FINAL REPORT B

Climate Change Action Fund

Project A217

SUMMARY OF COMMUNICATIONS AND PRESENTATIONS

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COMMUNICATIONS AND PRESENTATIONS

Results from this project have been presented at various workshops, symposiums and conferences in the past 8 months. To date, 7 presentations have been completed. Descriptions of presentations made are summarized below, while copies of material presented are attached to this document. Presenting author is underlined.

1). *Atlantic Canada Climate Change – A Community Forecast*: October 12 – 13th 2000, Rodd Miramichi River, Miramichi, New Brunswick

Authors:	N. El-Jabi, G. Chaput, D. Caissie, and E. Swansburg
Type of Communication:	Pamphlet
Title:	Impact of climate change on river water temperatures and fish growth

Distributed a pamphlet to government, industry, and community groups outlining the objectives and preliminary results of research on the effects of environmental conditions (temperature, discharge) on growth of juvenile Atlantic salmon.

2). *Miramichi Atlantic Salmon Workshop*: December 1, 2000, Atlantic Salmon Museum, Doaktown, New Brunswick

Authors:	N. El-Jabi, G. Chaput, D. Caissie, and E. Swansburg
Type of Communication:	Oral Presentation
Title:	Impact of climate change on river water temperatures and fish growth

This presentation briefly discussed preliminary changes in air temperature, discharge and fork length of juvenile Atlantic salmon in the last 30-50 years in the Northwest and Southwest Miramichi Rivers with reference to climate change. Workshop participants included government, industry, and community groups.

3). *Canadian Conference for Fisheries Research (CCFFR)*: January 4 – 6th 2001, Royal York Hotel, Toronto, Ontario

Authors:	E. Swansburg, N. El-Jabi, G. Chaput, and D. Caissie
Type of Communication:	Poster Presentation
Title:	Impact of climate change on river water temperatures and growth of Atlantic salmon (*Salmo salar*)

This presentation examined changes in air temperature, discharge and fork length of juvenile Atlantic salmon in the last 30-50 years in the Northwest and Southwest Miramichi Rivers with reference to climate change. Growth potential of juvenile Atlantic salmon (1970-99) was also examined using a maximum growth model and compared to changes in juvenile fork length. Conference participants included government, university, and industry.

4). *Miramichi Salmon Association Symposium*: February 10th, 2001, Boston, Massachusetts

Authors:	D. Moore and G. Chaput
Type of Communication:	Oral Presentation
Title:	What has caused decreased salmon returns to the Miramichi River in recent years - freshwater or marine factors?

This presentation examined whether declines in the return of adult salmon were as a result of decreased smolt production or decreased smolt survival at sea. Climate change (i.e. warmer river water temperatures) was examined as a factor contributing to decreased smolt production. Outfitters and anglers were in attendance.

5). *Fisheries and Oceans Open House – Science Branch*: March 2, 2001, Gulf Fisheries Centre, Moncton, New Brunswick

Authors:	E. Swansburg, N. El-Jabi, G. Chaput, and D. Caissie
Type of Communication:	Poster Presentation
Title:	Impact of climate change on river water temperatures and growth of Atlantic salmon (*Salmo salar*) / Impact du changement climatique sur la température de l'eau et sur la croissance du saumon Atlantic (*Salmo salar*)

This presentation examined changes in hydrological and meteorological conditions and fork length of juvenile Atlantic salmon in the Miramichi River over the past 30 – 50 years, with reference to climate change. Associations between increased temperature and decreased fork length were described. Open house participants included government employees at Gulf Fisheries Centre.

6). *Fisheries Oceanography Committee*: March 27 - 30th, 2001, Gulf Fisheries Centre, Moncton, New Brunswick

Authors:	D. Caissie, E. Swansburg, G. Chaput and N. El-Jabi
Type of Communication:	Oral Presentation
Title:	Long-term hydrologic conditions in the Miramichi River and potential implication of climate change to aquatic resources

This presentation outlined the results of the climate change action fund (CCAF) research relating environmental conditions of the Miramichi River to fish population and fish growth. Data were presented on trends in both seasonal and annual air and discharge. Long-term trends in summer fish growth and its potential relation to water temperatures were also presented.

7). *North Atlantic Working Group of the International Council for the Exploration of the Sea (ICES)*: April 2-12, 2001, Aberdeen, Scotland

Authors:	E. Swansburg, N. El-Jabi, G. Chaput, D. Caissie, and D. Moore
Type of Communication:	Oral Presentation, Distribution of Final Report
Title:	Impact of climate change on river water temperatures and juvenile salmon growth

A similar presentation was made at ICES as was given at the Fisheries Oceanography Committee. The working group consisted of national representatives from Canada and US and all European countries with interests in Atlantic salmon.

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CANADIAN CLIMATE ACTION FUND

IMPACT OF CLIMATE CHANGE ON RIVER WATER TEMPERATURES AND FISH GROWTH

N. El-Jabi[1], G. Chaput[2], D. Caissie[2], E. Swansburg[1]. [1]Université de Moncton, [2]Fisheries and Oceans Canada.

INTRODUCTION:

Climate change in the Maritime Provinces is projected to result in a 2 to 6° C increase in air temperature within the next 100 years. Higher air temperatures are expected to contribute to increased water temperatures, alterations in stream flow conditions, and ultimately reductions in available fish habitat. In the Miramichi River, New Brunswick, Atlantic salmon (*Salmo salar*) are located near the southern limit of its' distribution, making them sensitive to extreme environmental conditions.

Recent increases in water temperature, approaching upper lethal limits (30° C), and severe low flow conditions may be adversely affecting growth of juvenile Atlantic salmon and reducing at sea survival.

OBJECTIVES:

The objective of the present proposal is to examine hydrological conditions and river temperatures in eastern Canada during the past 50 years and to assess the potential consequences of climate change on the growth of juvenile Atlantic salmon.

Specifically, the study will:

1. use an existing database on air temperature (1940-99) and water temperature (1990-99) to extend the water temperature time series from 1970-99. Level and frequency of high summer temperature events (1970-99) against the historical occurrences (1940-99) and relative to the warming scenario of 2 to 6° C.

2. examine the association between extreme hydrological conditions (high temperature and low flow) and size-at-age juvenile Atlantic salmon (1970-99).

PRELIMINARY RESULTS:

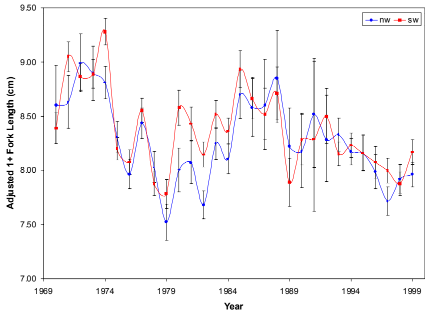
Record high summer air temperatures were observed in 1999, which resulted in a long duration of high water temperatures. In 1998 and 1999, deviations from monthly mean air temperatures were largest during the spring, fall and winter months. Extreme winter conditions (high peak flows) were not observed more frequently over recent years. However, severity of drought conditions has increased in the Miramichi Drainage Basin. The most severe low flow conditions in the past 60 years have been observed recently.

A stochastic model was calibrated using the Little Southwest Miramichi River temperatures, from 1992 to 1999. It was possible to predict stream water temperatures within 1.5° C of actual observed data on a daily basis. On a monthly basis, the stochastic model predicts water temperatures within 0.75° C of actual values.

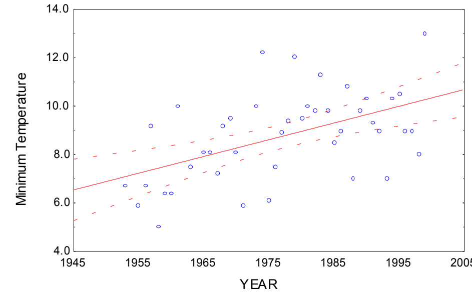
Mean annual fork length of small and large Atlantic salmon parr have decreased significantly (0.02 cm/year) since 1970 ($p<0.006$). Mean fork length of small and large salmon parr are 5.5% and 6.5% smaller, respectively, in 1999 than in 1970. Mean annual fork length of Atlantic salmon fry increased marginally (0.002 cm/year) since 1970, although this trend is not significant ($p<0.811$).

APPLICATIONS:

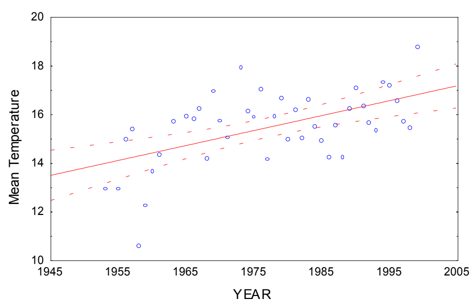
This study will allow us to better understand the potential negative effects of climate change on important resources and provide guidance for the development of mitigative measures, such as the protection of cold water streams.



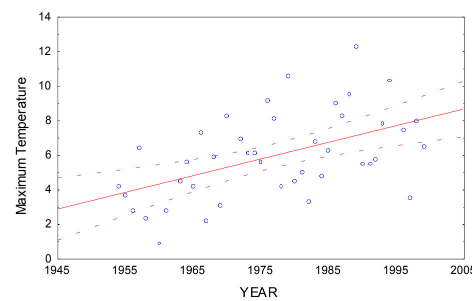
Fork Length (cm) of 1+ Atlantic Salmon in the Northwest and Southwest Miramichi Rivers (1970-1999). Data has been adjusted for sampling day and density



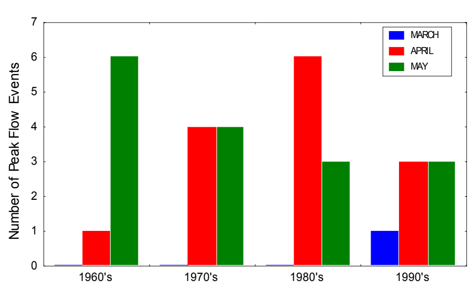
Minimum Air Temperature in June at Doaktown meteorological station from (1953-1999)



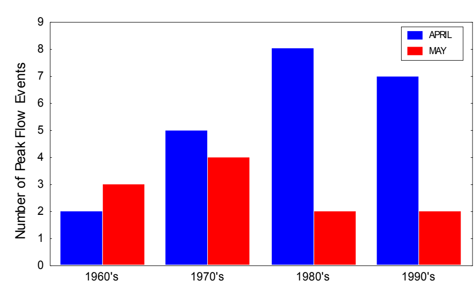
Mean Air Temperature in June at Doaktown meteorological station from (1953-1999)



Maximum Air Temperature in Winter at Doaktown meteorological station from (1953-1999)



Timing of Peak Discharge Events in the Northwest Miramichi River from (1963-1999)



Timing of Peak Discharge Events in the Southwest Miramichi River from (1962-1999)

IMPACT OF CLIMATE CHANGE ON RIVER WATER TEMPERATURE AND GROWTH OF ATLANTIC SALMON (*Salmo salar*)

E. Swansburg[1], N. El-Jabi[1], G. Chaput[2], and D. Caissie[2]
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[2]Fisheries and Oceans Canada / Pêches et Océans, Moncton, N.B.

ABSTRACT

Climate change in the Maritime Provinces is projected to result in a 2 to 6ºC increase in air temperature within the next 100 years. Higher air temperatures are expected to contribute to increased water temperatures, alterations in stream flow conditions, and ultimately reductions in available fish habitat. Recent increases in water temperature, may be adversely affecting growth of juvenile Atlantic salmon and reducing sea survival. Mean annual air temperature at Doaktown has increased significantly, by 0.22º C/decade, from 1955-1999 ($p<0.032$). Significant increases in air temperature were also observed in spring and summer months. Timing of spring peak discharge, in the Northwest Miramichi R., has shifted from May in the 1960's to April in the 1980's. In the 1990's peak discharge was observed in March. Mean annual fork length of small and large Atlantic salmon parr have decreased significantly (0.19 cm/decade) since 1970 ($p<0.006$). However, the potential for growth of juveniles in the Northwest and Southwest Miramichi R. has remained unchanged from 1970-1999, according to the growth potential model (GPI). In addition, there is a negative correlation between GPI and fork length of juveniles from 1970-1999 ($p<0.029$). In this system, alterations in air and water temperature are not directly contributing to changes in fish growth.

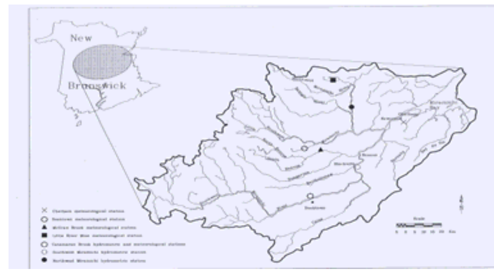


Figure 1: Hydrometric and meteorological stations of the Northwest and Southwest Miramichi Rivers, New Brunswick

INTRODUCTION

Among the most important environmental conditions linked to productivity in aquatic ecosystems are water temperatures and streamflow. Climate change in the Maritime Provinces is expected to increase air temperature by 2 to 6°C, altering water temperature regimes and streamflow conditions [1]. High water temperatures can adversely affect aquatic resources by limiting growth [2], reducing available fish habitat [3], increasing susceptibility to infection and disease [4], and increasing fish mortality [5,6].

High water temperatures (≅ 30°C) and severe low flow conditions have been observed recently in the Miramichi R., New Brunswick [7,8]. Coincident with these conditions, juvenile salmon at age were smaller than expected. While high juvenile Atlantic salmon abundance has been observed in the Miramichi River, this has not translated into high adult returns. In fact, returning adults have declined [9]. Recent high temperatures may be adversely affecting growth of juvenile Atlantic salmon and contributing to reduced sea survival.

OBJECTIVES

1). Examine trends in hydrological, meteorological and biological data over time

H_O : no change over time
H_A : ↑ in temperature, ↓ in fork length

2). Examine relationship between GPI and fish size from 1970-1999 in the Miramichi Drainage basin

H_O : no change in fish size with ↑ GPI
H_{A1} : ↑ fork length with ↑ GPI
H_{A2} : ↓ fork length with ↑ GPI

MATERIALS AND METHODS

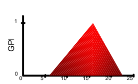
Data Collection

Air temperature and river discharge data were collected at 5 meteorological and 2 hydrometric stations operating in the Miramichi region from 1943-99 (Fig.1).

Juvenile Atlantic salmon fork length data was obtained from electrofishing surveys conducted on the Northwest and Southwest Miramichi Rivers (1970-1999).

Data Analysis

Growth potential was determined based on the model by Elliott and Hurley (1997):



GPI was calculated daily and summed over the parr growing season (early May - July 15).

Trends were analysed by linear regression (STATISTICA). All data was log_{10} transformed prior to analysis.

RESULTS

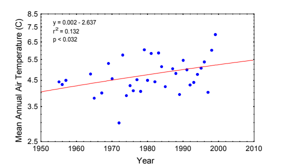


Figure 2: Mean annual air temperature (ºC) at Doaktown meteorological station (1955-1999).

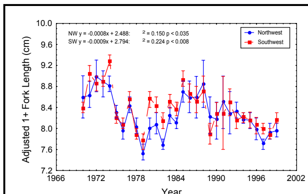


Figure 5: Mean (±1 SE) fork length (cm) of 1+ Atlantic Salmon in the Northwest and Southwest Miramichi Rivers (1970-1999). Data has been adjusted for sampling day and density.

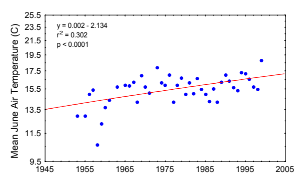


Figure 3: Mean air temperature (ºC) in June at Doaktown meteorological station (1953-1999).

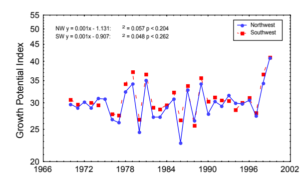


Figure 6: Growth potential index of 1+ Atlantic Salmon in the Northwest and Southwest Miramichi Rivers (1970-1999). Data is based on air temperature.

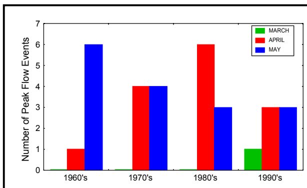


Figure 4: Number of peak discharge events per month in the Northwest Miramichi River from (1963-1999).

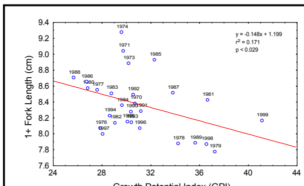


Figure 7: Relationship between growth potential and fork length of 1+ Atlantic Salmon in the Southwest Miramichi River (1970-1999).

DISCUSSION

Air temperature at Doaktown has increased significantly by 0.22° C/decade. Within the next 100 years, assuming this rate of increase is constant, air temperature will increase by 2.2° C, which is within the range (2-6 ° C) predicted for the Maritime region [1]. Such an increase in temperature may adversely affect growth [2], reduce available fish habitat [3], increase susceptibility to infection and disease [4], and inc rease fish mortality [5,6].

Peak discharge in the Northwest Miramichi River occurred earlier in the year with each subsequent decade. Earlier snow melt and runoff advances the onset of dry spring-summer conditions, hastening the occurrence of low flow conditions [10].

Juvenile Atlantic salmon were significantly smaller in recent years than previously documented. Smaller fork length could affect the ability of salmon to compete in freshwater habitats and survive a seaward migration [11].

Growth potential has not changed significantly over the past 30 years, despite increasing temperatures. In fact, contrary to our hypothesis, increasing growth potential is significantly correlated to decreasing fork length. Elliott and Hurley's [2] growth potential index may not be well suited to predict fish growth in these populations, perhaps due to the laboratory basis for its derivation (ample food, no competition, predation). Alternatively, these fish may not be frequently experiencing temperatures that are outside their range of tolerance for growth.

While environmental conditions are changing in the Miramichi River, these changes do not appear to contribute significantly to reductions in fish growth. Therefore, the effect of climate change on the Atlantic salmon populations remains uncertain.

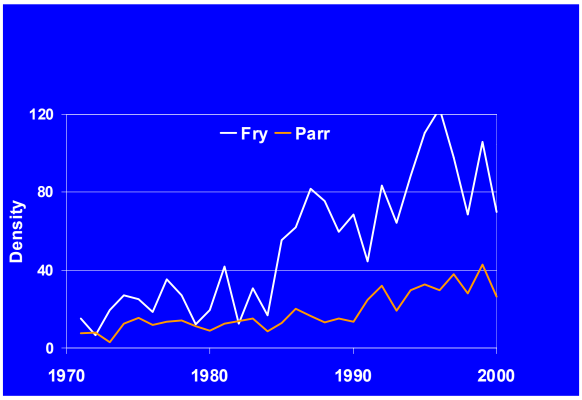
ACKNOWLEDGEMENTS

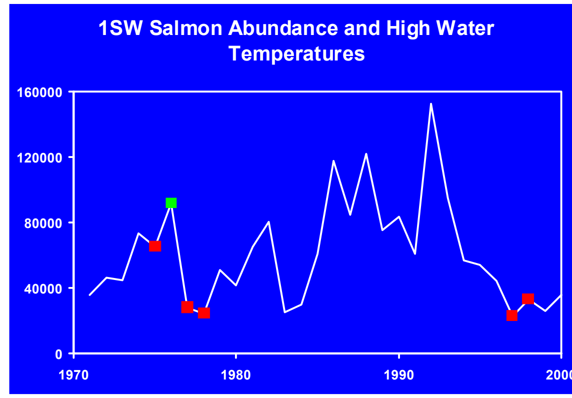
We would like to thank the Climate Change Action Fund (Project A217) for providing the funding for this project. We would also like to thank Environment Canada for providing some historical hydrological and meteorological data, Dave Moore (DFO) for compiling Atlantic salmon electrofishing data, and Jim Conlon (DFO) for preparing the Miramichi drainage basin site map.

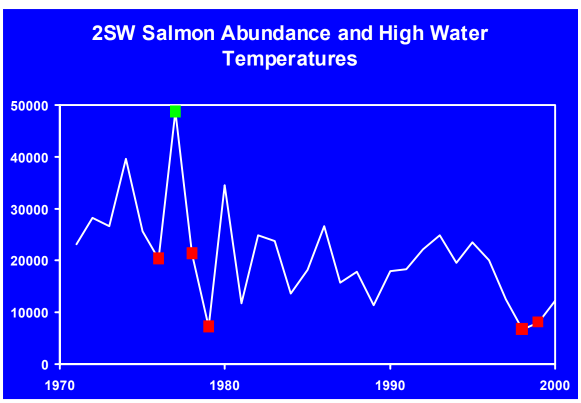
REFERENCES

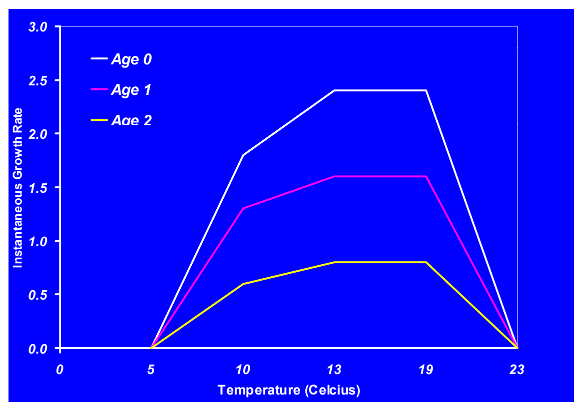
1. Parks Canada. 1999. Air issues bulletin no.100, Natural Resources Branch, Parks Canada, Ottawa.; 2. Elliott, J.M. and M.A. Hurley. 1997. Functional Ecology. 11: 592-603; 3. Cunjack, R.A., D. Caissie, N. El-Jabi, P. Hardie, J.H. Conlon, T.L. Polloc D.J. Giberson, and S. Komadina-Douthwright. 1993. Can. Tech. Rep. Fish. Aquat. Sci. 1914: 81p.; 4. Schreck, C.B. and H.W. Li. 1991. In: D.E. Brune and J.R. Tomasso (editors); Aquaculture and water quality. Advances in World Aquaculture 3. World Aquacult ure society, Baton Rouge, Louisiana, USA, p. 21-29.; 5. Lee, R.M. and J.N. Rinne. 1980. Transactions of the American Fisheries Society. 190(6): 632-635.; 6. Bjornn, T.C. and D.W. Reiser. 1991. In: W.R. Meehan (editor); American Fisheries Society, Spe cial Publication 19, pp. 83-138.; 7. Caissie, D. 1995. DFO Atlantic Fisheries Research Document. 95/88.; 8. Caissie, D. 2000. DFO Can. Stock Assess. Sec. Res. Doc. 2000/011, 30p.; 9. Chaput, G. and E. Prévost. 1999. DFO Atlantic Fisheries Research Document. 99/30, 45p.; 10. Manabe, S. and R.T. Wetherald. 1987. Journal of the Atmospheric Sciences. 44: 1211-1235.; 11. Ritter, J.A. 1977. International Council for the Exploration of the Seas, C.M. 1977/M:27, 6 p.

CCFFR - January 4-6, 2001





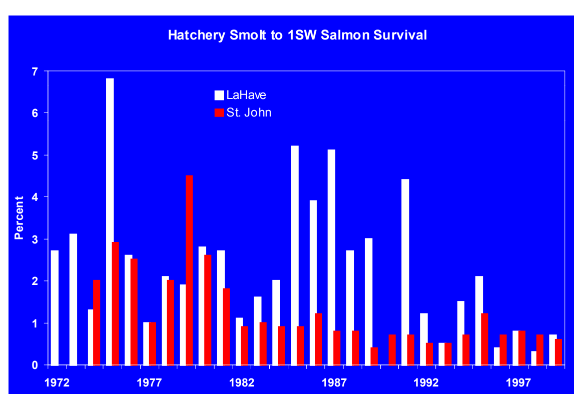


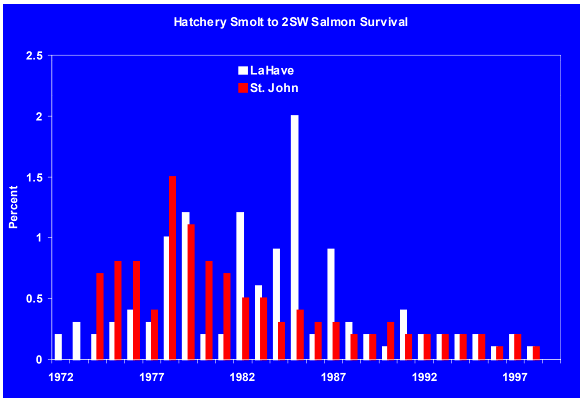


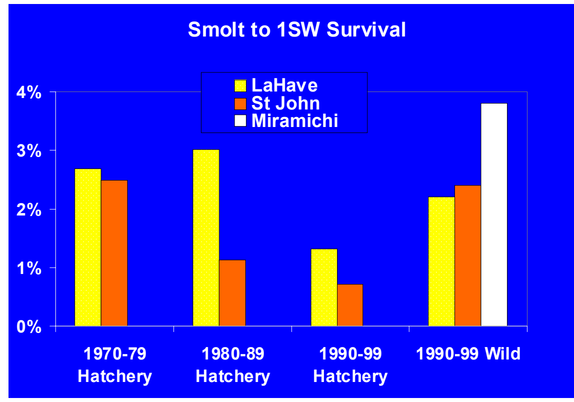
Consecutive days with water temperatures over 19° C

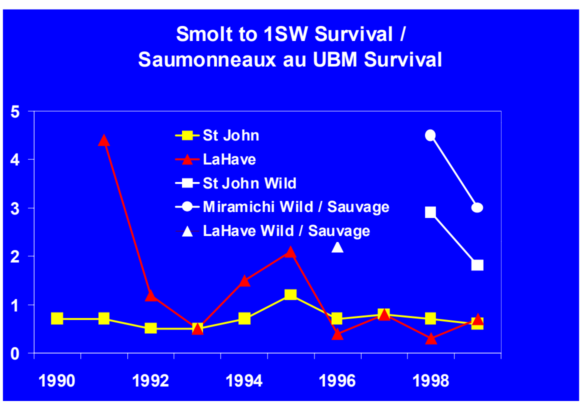
Extreme = 50 or more consecutive days of high temperatures

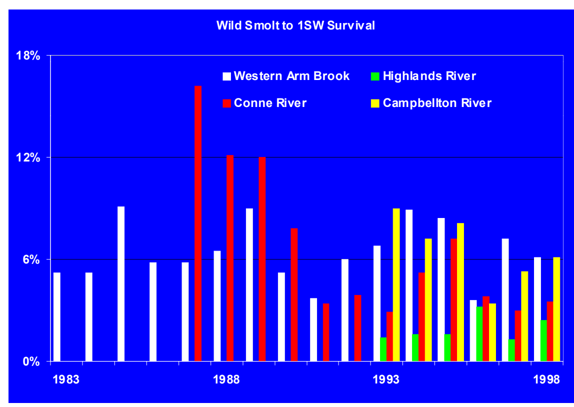
1975	57 days starting on June 24
1973	55 days starting on June 22
1995	50 days starting on July 3

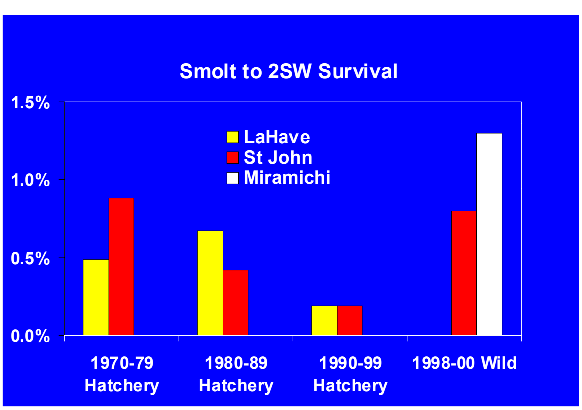


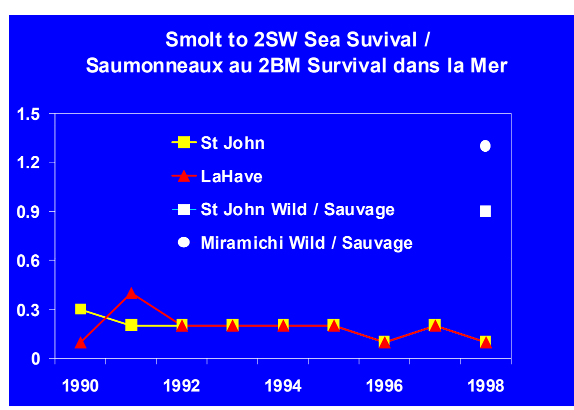

Hatchery Smolt to 2SW Salmon Survival
LaHave
St. John
Percent
2.5
2
1.5
1
0.5
0
1972
1977
1982
1987
1992
1997


Smolt to 1SW Survival
LaHave
St John
Miramichi
4%
3%
2%
1%
0%
1970-79 Hatchery
1980-89 Hatchery
1990-99 Hatchery
1990-99 Wild


Smolt to 1SW Survival / Saumonneaux au UBM Survival
St John
LaHave
St John Wild
Miramichi Wild / Sauvage
LaHave Wild / Sauvage
5
4
3
2
1
0
1990
1992
1994
1996
1998


Wild Smolt to 1SW Survival
Western Arm Brook
Highlands River
Conne River
Campbellton River
18%
12%
6%
0%
1983
1988
1993
1998


Smolt to 2SW Survival
LaHave
St John
Miramichi
1.5%
1.0%
0.5%
0.0%
1970-79 Hatchery
1980-89 Hatchery
1990-99 Hatchery
1998-00 Wild


Smolt to 2SW Sea Suvival / Saumonneaux au 2BM Survival dans la Mer
St John
LaHave
St John Wild / Sauvage
Miramichi Wild / Sauvage
1.5
1.2
0.9
0.6
0.3
0
1990
1992
1994
1996
1998

IMPACT OF CLIMATE CHANGE ON RIVER WATER TEMPERATURE AND GROWTH OF ATLANTIC SALMON (*Salmo salar*) /
IMPACT DU CHANGEMENT CLIMATIQUE SUR LA TEMPÉRATURE DE L 'EAU ET SUR LA CROISSANCE DU SAUMON ATLANTIC (*Salmo salar*)

Université de Moncton

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[2]Fisheries and Oceans Canada / Pêches et Océans, Moncton, N.B.

Fisheries and Oceans Canada / Pêches et Océans Canada

CLIMATE CHANGE IN THE MARITIME PROVINCES / CHANGEMENT CLIMATIQUE DANS LES PROVINCES MARITIMES

- air temperature ↑ of 2 - 6° C within next 100 years
- higher air temperature
  - increased water temperature
  - alterations in stream flow conditions
  - reductions in available fish habitat
- implications
  - reduce growth of juvenile Atlantic salmon
  - reduce at-sea survival

Fry

Parr

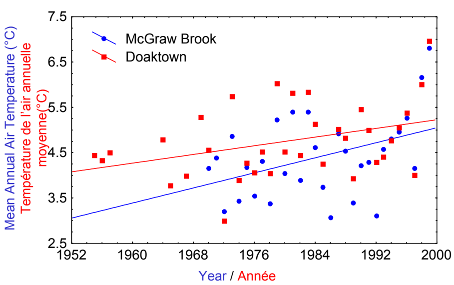
- ↑ de 2 - 6° C de la température de l'air dans les 100 prochaines années
- température de l'air plus élevée
  - augmentations de la température de l'eau
  - changement dans l'écoulement de surface
  - réduction de l'habitat disponible du poisson
- implications
  - réduction de la croissance des saumons juvéniles
  - réduction de la suivie en mer

DATA COLLECTION / COLLECTE DE DONNÉES

- meteorological and hydrological data collected (1943-1999)
- biological data collected from electrofishing surveys in the NW and SW Miramichi R. (1970-1999)

- données météorologiques et hydrologiques (1943-1999)
- données biologiques de pêche électrique des rivières NW et SW Miramichi (1970-1999)

MEAN ANNUAL AIR AND WATER TEMPERATURE AT DOAKTOWN AND MCGRAW BROOK (1955-1999) / TEMPÉRATURE ANNUELLE MOYENNE DE L'AIR ET DE L'EAU À DOAKTOWN ET MCGRAW BROOK (1955-1999)

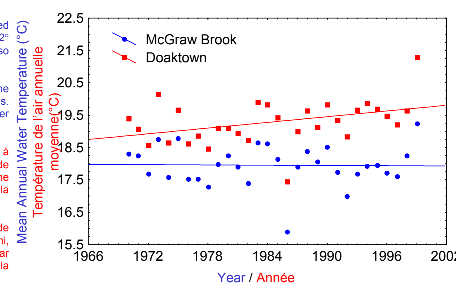


Mean annual air temperature at Doaktown and McGraw Brook increased significantly from 1952-1999 ($p<0.028$), by 0.24° C/decade and 0.42° C/decade, respectively. Air temperature during spring and summer also increased significantly ($p<0.008$).

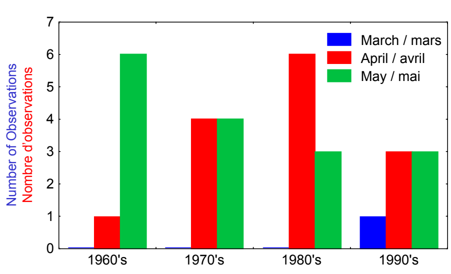
Annually, water temperature did not change significantly in either the Northwest or SW Miramichi R., despite air temperature increases. However, water temperature did significantly increase during summer months in the SW Miramichi R. ($p<0.037$).

Une augmentation significative de la température moyenne de l'air à Doaktown et McGraw Brook a été observée de 1952-1999 ($p<0.028$), de 0.24° C/décennie et de 0.42° C/décennie, respectivement. Une augmentation significative a aussi été observée au niveau de la température de l'air au printemps et en été ($p<0.008$).

Sur une base annuelle la température de l'eau ne démontra pas de changements significatives pour les rivières Northwest ou SW Miramichi, même que la température de l'air démontra une augmentation. Par contre, la température de l'eau démontra une augmentation durant la période estivale pour la rivière SW Miramichi ($p<0.037$).



MONTHLY DISTRIBUTION OF PEAK DISCHARGE EVENTS IN THE NW MIRAMICHI R. (1961-1999) / DISTRIBUTION MENSUELLE DES DÉBITS DE POINTE DE LA RIVIÈRE NW MIRAMICHI (1961-1999)



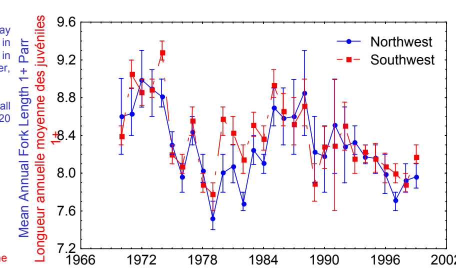
Timing of spring peak discharge, in the NW Miramichi R., shifted from May in the 1960's to April in the 1980's, with a single peak discharge event in March in the 1990's. Timing of peak discharge changed significantly in both the NW and SW Miramichi, occurring 6 and 5 days earlier, respectively, with each subsequent decade ($p<0.026$).

In both the NW and SW Miramichi R., mean annual fork length of small (1+) and large (2+) Atlantic salmon parr decreased significantly (0.20 cm/decade) since 1970 ($p<0.029$).

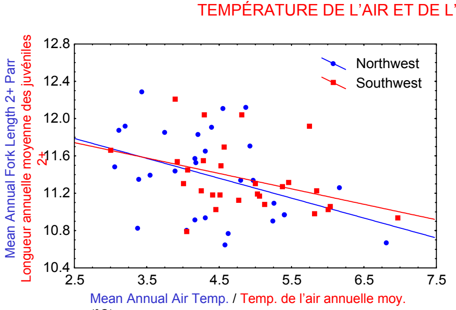
Le temps d'occurrence des crues printanières de la rivière NW Miramichi ont été observé en mai durant les années 60, en avril durant les années 80 et une crue printanière a été observé en mars durant les années 90. Le temps d'occurrence des crues printanières est plus tôt de façon significatifs sur les rivières NW et SW Miramichi de 5 à 6 jours par décennie ($p<0.026$).

Sur les rivière NW et SW Miramichi, la longueur moyenne annuelle des saumons de l'Atlantique juvéniles alevin (1+) et juvéniles (2+) ont subi une diminution significative (0.20 cm/décennie) depuis 1970 ($p<0.029$).

MEAN ANNUAL FORK LENGTH (cm) OF 1+ PARR (1970-1999) / LONGUEUR ANNUELLE MOYENNE (cm) DES JUVÉNILES 1+ (1970-1999)



AIR AND WATER TEMPERATURE VS. FORK LENGTH OF JUVENILE ATLANTIC SALMON / TEMPÉRATURE DE L'AIR ET DE L'EAU EN FONCTION DE LA LONGUEUR DES SAUMONS ATLANTIQUES JUVÉNILES

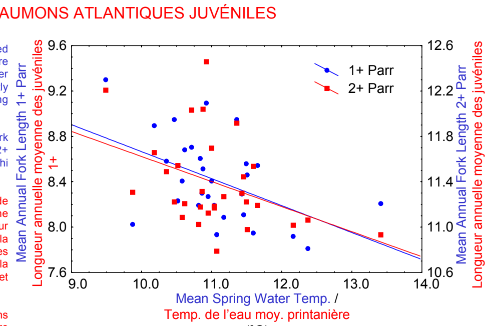


In both the NW and SW Miramichi R., fork length of 2+ parr decreased significantly (0.17 - 0.21 cm/°C) with increased annual air temperature ($p<0.041$). Fork length in the NW Miramichi was not correlated to water temperature. In the SW Miramichi R., fork length decreased significantly with increased water temperature both annually and seasonally (spring and fry growth season) ($p<0.037$).

Within the next 100 years we should expect to see declines in the fork length of juvenile Atlantic salmon in the Miramichi R. Fork length of 2+ parr may decline by 0.42 (± 0.18) - 1.26 (± 0.55) cm in the NW Miramichi R., and 0.34 (± 0.15) - 1.02 (± 0.46) cm in the SW Miramichi R.

Pour chaque rivière, NW et SW Miramichi, une diminution significative de la longueur des juvéniles 2+ a été observée (0.17 - 0.21 cm/°C) avec une augmentation de la température de l'air annuelle ($p<0.041$). La longueur des juvéniles de la rivière NW Miramichi n'était pas reliée avec la température de l'eau. Pour la rivière SW Miramichi, la longueur des juvéniles démontra une diminution avec une augmentation de la température de l'eau sur une base annuelle et saisonnière (printemps et saison de croissance des alevins 0+) ($p<0.037$).

Dans les prochaines 100 années, on devrait observer une diminution dans la longueur des juvéniles de saumons Atlantiques dans la rivière Miramichi. La longueur des juvéniles 2+ subira une diminution de 0.42 (± 0.18) - 1.26 (± 0.55) cm dans la rivière NW Miramichi, et de 0.34 (± 0.15) - 1.02 (± 0.46) cm dans la rivière SW Miramichi.



Long-term hydrological conditions in the Miramichi River and potential implication of climate change to aquatic resources

by

D. Caissie[1], E. Swansburg[2], G. Chaput[1], D. Moore[1], N. El-Jabi[2]

1. Fisheries and Oceans; 2. Université de Moncton

Introduction

– Climate change projections: air temperature ↑ of 2 - 6° C within next 100 years (Atlantic):

– Higher air temperature:
  - increased water temperature;
  - alterations in streamflow regime;
  - changes in available fish habitat.

– Potential biological implications:
  - reduced growth of juvenile Atlantic salmon;
  - reduced at-sea survival.

Materials and methods

- Meteorological and hydrological data in the Miramichi River, 1943-99;
- River water temperatures,1992-99;
- Biological data collected from electrofishing surveys in the Miramichi R., 1970-99.

Study Sites

- Hydrological Data (discharge):
  – Southwest Miramichi River (Blackville);
  – Northwest Miramichi River (Trout Brook);
- Air temperature Data:
  – Doaktown station;
  – McGraw Brook station;
- Water Temperature Data:
  – SW Miramichi at Doaktown;
  – Little Southwest Miramichi R.;
- Biological Data (electrofishing):
  – SW Miramichi R., (>13 sites);
  – Northwest Miramichi R., (> 22 sites).

Annual/seasonal trends

- Annual, seasonal & growth season:
  – Winter (Jan-Mar), Spring (Apr-Jun);
  – Summer (Jul-Sep), Autumn (Oct-Dec);
  – Fish growth season.
- Fish growth season:
  – Starting with the 3-day moving avg. reaching 6°C for water temperature;
  – Ending on July 15 for parr & Aug 31 for Fry.

Extending water temperature time series (1970-99)

- Stochastic water temperature model:
  – With data from Little Southwest Miramichi R. (1992-99) and SW Miramichi R. (1999-00), calibrate a stochastic water temperature model.
- Simulate water temperatures (1970-99):
  – Simulation of water temperatures for both Northwest and Southwest Miramichi R.;

Stochastic water temperature model
calibration (1992-99), simulation (1970-99)

Water temperature (*Tw*) :

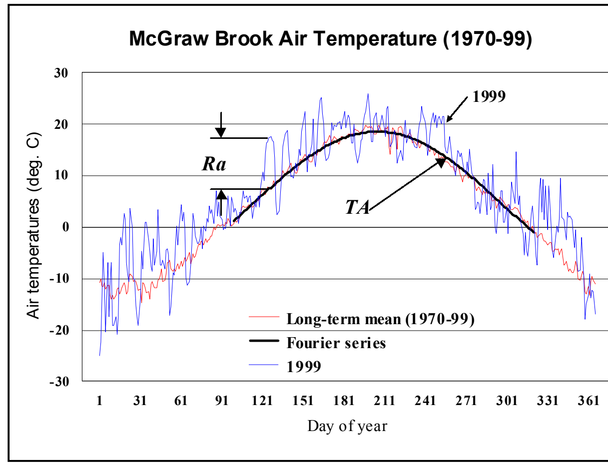
$$Tw(t) = TA(t) + Rw(t)$$

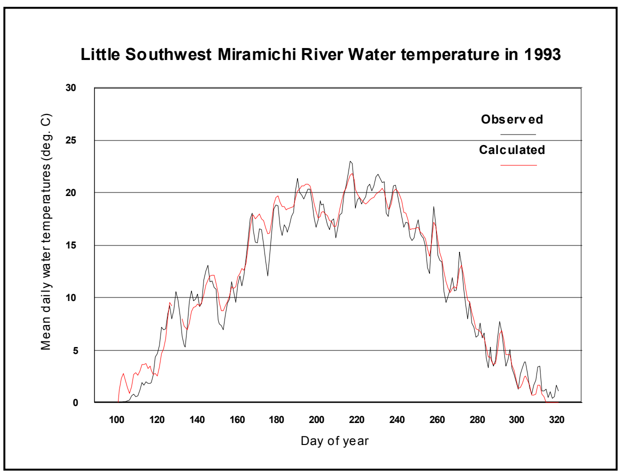
Annual component, Fourier series (*TA*):

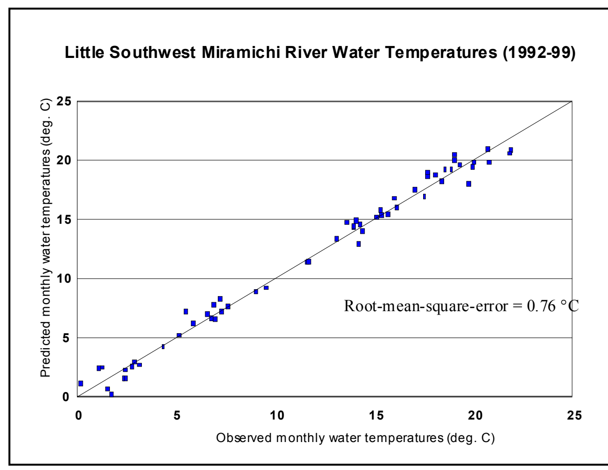
$$TA(t) = \frac{A_o}{2} + \sum_{n=1}^{\infty} \left(A_n \left[\cos\left((t - j - 1) \frac{2n\pi}{N} \right) \right] + B_n \left[\sin\left((t - j - 1) \frac{2n\pi}{N} \right) \right] \right)$$

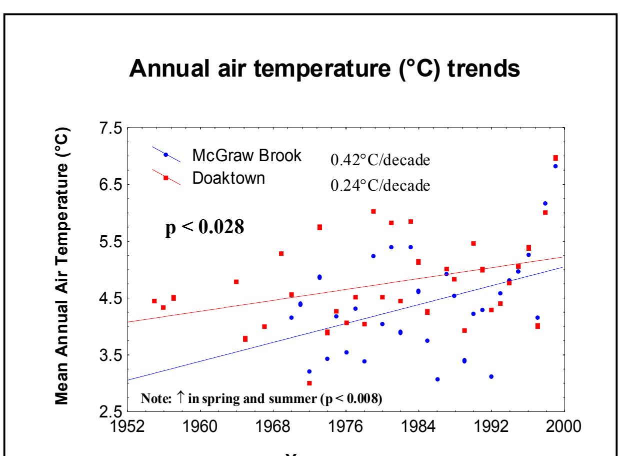
Short-term residuals, i.e. departure from annual (*Rw*):

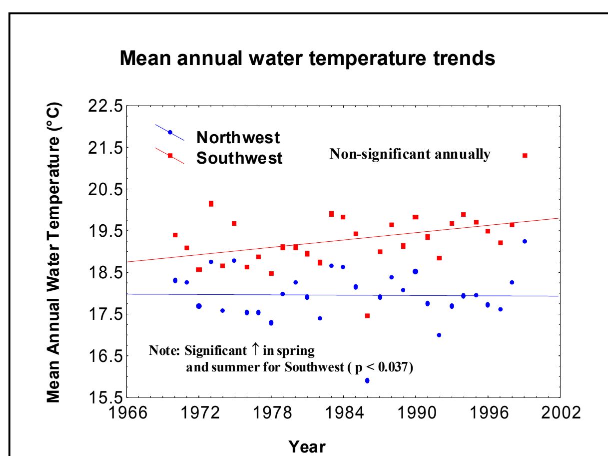
$$Rw(t) = A_1 \, Rw(t-1) + A_2 \, Rw(t-2) + K \, Ra(t)$$

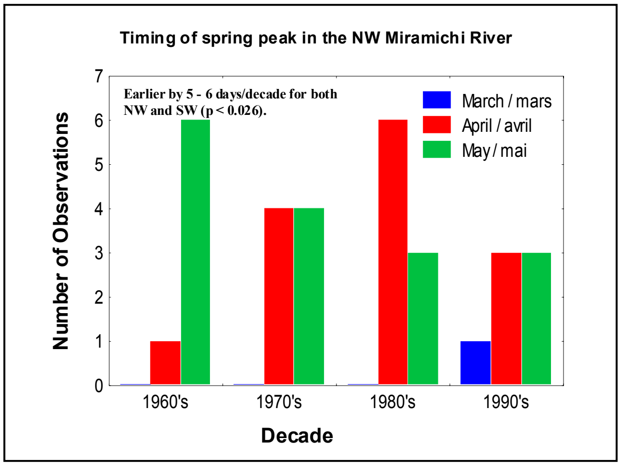


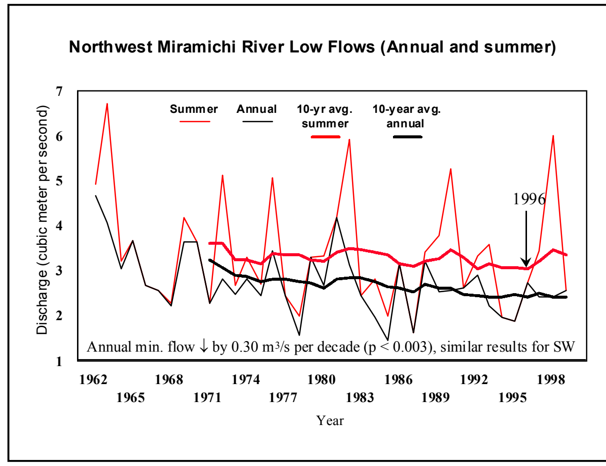












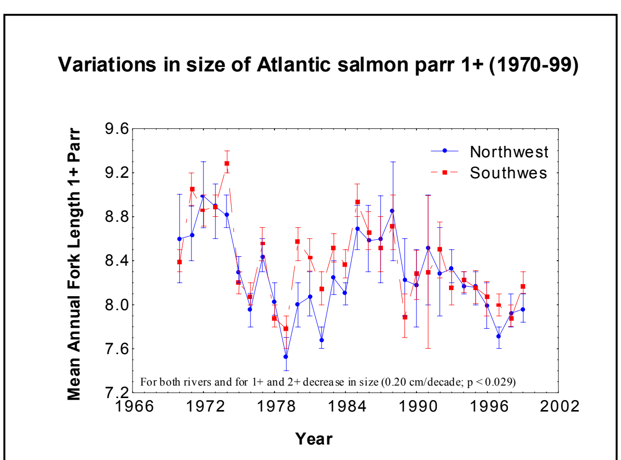
Summer low flow

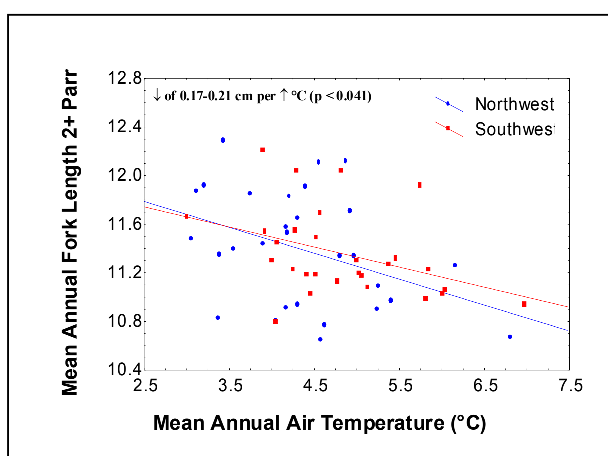
- Duration (days) and years of summer low flow in the SW Miramichi River ($Q < 20\ m^3/s$):

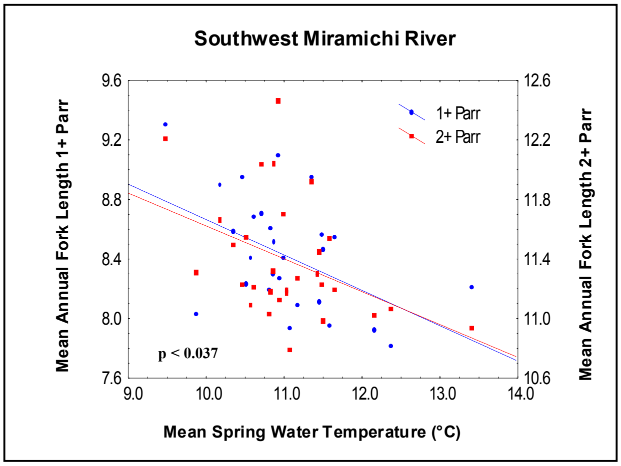
Period	# Years	Duration in days
1960-69	5	126
1970-79	2	27
1980-89	2	34
1990-99	6	148

Trends in Biological data

- Fork length (FL) was used to represent fish condition:
- FL was corrected for sampling date;
- FL was corrected for density of age class;
- All FL data were adjusted to common date (Aug 12) for each year.







Conclusions

- **Air temperature:**
  - Significant increases calculated in air temperature were within the projected range of 2-6 °C;
- **Water temperature:**
  - Increase was less evident, however good link between air and water temperatures;
  - Evaporative cooling a factor;
  - Lack of long-term data;
  - More days with temperature exceeding 23°C (Caissie 2000).

Conclusions (cont)

- **River discharge:**
  - Changes in the timing of the spring flood peaks (5-6 day earlier per decade);
  - Increase in the severity of low flow conditions annually and highest duration (days) of summer low flow in 90s.
- **Fish condition:**
  - Decrease in size of salmon 1+ and 2+ parr.
  - Significant relation with size of fish and water temperature (annual + spring).

Other research / Acknowledgement

- **Interannual fish growth study:**
  - Calculated growth potential within the summer season using Elliot's Model;
  - Bi-weekly sampling of fish to estimate actual growth during the summer season.

- **Acknowledgement:**
  - Climate Change Action Fund;

Impact of climate change on river water temperatures and juvenile salmon growth

E. Swansburg[2]

N. El-Jabi[2]

G. Chaput[1]

D. Caissie[1]

D. Moore[1]

1. Fisheries and Oceans; 2. Université de Moncton

Impact of climate change on river water temperatures and juvenile salmon growth

- Water temperature and streamflow are important environmental determinants of distribution and productivity of Atlantic salmon in freshwater
  - affect growth, behaviour, and survival
- Temperature tolerance of 0 - 28 ° C
  - Begin feeding at 6 - 7 ° C
  - Optimal growth at 16 - 19 ° C
  - Seek refuge from thermal stress at 22 - 24 ° C
- Juvenile salmon in the Miramichi are already experiencing water temperatures approaching lethal limit (30 ° C)

Impact of climate change on river water temperatures and juvenile salmon growth

- Climate change projections: air temperature ↑ of 2 - 6° C within next 100 years (Atlantic):

- Higher air temperature:
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  - alterations in streamflow regime;
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- Potential biological implications:
  - reduced growth of juvenile Atlantic salmon;
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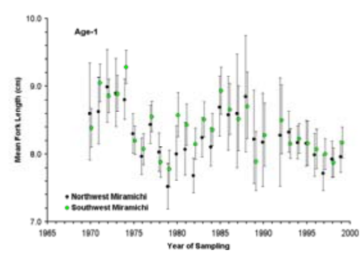
Impact of climate change on river water temperatures and juvenile salmon growth

- Large annual variation in mean size at age of all age groups of juveniles
- Small mean sizes have been prevalent through the 1990s
- Juvenile salmon abundance has increased but adult returns have declined



Impact of climate change on river water temperatures and juvenile salmon growth

- Objectives of the study:
  - simulate water temperatures between 1970 to 1999 using a stochastic model based on air temperature (Caissie et al. 1998)
  - describe variations in air and water temperatures, discharge, and size-at-age of juvenile salmon for the period 1970-1999
  - examine the association between environmental variables (temperature, hydrology) and size-at-age of juvenile salmon
  - examine the utility of a juvenile growth model to predict the effects of water temperature on size-at-age of juveniles

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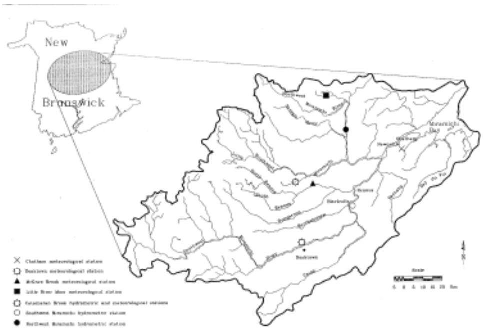

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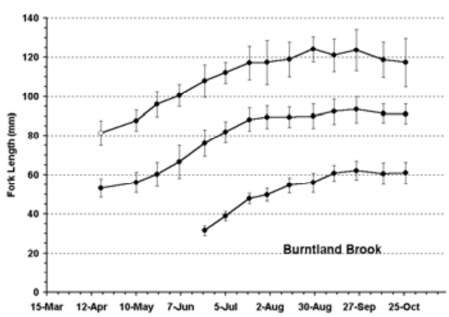
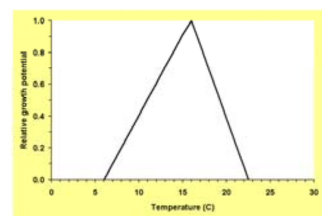
Data inputs - fish growth season



Growth potential index

Model (Elliott and Hurley (1997))		
$G_w = cW^{-b}((T - T_{L/M})/(T_M - T_{L/M}))$		
c	3.53	
W (g)	starting weight	
b	0.31	
T_M	15.94	
$T_{L/M}$ (if $T<T_M$)	5.99	
$T_{L/M}$ (if $T>T_M$)	22.51	
c = growth rate at optimaum temperature		
W = mass of fish (g)		
b = power transformation of mass		
T_M = temperature at optimum growth		
T_L = lower temperature limit for growth		
T_u = upper temperature limit for growth		



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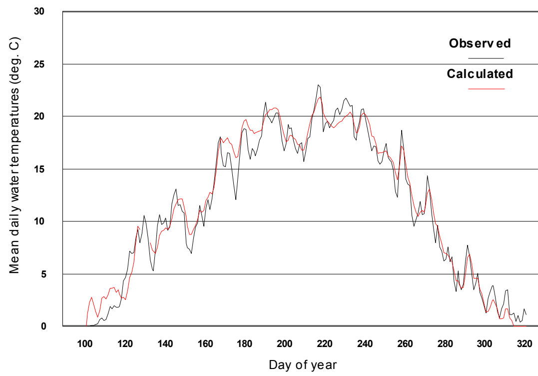
Short-term residuals, i.e. departure from annual (*Rw*):

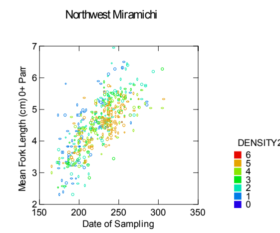
$$Rw(t) = A_1\, Rw(t-1) + A_2\, Rw(t-2) + K\, Ra(t)$$

Little Southwest Miramichi River Water temperature in 1993

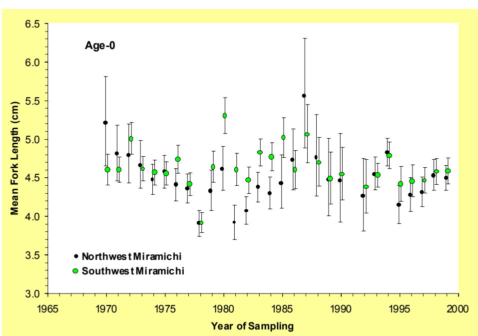


Biological Data

- Mean lengths at individual sites were corrected for sampling date and density
- Included the major tributary effect, Northwest versus Southwest Miramichi
- using GLM and assuming a linear association between size, date and density



Juvenile adjusted mean length



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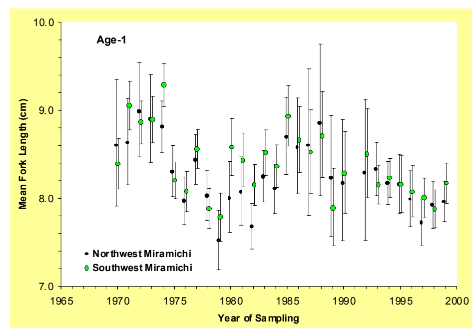

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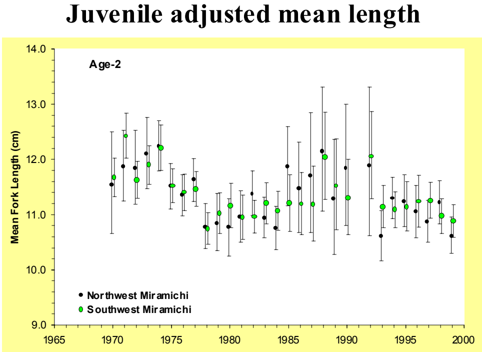
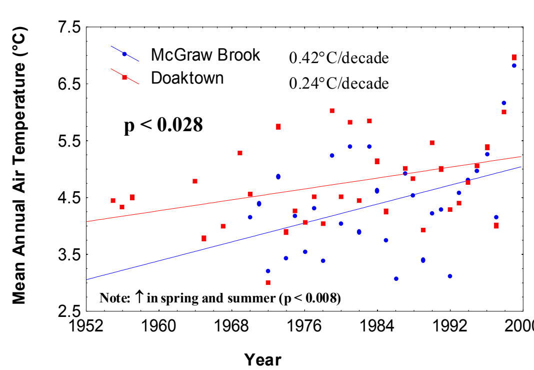
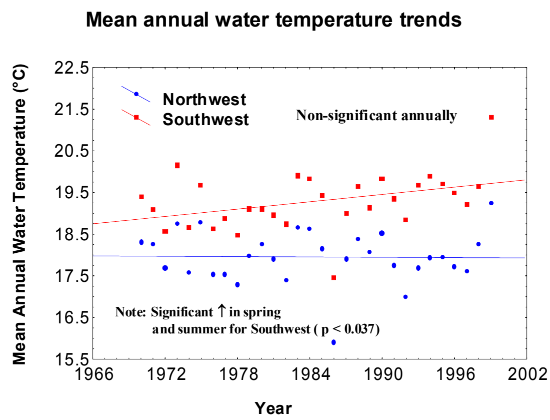
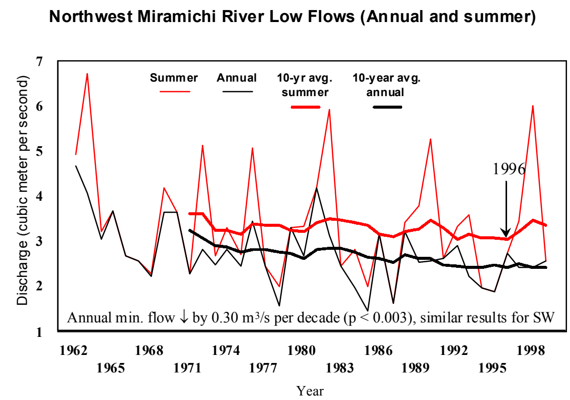


Annual air temperature (°C) trends







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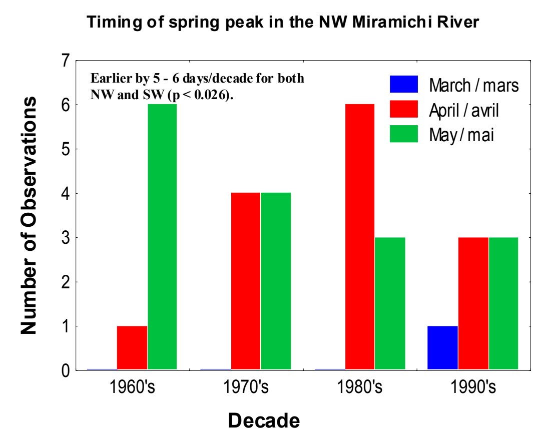
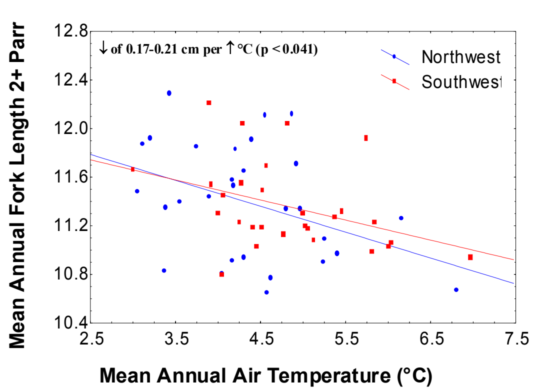
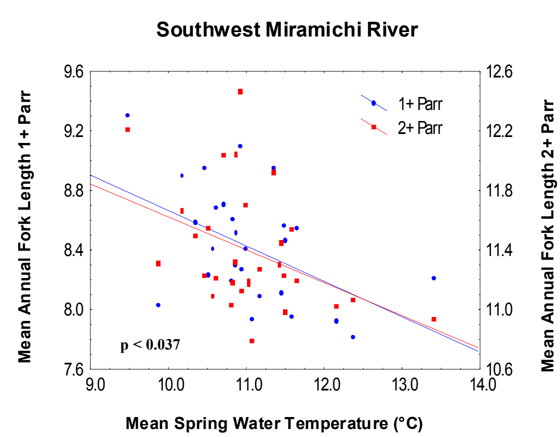
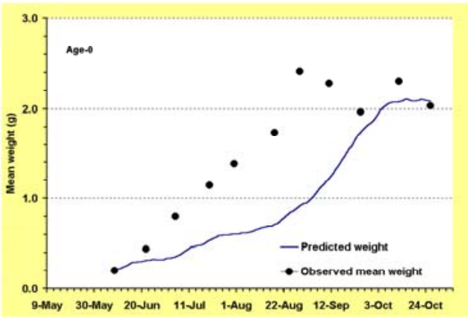






Growth potential index and juvenile size



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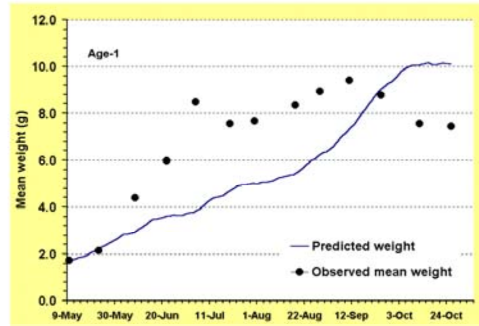

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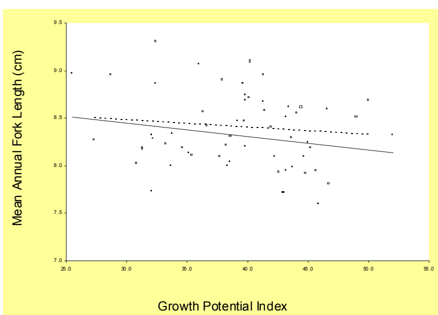

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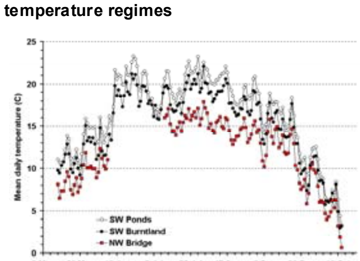
Conclusions (cont)

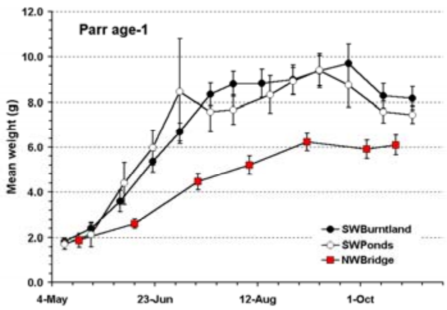
- River discharge:
  - Changes in the timing of the spring flood peaks (5-6 day earlier per decade);
  - Increase in the severity of low flow conditions annually and highest duration (days) of summer low flow in 90s.
- Fish size:
  - Decrease in size of juvenile salmon particuarly in 1990s
  - Significant negative correlation of size of juveniles and water temperature (annual, spring)
  - Optimal growth model did not apply to field observations
  - Variations in optimal growth index not associated with variations in fish size

Conclusions (cont)

- Problems with the analyses
  - Size-at-age is variable among sites and reflects temperature regimes



Problems with the analyses



Problems with the analyses

- Size-at-age is variable among sites and reflects temperature regimes
  - Difficult to relate size-at-age in a large system with variable growth conditions to general indices of environmental conditions
- Temperature and discharge may ultimately explain only a small part of the growth potential in the wild
  - Food availability is likely more important but difficult to measure (as an index)

Direction for future research