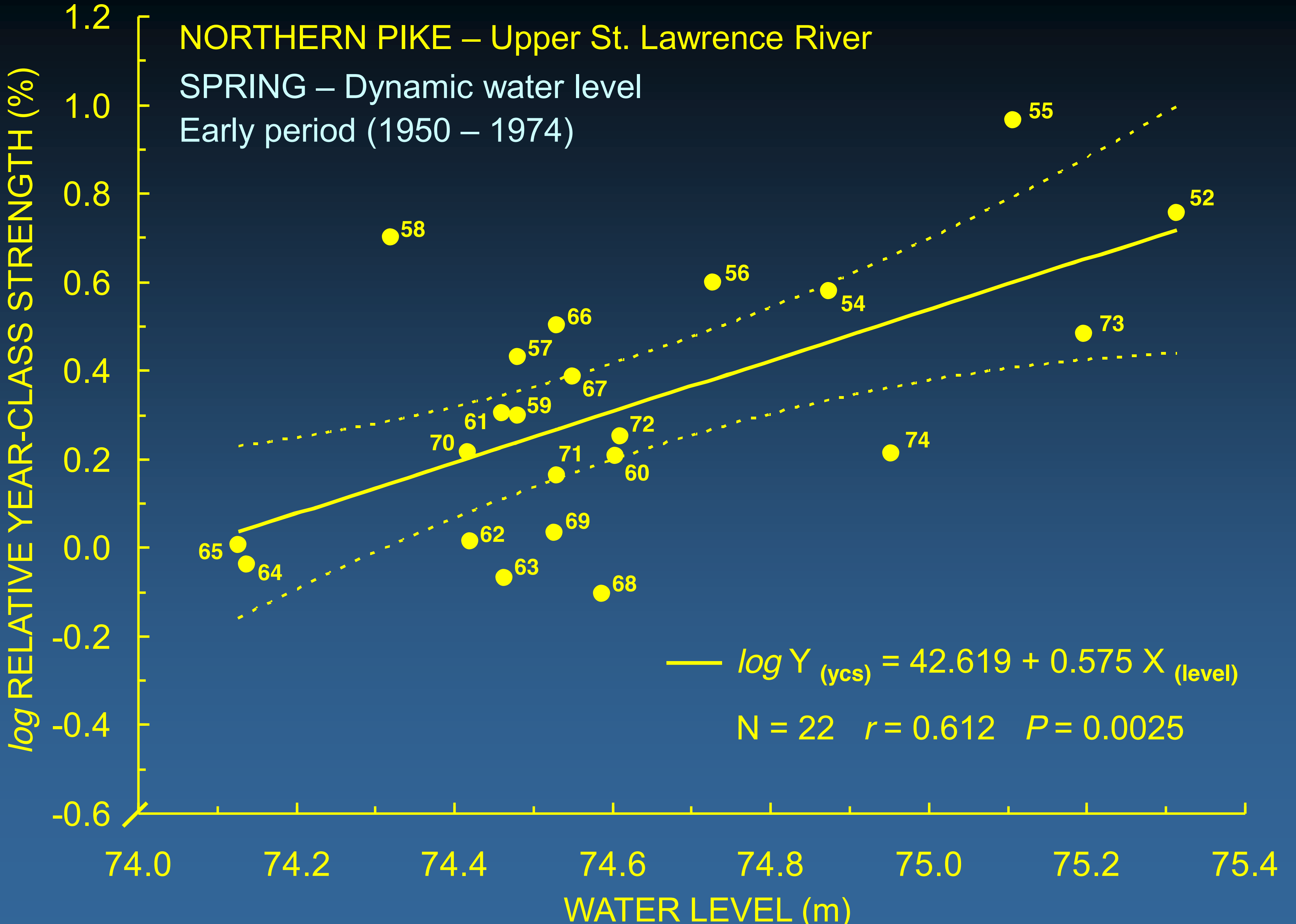


Stabilized, declining water levels and droughts

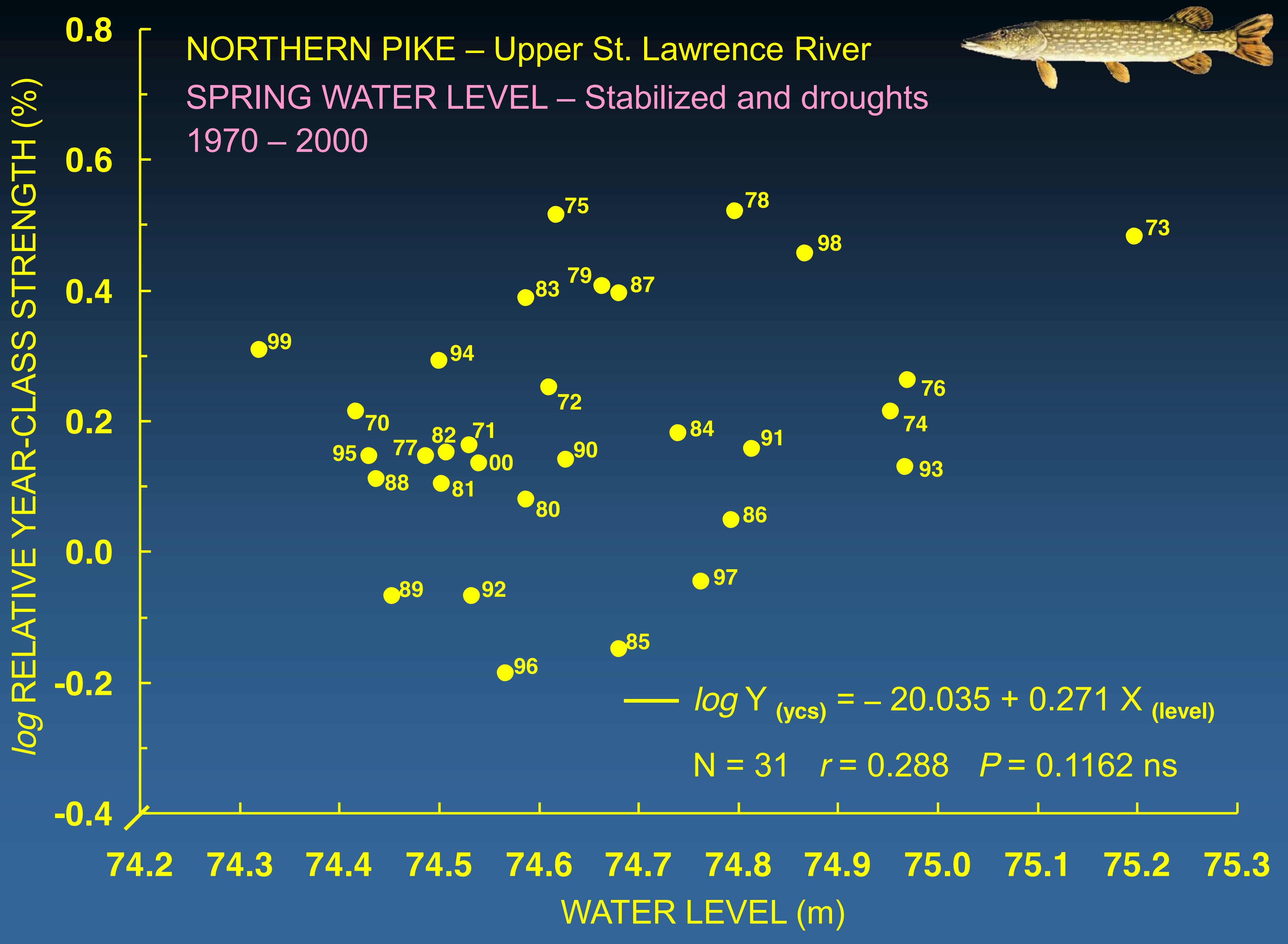


Pike Nursery Habitat


PIKE
Upper St. Lawrence River
Regulated water level
Dynamic Levels
Transitional Period
Stabilization and droughts
YEAR – CLASS STRENGTH (%)
10
8
6
4
2
0
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
CUSUM (%)
20
15
10
5
0
-5
1958
1967
1979
Mean = 2.08 ± 0.45



NORTHERN PIKE – Upper St. Lawrence River
SPRING – Dynamic water level
Early period (1950 – 1974)
log RELATIVE YEAR-CLASS STRENGTH (%)
WATER LEVEL (m)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
74.0
74.2
74.4
74.6
74.8
75.0
75.2
75.4
55
52
58
56
54
66
73
57
67
59
61
72
70
74
71
60
69
62
65
64
63
68
log Y (ycs) = 42.619 + 0.575 X (level)
N = 22 r = 0.612 P = 0.0025

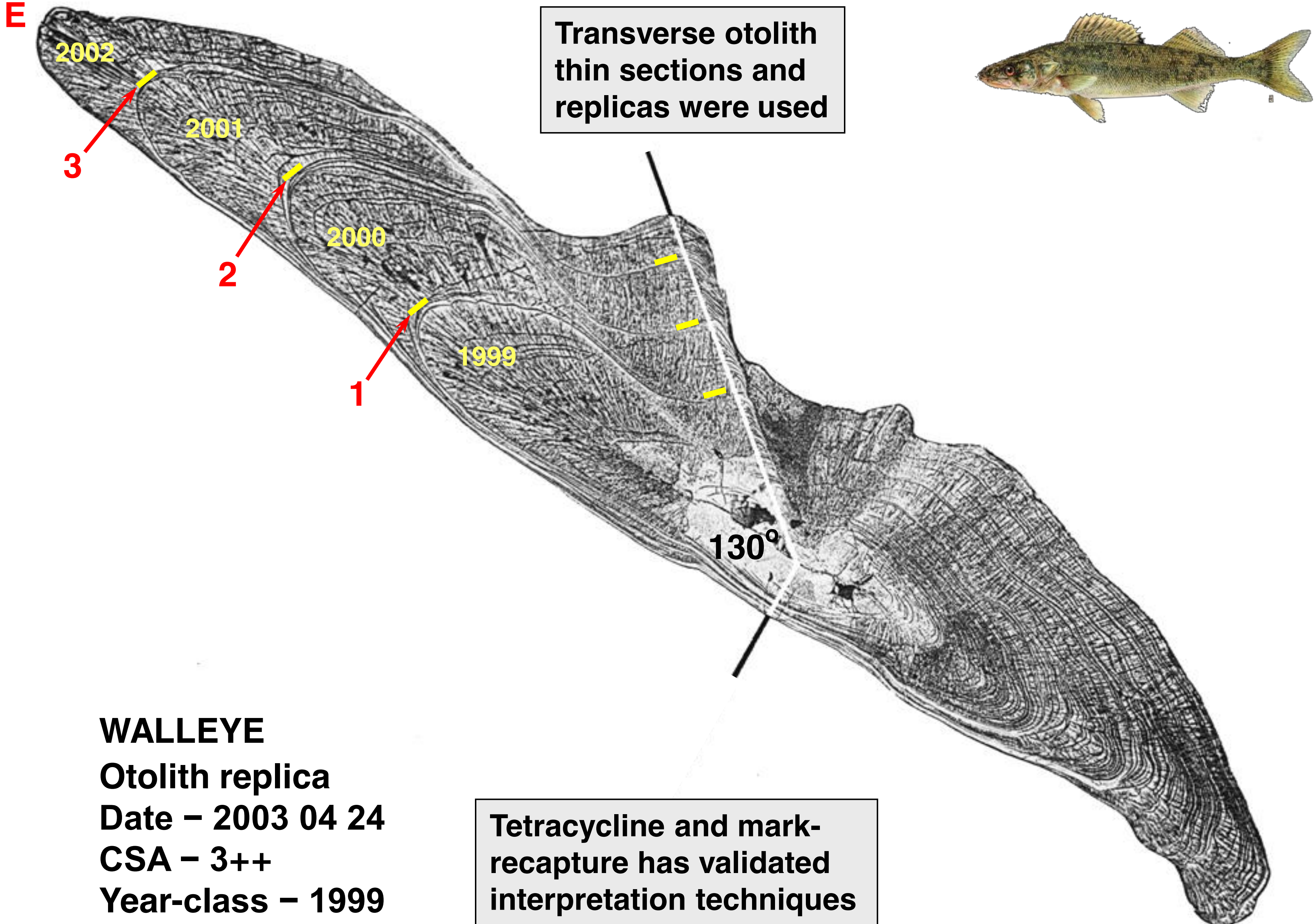


NORTHERN PIKE – Upper St. Lawrence River
SPRING WATER LEVEL – Stabilized and droughts
1970 – 2000
log RELATIVE YEAR-CLASS STRENGTH (%)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
WATER LEVEL (m)
74.2
74.3
74.4
74.5
74.6
74.7
74.8
74.9
75.0
75.1
75.2
75.3
75
78
73
98
83
79
87
99
94
72
76
70
74
95
77
82
71
00
90
84
91
93
88
81
80
86
97
89
92
85
96
log Y (ycs) = – 20.035 + 0.271 X (level)
N = 31 r = 0.288 P = 0.1162 ns

Growth Response, Climate Change, and Global Warming

Body growth in length and weight by thermal grouping, determined from otolith growth





Transverse otolith thin sections and replicas were used

Tetracycline and mark-recapture has validated interpretation techniques

WALLEYE
Otolith replica
Date – 2003 04 24
CSA – 3++
Year-class – 1999
Lake Ontario

Relative change in otolith growth and body length and weight for Lake Ontario smallmouth bass, walleye, and lake whitefish in an increasing nearshore summer temperature regime.

Species	Temperature		Otolith growth (%)	Change in body size (%)	
	Mean (°C)	Change		Length	Weight
Smallmouth bass	22.6	0			
	23.6	+1°	+9.4	+9.2	+33.0
	24.6	+2°	+19.0	+18.1	+68.4
	25.6	+3°	+28.2	+27.6	+92.0
Walleye	22.6	0			
	23.6	+1°	+10.1	+9.1	+32.8
	24.6	+2°	+20.3	+18.1	+63.3
Lake whitefish	22.6	0			
	23.6	+1°	- 11.0	- 4.5	- 14.3
	24.6	+2°	- 22.1	- 9.4	- 28.1
	25.6	+3°	- 33.1	- 14.4	- 41.2

Summary

- **The new challenge will be to manage changing water and fish resources and fisheries in a changing and more variable environment.** ***Fortunately, some of these changes and responses are predictable and can be quantified.***

- **Changing environmental conditions necessitate more regular and rigorous monitoring of not only fish and fisheries but also environmental conditions, taking into consideration water-body specifics.** ***Need more and better data and science by locale and latitude.***

Summary

How will we manage and adapt?

We should . . .

- **Publicize that fish are very sensitive indicators of climate change and that fish are responding and fish communities are changing; some fish are adapting, but displacement will be most common.** ***Unprecedented change is underway.***

- **Emphasize the increasing value of local fish resources and manage to take advantage of those that are increasing in abundance while protecting those that are declining and being displaced.** ***Adapt by using local fish and fisheries.***

How do we both adapt and mitigate?

We should . . .

Reduce our carbon footprint by making local fish an important part of our local menu !

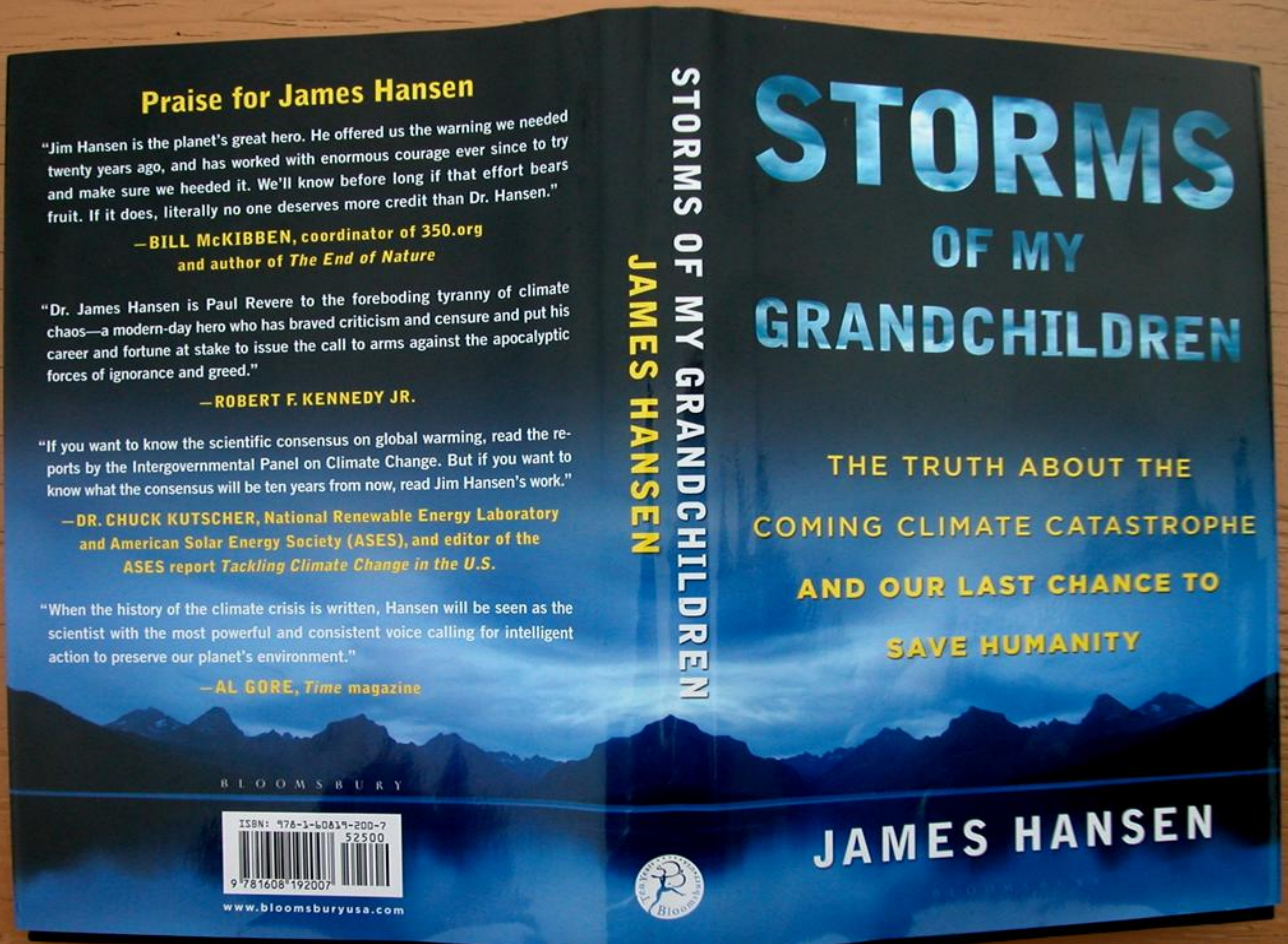
Natural Resources Canada
Ressources naturelles Canada

Mississippi Valley Conservation

Queen's University

Ontario

Thank you !


Praise for James Hansen
"Jim Hansen is the planet's great hero. He offered us the warning we needed twenty years ago, and has worked with enormous courage ever since to try and make sure we heeded it. We'll know before long if that effort bears fruit. If it does, literally no one deserves more credit than Dr. Hansen."
—BILL McKIBBEN, coordinator of 350.org and author of The End of Nature
"Dr. James Hansen is Paul Revere to the foreboding tyranny of climate chaos—a modern-day hero who has braved criticism and censure and put his career and fortune at stake to issue the call to arms against the apocalyptic forces of ignorance and greed."
—ROBERT F. KENNEDY JR.
"If you want to know the scientific consensus on global warming, read the reports by the Intergovernmental Panel on Climate Change. But if you want to know what the consensus will be ten years from now, read Jim Hansen's work."
—DR. CHUCK KUTSCHER, National Renewable Energy Laboratory and American Solar Energy Society (ASES), and editor of the ASES report Tackling Climate Change in the U.S.
"When the history of the climate crisis is written, Hansen will be seen as the scientist with the most powerful and consistent voice calling for intelligent action to preserve our planet's environment."
—AL GORE, Time magazine
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