Mathematical Modelling of Fisheries Dynamics and Management
Modélisation mathématique de la dynamique et de la gestion des pêches
(Org: **Sophie Léger** (Université de Moncton) and/et **Alexandre Pepin** (Université Laval))

SOPHIE LÉGER, Université de Moncton
The Role of Cannibalism in Cyclic Snow Crab Population Dynamics

The snow crab fishery is among Canada's most valuable fisheries and plays a critical role in the economy of coastal communities across Atlantic Canada and Quebec. As a cold-water stenothermic species, snow crab may be particularly vulnerable to environmental change associated with ocean warming. Understanding the mechanisms governing population variability is therefore essential for sustainable management.

In this talk, we present a discrete-time population dynamics model for snow crab in the southern Gulf of St. Lawrence that incorporates sex-specific developmental stages: immature, adolescent, and adult males, and immature, prepubescent, and adult females. The model includes density-dependent interactions through intercohort cannibalism, while excluding groundfish predation due to its limited influence in this ecosystem.

Using this framework, we analyze how biological interactions and demographic processes influence snow crab population dynamics. In particular, we investigate the effects of cannibalism, recruitment variability, natural mortality, fertility, and fishing mortality on long-term population behaviour. We also examine the conditions under which the model exhibits stable equilibria or cyclic dynamics through the use of dynamical systems tools such as bifurcation analysis and periodograms.

This work aims to improve understanding of the mechanisms driving variability in snow crab populations and to contribute to the development of stock assessment models that better account for nonlinear biological processes in a changing environment.

JÉRÔME MAZEROLLE, Université de Moncton
Modeling Snow Crab Diffusion Using a Finite Element Method

Snow crabs are an important asset to New Brunswick fisheries. As a cold-water species, their survival is highly sensitive to fluctuations in water temperature. Most snow crab mortality occurs during the larval phase, where only 1.5% of the larvae survive migration.

Being too small to move on their own, snow crab larvae are transported by water currents across the Gulf of St. Lawrence. Their small size also causes them to behave similarly to suspended particles in water, making diffusion an important factor in their movement.

The transport and dispersion of snow crab larvae can therefore be modeled using the advection-diffusion equation :

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2}\right)$$

In this equation, the advection velocities u and v represent ocean current data provided by Fisheries and Oceans Canada. Because the available data was not sufficiently detailed for direct mathematical modeling, it was interpolated using the Kriging method. The model also includes a diffusion coefficient D and the larval concentration field C, which must be solved for numerically.

Since no realistic analytical solution exists for this system, numerical approximation techniques are required. A finite element method was therefore applied to solve the advection–diffusion equation on a computational mesh designed to simulate the conditions of the Gulf of St. Lawrence.

SOKHNA NDIAYE, Moncton University
On the Adequacy of Simple Continuous-Time Models for Snow Crab Population Dynamics

Abstract

Snow crab (*Chionoecetes opilio*) is a major component of the maritime economy in the Gulf of St. Lawrence, with landings generating over $300 million in 2021 according to Fisheries and Oceans Canada (DFO). Beyond its commercial importance, this species plays a key ecological role, but its management is complicated by high sensitivity to climate change and a life cycle characterized by discontinuous growth and cannibalistic behavior.

In this work, we investigate the relevance of continuous-time modeling for describing the dynamics of this resource using a stage-structured framework distinguishing immature and mature crabs. We compare two approaches: a model incorporating cannibalism as a trophic regulation mechanism, and a delay differential equation model accounting for maturation time.

We conduct a mathematical analysis of both models, focusing on equilibrium points and the occurrence of Hopf bifurcations that may explain observed population oscillations. Analytical results are complemented by numerical simulations to assess the ability of each model to reproduce stock dynamics. These findings provide insight into the suitability of stage-structured continuous-time models for understanding snow crab population cycles and supporting sustainable fisheries management under changing environmental conditions.

JULIEN THIBODEAU, Université de Moncton
Bifurcation detection in dynamical systems using deep learning

Developing robust numerical methods for dynamical systems is an important issue across many scientific and industrial applications. In fisheries science, ordinary differential equation (ODE) models are commonly used to study how parameters such as harvesting rates influence population dynamics. Variations in these parameters can lead to qualitative changes in system behaviour, including the appearance or disappearance of equilibrium points or changes in their stability. These phenomena, known as bifurcations, are crucial to fully understand the long-term dynamics of the system but are often difficult to capture using traditional simulation methods.

Continuation methods, such as the Moore-Penrose continuation, provide an effective framework for tracking equilibrium solutions as parameters vary and can successfully handle many types of bifurcations. However, in more extreme cases of bifurcations, these methods may exhibit convergence difficulties. Detecting such problematic regions in advance would therefore significantly improve the reliability of numerical simulations.

In this work, we propose a deep learning approach for the early detection and classification of bifurcation points from time-series data. The model is trained to recognize characteristic patterns associated with different bifurcation types. Once validated, the model will be integrated with the Moore-Penrose continuation to improve the quality of its simulations. The proposed framework will then be tested on a variety of dynamical systems arising in applied mathematics and population dynamics.

ELLIE WEISE, Dalhousie University
Close-Kin Mark-Recapture in Atlantic Halibut

Atlantic Halibut are the target of an important fishery in the Northwest Atlantic; knowledge of their abundance is crucial for proper management and conservation. However, estimating the population size of a widely distributed and abundant marine fish is notoriously difficult. We plan to estimate the population abundance of Atlantic halibut on the Scotian Shelf using the Close Kin Mark Recapture (CKMR) approach. The method is based on the genotypic identification of kin (parent-offspring pairs, half-sib pairs, etc.), which are used as a substitute for physical recaptures in a traditional mark-recapture framework. We genotyped 10,303 samples collected between 2017 and 2024 at 4,000 single nucleotide polymorphic (SNP) markers. Pairwise pseudo-likelihood odds ratios were calculated across all individuals to identify 29 parent-offspring pairs and 571 half-sibling pairs in the sample. The CKMR likelihoods for Atlantic Halibut were constructed for parent-offspring pairs, cross-cohort half-siblings and grandparent-grandchild pairs. Likelihoods were adjusted according to the sex of parent in the kin pair and to include uncertainty from incomplete age information. The ultimate goal of the project is to provide the modeling framework for the estimation of population abundance, survivorship rates and connectivity for Atlantic Halibut that can be used to assess the state of the population on the Scotian Shelf and set sustainable fishing targets.