Linear or non-linear?
Understanding the effect of Climate Change on Atlantic Cod recruitment

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Why is Recruitment important?

“Number of juveniles entering in the adult stock”
Why is Recruitment important?

“Number of juveniles entering in the adult stock”

PRODUCTIVITY

Relevance

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PRODUCTIVITY

Efficient management measures

Relevance

Recruitment is complex and influenced by multiple factors

Introduction

Recruitment is complex and influenced by multiple factors

- N° of adults
- Maturity
- Weight

Recruitment is complex and influenced by multiple factors

- N° of adults
- Maturity
- Weight

- Environmental factors
- Currents
- Predation

Recruitment is complex and influenced by multiple factors:

- Number of adults
- Maturity
- Weight
- Environmental factors
- Currents
- Predation
- Environmental factors
- Predation
- Competition
- Cannibalism

Introduction

Recruitment Paradox

R dynamics often chaotic

Myers 1998; Duffy – Anderson et al., 2005, Olsen et al., 2011, Ye et al., 2015
Recruitment Paradox

R dynamics often chaotic

Parametric models still the rule

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Effect of environmental factors often spurious

Myers 1998; Duffy – Anderson et al., 2005; Olsen et al., 2011; Ye et al., 2015
Recruitment Paradox

R dynamics often chaotic

Parametric models still the rule

Effect of environmental factors often spurious

All stocks treated as if they show same dynamics
Recruitment Paradox

R dynamics often chaotic

Parametric models still the rule

Effect of environmental factors often spurious

All stocks treated as if they show same dynamics

We ignore possible discontinuous, state-dependent dynamics
Research Questions

Is Atlantic cod recruitment non-linear?

Aims
Research Questions

Is Atlantic cod recruitment non-linear?

Can alternative models be used to predict recruitment?
Research Questions

Is Atlantic cod recruitment non-linear?

Can alternative models be used to predict recruitment?

Are environmental factors important?
Stock Assessment Data of 20 Atlantic cod stocks
Stock Assessment Data of 20 Atlantic cod stocks

Data used

- Recruitment
Stock Assessment Data of 20 Atlantic cod stocks

Data used

- **Recruitment**
- **SSB**
Data

Stock Assessment Data of 20 Atlantic cod stocks

Data used

- Recruitment
- SSB
- Environment: SST, AMO, NAO
Tests for non-linearity in recruitment dynamics

- Simplex Projection
- S-Map
Tests for non-linearity in recruitment dynamics

- Simplex Projection
- S-Map

Taken’s theorem

Ye et al., 2015; Harford et al., 2017, Perlala et al., 2017, Sguotti et al., in prep
Tests for non-linearity in recruitment dynamics

- Simplex Projection
- S-Map

\[ \text{Taken's theorem} \]

Attractor manifold or state space reconstruction of n-dimensional system

Ye et al., 2015; Harford et al., 2017, Perlala et al., 2017, Sguotti et al., in prep
Tests for non-linearity in recruitment dynamics

- Simplex Projection
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Tests for non-linearity in recruitment dynamics

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3 different types of model applied

- Standard parametric model
- Model based on catastrophe theory
- State-dependent model

Ye et al., 2015; Harford et al., 2017; Perlala et al., 2017; Sguotti et al., in prep
Methods

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Tests for non-linearity in recruitment dynamics

- Simplex Projection
- S-Map

3 different types of model applied

- Standard parametric model
- Model based on catastrophe theory
- State-dependent model

Model Comparison

- 5 fold Cross Validation

Ye et al., 2015; Harford et al., 2017; Perlala et al., 2017; Sguotti et al., in prep
Parametric model: Ricker S-R model

Methods

Ricker 1954, Olsen et al. 2011
Catastrophic model: Stochastic Cusp Model

Methods
State dependent Model: Empirical Dynamic Modelling

Multivariate Simplex Projection to forecast n-dimensional system
Linear & non-linear Recruitment dynamics

13 out of 20 stocks shows non-linear recruitment dynamics
Linear & non-linear Recruitment dynamics

North-East Arctic: Linear
Linear & non-linear Recruitment dynamics

North-East Arctic: Linear

Flemish Cap: Non-linear
Different dynamics require the use of specific models
Different dynamics require the use of specific models

Linear dynamics or high biomass

Ricker model
Different dynamics require the use of specific models

Linear dynamics or high biomass

Catastrophic dynamics

Ricker model

Stochastic Cusp Model
Different dynamics require the use of specific models

- **Linear dynamics or high biomass**: Ricker model
- **Catastrophic dynamics**: Stochastic Cusp Model
- **Chaotic dynamics**: Empirical Dynamic Modelling
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Results

Importance of environmental factors

![Graph showing the predictive power of environmental factors with SSB and SSB + Env categories. The graph compares Ricker, Cusp, and EDM models.](image-url)
Importance of environmental factors

Results
Importance of environmental factors

Results
Conclusions

- Recruitment can present non-linear/discontinuous dynamics
Conclusions

• Recruitment can present non-linear/discontinuous dynamics

• Depending on stock dynamics there might be better models to apply
Conclusions

• Recruitment can present non-linear/discontinuous dynamics

• Depending on stock dynamics there might be better models to apply

• Environmental factors can increase predictive power
Conclusions

• Recruitment can present non-linear/discontinuous dynamics

• Depending on stock dynamics there might be better models to apply

• Environmental factors can increase predictive power

• Multiple stressors can be included in these models
A flexible model choice is fundamental to move towards Ecosystem Based Management
Conclusions

A flexible model choice is fundamental to move towards Ecosystem Based Management

Future perspectives

• Investigate discontinuous dynamics in fish stocks
• Understand R-SSB dynamics in Atlantic cod better
• Ways to incorporate alternative models in management
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- Prof George Sugihara and Dr Ethan Deyle
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Questions?

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