Effect of hypoxia on cod bioenergetics

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Introduction

Hypoxia in coastal marine systems is a growing phenomenon around the world, accelerated as a result of human activities. It is defined as a reduction of dissolved oxygen saturation levels (% DO sat.).

Effects of hypoxia at the physiological level include:
- Disturbance of the phenology (e.g. spawning time)
- Reduced growth
- Limitation of reproductive success
- Increased vulnerability to diseases

In the past century, Hypoxia has become a global concern with over 550 coastal areas identified as experiencing this issue.

Beatty (2016)
**Introduction**

The **Atlantic cod** is an iconic species facing important challenges from its changing environment, human activities and, in some populations, intense **predation**.

2 populations: north and south (different migration and residency patterns)

**DO (% sat.) in the Gulf of Saint Lawrence**
Introduction

**Realized habitat** of Atlantic cod in the northern Gulf of Saint Lawrence (nGSL).
Modeling hypoxia

Dynamic Energy Budget theory:
- Mechanistic and generic approach
- Full life cycle
- Scale transfer (population)
- Multi-stressor perspective

Thomas et al. (2018) identified that the main effect of hypoxia on the metabolic response of cod was on ingestion.

DO correction factor of ingestion

\[ c_{DO}(t) = \begin{cases} 
\alpha \frac{DO(t) - DO_{crit}}{DO(t) - DO_{crit} + \beta}, & \text{if } DO(t) > DO_{crit} \\
0, & \text{if } DO(t) \leq DO_{crit} 
\end{cases} \]
Objectives

 Quantify the effect of hypoxia in two populations of Atlantic cod in the Gulf of Saint Lawrence

1) Disentangle the importance of **environmental variables:**
   - Temperature,
   - Food availability
   - DO saturation
   on the energy budget of cod from each population

2) Investigate potential effects of hypoxia on **life history traits**
Methods

Many identified **stocks** with contrasted life-history traits (Brander, 2005)

| Arcto-Norwegian | Iceland | Northern Gulf of Saint-Lawrence |
| Baltic          | Irish Sea | Southern Gulf of Saint-Lawrence |
| Celtic Sea      | North Sea | Southern Grand Bank |
| Greenland       | Scotland  | Southern Newfoundland |
| Faroese Islands | Scotian Shelf | Northern Newfoundland and Labrador |
|                 |          | Gulf of Maine and Georges Bank |
Methods

Re-estimation of parameters for our populations
Data

Annual monitoring surveys conducted in the nGSL since 1990 and in the sGSL since 1971, providing:

- Length
- Wet mass
- Stomach content
- Temperature

Additional data for sGSL cod from a physiological condition monitoring conducted annually since 1992 (typically monthly in April and June–October) and January surveys of cod overwintering grounds in 1994 and 1995.
Modeling scenarios

Scenario S1: Reference scenario without implementing DO effect
   stomach content data already incorporate this effect

Scenario S2: Quantification of the temperature effect
   imposing same temperature forcing to each population
   keeping other variables untouched

Scenario S3: quantification of the DO effect on growth
   by removing the DO effect on ingestion, estimate the potential gain in growth
   ingested food is corrected by $1/c_{DO}$
Results – Scenario S1 (ref)
Results – Scenario S1 (ref)

Wet Mass
Good predictions from the model in reference scenario (S1)

From comparing S1 with S2 scenario we found that temperature explained 48% of the difference in length between populations and 59% of the difference in mass
Results
Results

Comparing S1 with S3, we observed more pronounced difference in nGSL compared to sGSL.

This tells us that the energy input data we used for the nGSL were more impacted by hypoxia (twice as much as sGSL).
Impact of hypoxic conditions on cod life-history traits

DO level scenarios

Month

Date

Jan Mar May Jul Sep Nov

Jan Mar May Jul Sep Nov

Jan Mar May Jul Sep Nov

Jan Mar May Jul Sep Nov

Jan Mar May Jul Sep Nov
Impact of hypoxic conditions on cod life-history traits

(a)

(b)

(c)
Impact of hypoxic conditions on cod life-history traits

(a) Ultimate length (cm) vs. Mean DO saturation over year (%)
(b) Time to reach 40 cm (year) vs. Mean DO saturation over year (%)
(c) Reproductive investment (# egg) vs. Mean DO saturation over year (%)
(d) Age at puberty (year) vs. Mean DO saturation over year (%)
Conclusions

Contrasted effects of Temperature and hypoxia in the nGSL population.

• Temperature seems to explain about half of the difference between populations
• More data needed to ascertain the effect of DO
• Other pressures should be considered (predation, evolution from fishing pressure)
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Further investigations

Tracking of individuals equipped with loggers

- High-resolution of individual trajectories of experiences conditions
- Comparison of different behaviours (migratory vs. resident, coastal vs. deep dwellers)
Thank you!

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Seasonal stomachal content v Length