2024 International symposium on ecohydraulics and fish passage

DIURNAL DYNAMICS OF THERMAL REFUGE IN ATLANTIC SALMON RIVER POOL

Simon Joly-Naud

Supervisor : Normand Bergeron

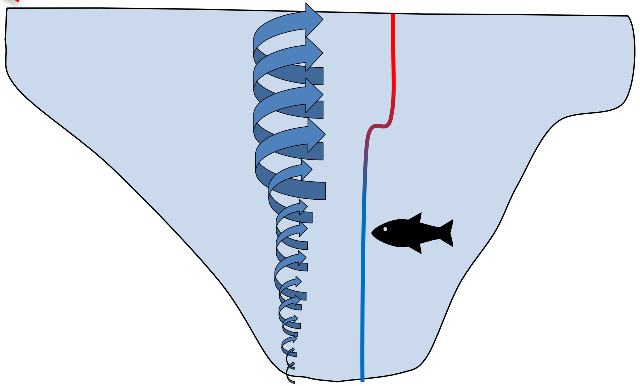
Co supervisor : Isabelle Laurion

INRS
Institut national de la recherche scientifique

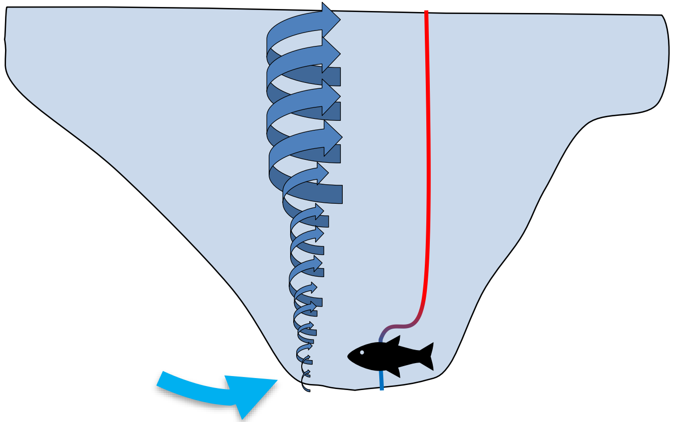
What is a pool thermal refuge ?

- **Pool thermal refuges are formed by thermal stratification**
- Cold tributary plumes and bank seeps are more studied compared to pools
- Two mechanisms are described in the literature:

Diurnal density cycle



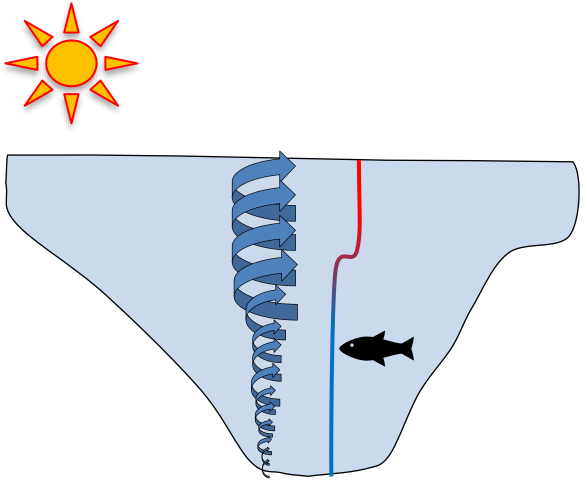
Groundwater resurgences



Buxton et al. 2022/ Hester et al. 2009/ Frechette et al. 2018/ Matthews et al. 1997

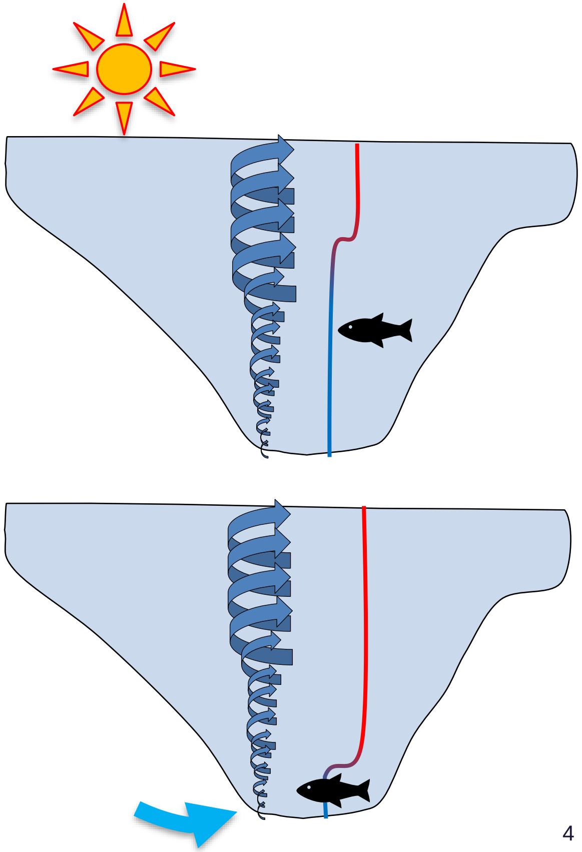
How diurnal cycle creates stratification in pools?

1. **Insolation** increases water temperature
2. **Incoming hot water flows** onto **cold and slow** bottom water
3. **Buoyancy differences** build stratification
4. **Insolation** stops → water cools down
5. **Cold water sinks** to the bottom and engage vertical mixing



Buxton et al. 2022

What controls stratification?



- ↑ Air T°C
- ↑ Direct insolation
- ↓ Wind speed
- ↑ Morphology
- ↓ Discharge
- ↑ Colored dissolved organic matter (CDOM) (Shown in lakes, not yet in river pools)

Tate et al. 2007/ Bormans et Webster 1998/ Ozaki 1984/ Turner et al. 2005/ Turner et al. 2005/ Buxton et al. 2022/ Bormans et Webster 1998/ White et al. 2016 /Bartosiewcz et al. 2019

Objectives : What do we want to learn?

Main mechanisms behind the formation of cool water zones in pools

- **How and when** in pools?
- **What controls** short and long term variations in stratification?

Spatial controls on stratification intensity and occurence

- What **factors favor the establishment** of a stratification in pools

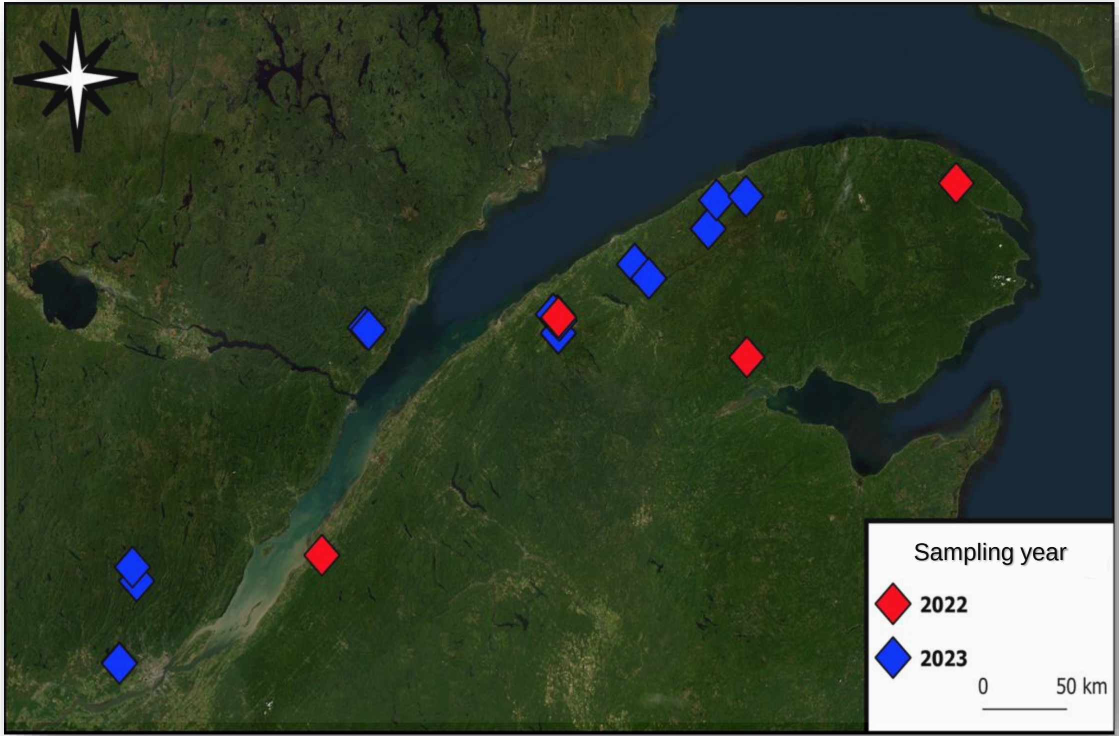
Which pools can potentially be **a thermal refuge?**

- What are the **common characteristics** of pools with cool water zones?

INRS

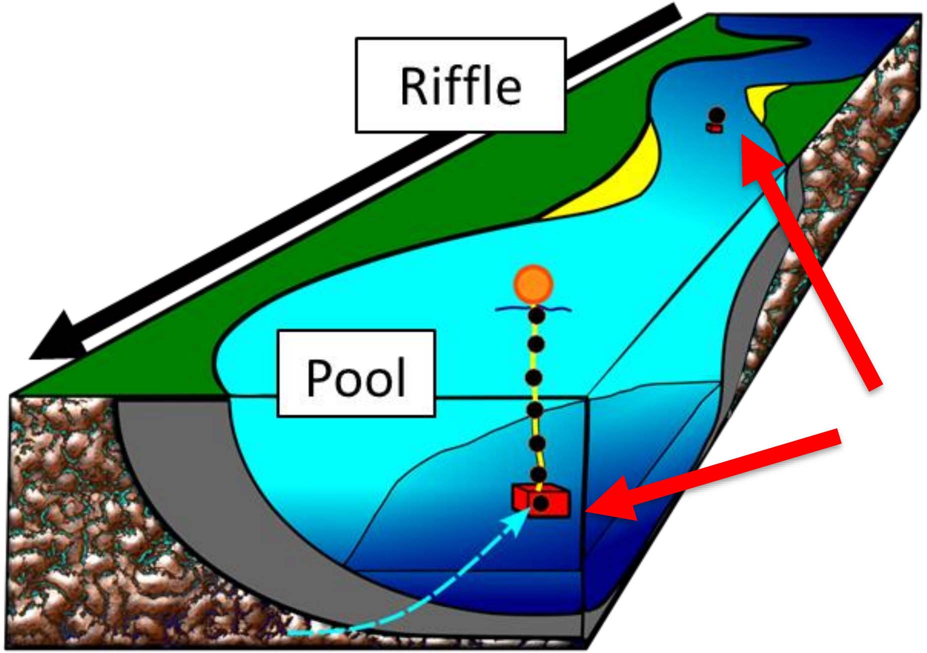
Study sites

- Rivers along a **CDOM gradient**
- Pools cover a broad range of morphologies and turbulences
- **2022** : 4 pools in 4 rivers
- **2023** :16 pools in 7 rivers



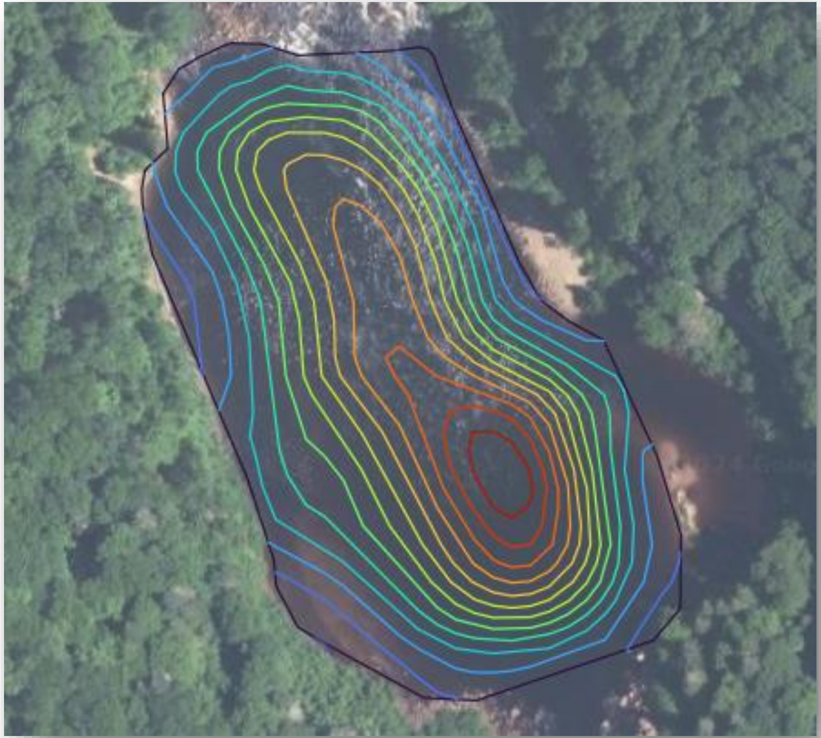
Thermal

- Vertical profiles with moorings and inlet riffle temperature logger
- **2022** : 10 min interval, 3 months duration
- **2023** : 5 min interval, 3-6 days duration
- **Stratification : Maximum vertical temperature gradient (ΔT°)**



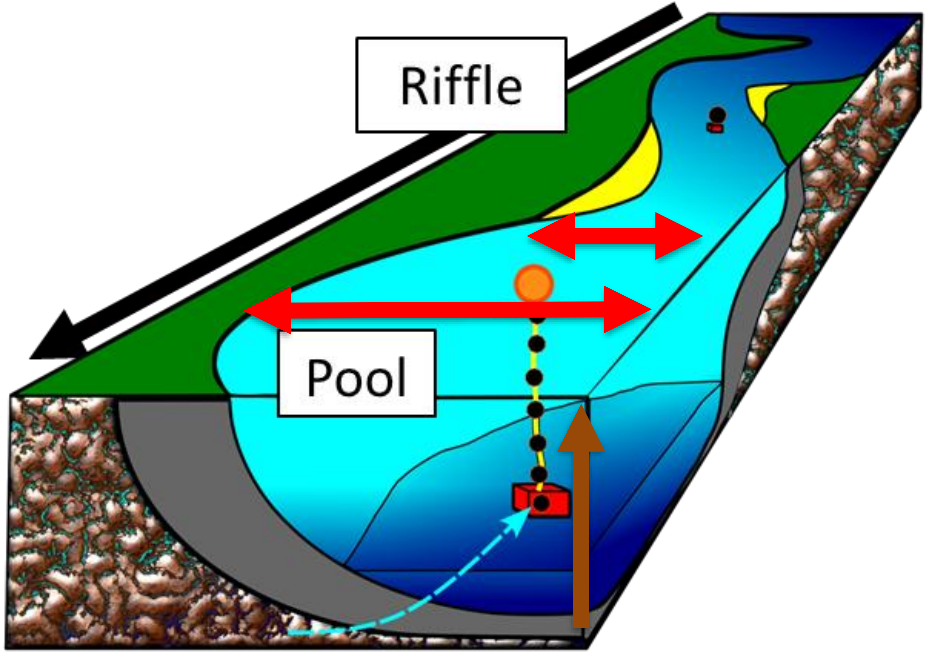
Geomorphology

- **2022** : Cross transects with an acoustic doppler current profiler **(ADCP)**
- **2023** : Full bathymetric survey with a high resolution **sonar**



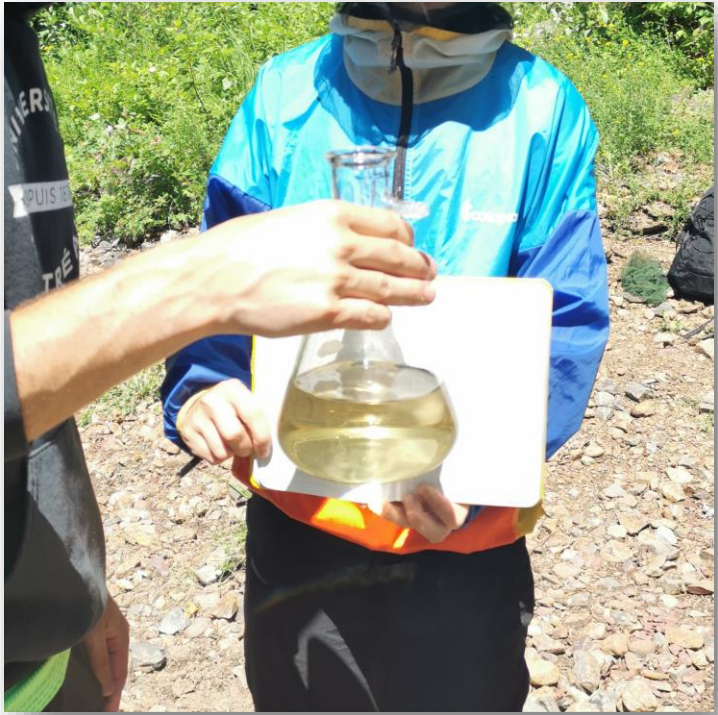
Hydraulic

- **2022** : Cross transects with an acoustic doppler current profiler **(ADCP)**
- **2023** : Horizontal and vertical current profiles at the sampling point

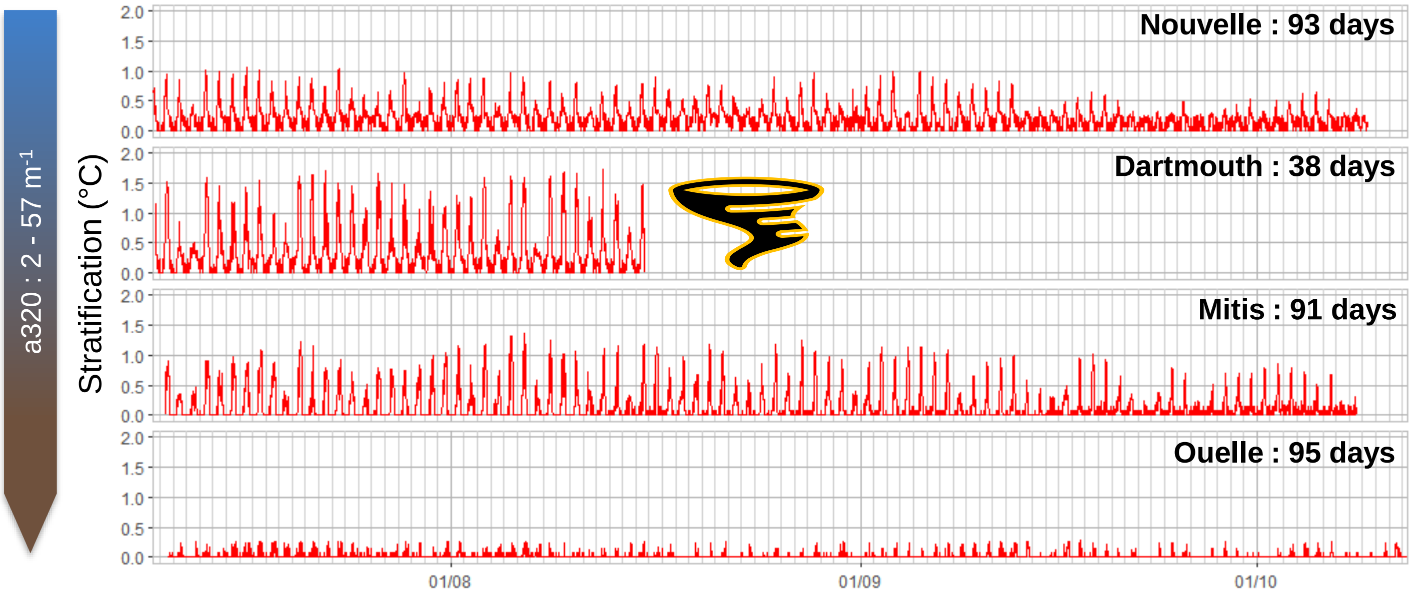


Colored dissolved organic matter

- **Surface water** sampled for CDOM
- **a320:** absorption at 320 nm (measure of water coloration)



Temporal evolution of stratification



Diurnal cycles in each river

- Intense **daily** variations and **seasonnal** variations
- **Large differences** among rivers
- Max ΔT° range : **0,3 – 1,7 °C**

Control factors on stratification over time

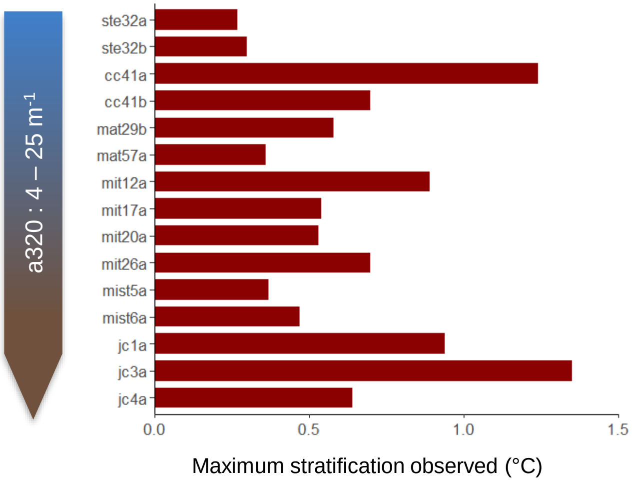
Linear regression on stratification (R^2)	Literature controls						Newly tested controls		
Sites	**Air T°C**	**Inlet T°C**	**Discharge**	**Precipitation rate**	**Wind speed**	**Direct insolation**	**6 days cumulated degree**	**6 days cumulated rain**	**3 hours cumulated insolation**
Nouvelle	0.42*	0.29*	0.04	0.07*	0.03*	**0.68***	0.41*	0	**0.58***
Dartmouth	0.05	0.2*	0.07	0.16*	0.1	**0.56***	0.09	0	**0.57***
Mitis	0.2*	0.27*	0.03	0.06*	0	**0.5***	0.21*	0.05*	**0.59***
Ouelle	0.21*	0.12*	0	0.02	0	**0.05***	0.06*	0	**0.23***

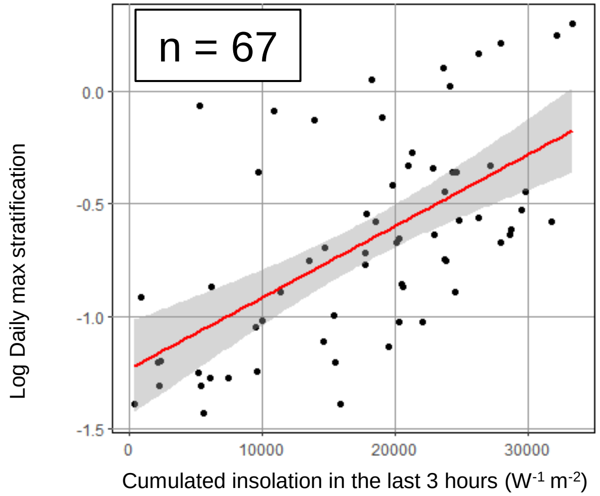
Era-5 meteorological data / SolCast solar data
*p-value < 0,05

INRS

Most systematic effects : Direct insolation and cumulated insolation in the last 3 hours

Synoptic view : Spatial variations in stratification





15/16 sites follow diurnal cycle

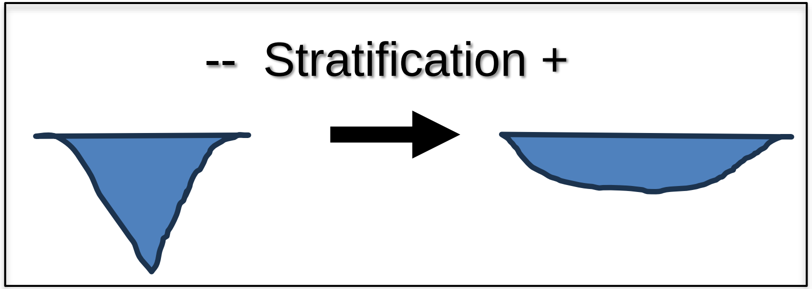
- Large variations
- Max ΔT° range : **0,3 – 1,4 °C**
- No significant effect of CDOM

Cumulated insolation (R^2 : 0,37*)

- Strongest effect on daily max ΔT°
- Outliers
- Group effect

Effect of pool morphology on stratification

- Testing the effect of **12 metrics**
- **Mid section width to depth ratio (W/z)**: Strongest effect on stratification **(R^2 : 0.33)**
- **Combined with cumulated insolation**: Significant effect on stratification **(R^2 : 0.55)**



Linear regression on stratification	Variable	R^2
Form metrics	Bed slope	0.02
	Expansion factor	0.03
	Width (W)	0.08*
	Length (L)	0
	Depth (z)	0
	Perimeter (p)	0.04
	Volume (v)	0.07*
	Surface area (A)	0.06
Form factors	A/p	0.06
	L/w	0
	W/z	**0.33***
	L/z	0.02

*p-value < 0,05

Effect of turbulence on stratification

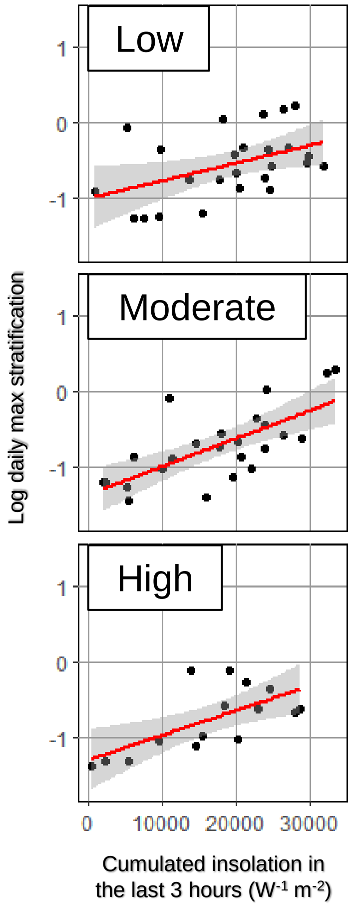
Classification in 3 groups by their horizontal and vertical turbulence : **Low, moderate and high.**

Varying effect of cumulated insolation and pool morphology on stratification

- **No added effect** of morphology on pools of moderate turbulence
- **Stronger effect** on pools of low and high turbulence

Linear regression on stratification (R^2) Levels of turbulence	Insolation alone	Insolation and morphology
Low	0.2*	**0.55***
Moderate	0.49*	**0.49***
High	0.44*	**0.81***

*p-value < 0,05



Diurnal density cycle is a very common mechanism of stratification in river pools

- ✓ This mechanism was observed at **19/20 sites :**
- ✓ **Highly variable** in intensity and frequence of occurrence
- ✓ Wide scale spatial description and quantification : Done for the first time

INRS

Cumulated insolation is the strongest control factor of diurnal stratification

✓ Cumulated insolation better explains the **progressive building** of diurnal stratification

✓ Its control on temporal dynamics has **never been shown before**

✓ CDOM has no clear effect (strong effect by covariates):

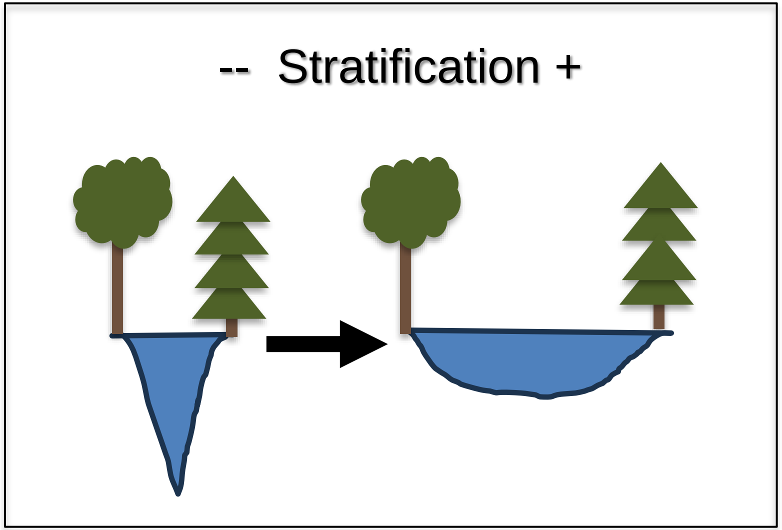
- A CDOM effect is still expected : Strong **relation with insolation**
- **More pools needs to be studied** to isolate its effect

INRS

(Bartosiewicz et al., 2019/ Bormans et Webster, 1998/ Buxton et al., 2022/ Nielsen et al., 1994)

First time observed synergistic controls between pool morphology, turbulence and cumulated insolation

- ✓ **Shallower and wider** pools present stronger **diurnal stratification**
- ✓ **Shallower and wider** pools exhibit **horizontal heterogeneity and vertical homogeneity** of flow velocity
- ✓ Wider pool are **more exposed** to insolation



Conclusion : Take home message

Main temporal mechanisms

- Diurnal density cycle
- Happens almost everywhere at different intensity

Spatial and environmental controls

- Morphology + Turbulence + Insolation
- Wider and shallower

Which pools?

All pools : A. salmon exploit **small temperature differences** to maintain their body temperature within a narrow range (Fréchette et al., 2018)

Thank you for your time

Remerciements spéciaux : André St-Hilaire, Zec de la rivière Nouvelle (Louis Laflamme), Société de gestion des rivières de Gaspé (Rémi Lesmerises), Zec de la rivière Mitis (Élie-Merlin Mercier-Ouellet), Organisme de bassins versants de Kamouraska, L'Islet et Rivière-du-Loup (Véronique Furois), et toutes les autres zecs membres de la Fédération québécoise du saumon Atlantique

Les Premières Nations Innu, Mi'kmaq et Huron-Wendate, pour avoir participé, au travers de leurs organismes associées, à la planification de la campagne de terrain.

Équipe de terrain: Olivier Grimard, Brune Collaudin, Mathias Chabal, Savannah Turcotte

Équipe de laboratoire: Thomas Pacoureau, Martial Leroy, Charis Wong et les autres membres des laboratoires de l'INRS ayant participé de près ou de loin au projet.

Organismes partenaires: Fondation de la faune, Conseil de recherche en sciences de la natures et génie du Canada, Fonds de recherches du Québec en sciences natures et technologies, Centre interuniversitaire de recherche sur le saumon Atlantique , Groupe de recherche interuniversitaire en limnologie, Institut nordique du Québec, Institut national de la recherche scientifique

Directeurs.rice de recherches : Merci à Normand Bergeron et Isabelle Laurion pour leur encadrement, leur dévouement, leur implication et leur passion.

INRS Institut national de la recherche scientifique

Fondation de la faune du Québec

Institut nordique du Québec Ensemble pour le Nord

NSERC CRSNG

Fonds de recherche Nature et technologies Québec

GRIL

SAUMON QUÉBEC

CIRSA

LIMNORD Nordic limnology laboratory

INRS.CA