

# Seasonal-to-Decadal Prediction of Marine Ecosystems

# **A European Perspective**

Mark R Payne

mpay@aqua.dtu.dk



DTU Aqua National Institute of Aquatic Resources



# Acknowledgements



Travel funding



The research leading to these results has received funding from the European Union 7th Framework Programme (FP7 2007-2013) under grant agreement number 308299 (NACLIM project).



# The dream of biological prediction



Helland-Hansen and Nansen, 1909

Seasonal-to-Decadal Prediction of Marine Ecosystems









# Meanwhile, a revolution is taking place...

**Seasonal-to-Decadal Prediction of Marine Ecosystems** 



# Seasonal-scale forecasting of the ocean is a reality



**Seasonal-to-Decadal Prediction of Marine Ecosystems** 



# Decadal-scale forecasting of the ocean is a reality

Multiyear Prediction of Monthly Mean Atlantic Meridional Overturning Circulation at 26.5°N Daniela Matei, <sup>1</sup>\* Johanna Baehr, <sup>2</sup> Johann H. Jungclaus, <sup>1</sup> Help Daniela Mater, - Jonanna Baenr, Jonann Wolfgang A. Müller, 1 Jochem Marotzke1. ttempts to predict changes in Atlantic Meridion tempos to previce changes in musice inclusions to date. Here, we demonstrate 5°N for up to 4 years in advance, ye -wide upper-mid-ocean geose CrossMark January 2008 Multiyear predictability of tropical marine productivity brief wind-ind ur results establ Roland Séférian<sup>a,b,1</sup>, Laurent Bopp<sup>b</sup>, Marion Gehlen<sup>b</sup>, Didier Swingedouw<sup>b,c</sup>, Juliette Mignot<sup>d,e</sup>, Eric Guilyardi<sup>d,d</sup>, ions in Atlantic Ig Circulation (A \*Centre National de Recherches Météorologiques-Groupe d'Etude de l'Atmosphère Météorologique/Groupe de Météorologie de Grande 13100 Touloure, France: Prostitut Rierre Scroon Landarat aburatoire des Sciences du Climat et de l'Environnement, 91191 Git un Yaragan ly affect northwa OPEN "Centre National de Recherches Meteorologiques-Groupe d'Etude de l'Atmosphere Meteorologique/Groupe de Meteorologie de G 3100 Toulouie, France, "Imitiut Pierre Simon Laplace/Laboratoire des Sciences du Climat et de l'Environnement, 91191 Gif un Yvet Roukero Reviewerente et Balloueuronnemente Contaniques et Continentation, 35615 Baussie, France, Reutitut Pierre Guerre Decadal predictions of the North Atlantic 31100 Toulouie, France, "Initituit Pierre Simon Laplace/Laboratoire des Sciences du Climat et de l'Environnement, 91191 Gi BordesauEnvironnements et Paléoenvironnements Océaniques et Continentaux, 33615 Pessac, France; "Initituit Pierre Si Océanographie et du Climat: Experimentatives et Aneroches Numériques, 25353 Paris, France: Polissies and Engag BordeauxEnvironnements et Paleoenvironnements Oceaniques et Continentaux, 33615 Pessac, France; "Tittibut Piet d'Oceanographie et du Cimat: Experimentations et Approches Numériques, 75252 Paris, France; "Climate and Emil Durihard Canter of Climate Durine Responde: University of Bern, CM-3012 Born, Subtractured and National Emil d'Océanographie et du Cimat: Experimentations et Approches Numériques, 75252 Paris, France; "Climate et Oechger Centre of Climate Change Research, University of Bern, OH-3012 Bern, Sentzerland; and "National Edu II Bearling, Revenue RCA Care, Lindeet Klimater COMMUNICATIONS 5 SCIENCE W AKTICLE Received 10 May 2015 Accepted 19 Feb 2016 Published 30 Mar 2016 nature Edited by David M. Karl, University of Hawaii, Honolulu, HI, and approved June 27, 2014 (received for it of Reading, Reading RG6 688, United Kingdom ANd sea-viewing wide field-With the emergence of decadal predictability simulations, research the moderate-resolution toward forecasting variations of the climate system now covers (2003-2012). Despite Innomei Li<sup>1</sup> Tatiana Ibina<sup>1</sup>, Wolfgang A. Müller<sup>1</sup> & Frank Sienz<sup>1</sup> state related to the diffe a large range of timescales. However, assessment of the capacity ARTICLE to predict natural variations of relevant biogeochemical variables the various algorithms s numerically its subpolar syre region, is essential for the terannual-to-decadal vari like carbon fluxes, pH, or marine primary productivity remains - especially its subpolar sine report, o essential for the temporal distributions of N unexplored. Among these, the net primary productivity (NPP) is of CO2 uptake tation by nutrients, and ten particular relevance in a forecasting perspective. Indeed, in regions to opene in the neuron reliance, suppose sine, were the Atlantic merinterannual fluctuations are like the tropical Pacific (30°N-30°5). NPP exhibits natural fluctuawhite second sec tions at interannual to decadal timescales that have large impacts (17). Despite large difference vears in advance by on maxime ecosystems and fisheries. Here, we investigate predic-NPP and SST in these region mained unexplored. (with a SD of ~120 TgC-mobloor over the last decades (i.e., from 1997 to of the MPIset floctuations, both being it (ENSO)





# So how do we convert this into biology?

Seasonal-to-Decadal Prediction of Marine Ecosystems



### What can we actually predict?

Seasonal-to-Decadal Prediction of Marine Ecosystems



# What would a predictable biological response look like?

- Drivers must be predictable e.g.
  - -Response depends on SST 🙂
  - –Response depends on prey abundance
- Prefer Mechanistic understanding
- •Tight physics-biology coupling -Coupling is unique and constant
- Good data -Fish Recruitment

Seasonal-to-Decadal Prediction of Marine Ecosystems





# Species distributions and migrations might work..

- Lots of distributional data available
  - e.g. Fisheries surveys
- Mechanistic links to environment
  - e.g. due to physiological tolerances
- Well developed tools –Environmental niche modelling (ENM)
- Particularly promising for pelagic fish
  Ability to influence distribution

Seasonal-to-Decadal Prediction of Marine Ecosystems



DTU



## **Bluefin tuna case study**

**Seasonal-to-Decadal Prediction of Marine Ecosystems** 





- . Warming brings bluefit tuna to Greenland
- Risk assessment of West Nile strue under climate change
- · The potential and realized spread of wildlives across Canada
- Increased topical carbon stock across China's forests

#### The Sunday Times 3 August 2014



# Tuna follow global warming to Arctics

Seasonal-to-Decadal Prediction of Marine Ecosystems



# **Availability of Thermally Suitable Habitat**



Area of suitable habitat increased by size of France

Could we have predicted this shift?

Seasonal-to-Decadal Prediction of Marine Ecosystems



### **Retrospective Forecast (Hindcast) Skill -Area of Potential Bluefin Tuna Habitat**



### Multi-annual prediction of an ecosystem indicator?

Seasonal-to-Decadal Prediction of Marine Ecosystems

# **Bluefin Habitat Forecasts**



Seasonal-to-Decadal Prediction of Marine Ecosystems



# DTU

# The future

Seasonal-to-Decadal Prediction of Marine Ecosystems



# **ICES Annual Science Conference 2016**

# Seasonal-to-Decadal Prediction of Marine Ecosystems: Opportunities, Approaches, and Applications

Mark Payne (ICES) DTU Aqua

Desiree Tommasi (PISCES) GFDL, Princeton

Alistair Hobday CSIRO, Australia



Riga, Latvia, September 2016

Seasonal-to-Decadal Prediction of Marine Ecosystems



# **Frontiers in Marine Science Research Topic – Abstracts due 1 Oct**



## http://tinyurl.com/frontiersS2D

#### Seasonal-to-Decadal Prediction of Marine Ecosystems

## Focus on Climate-Services EU H2020 Project "Blue Action"

- Climate services for
  - -Shipping + polar lows
  - -Arctic tourism (skifields)
  - Oil +gas exploitation in Russian arctic
  - -Heatwave mortality
  - Marine fisheries

- Co-creation
  - -Fishing Industry
  - -Scientists (field camp.)
  - Management
- Four phases
  - -Identify needs
  - Develop models
  - –Quantify skill
  - –Valuate skill (€)



Seasonal-to-Decadal Prediction of Marine Ecosystems



# ICES WGS2D Working Group on Seasonal-to-Decadal Prediction of Marine Ecosystems

- First meeting 12-16 June 2017, Copenhagen
- End user-driven process to identify and develop predictive products
- Aiming at operationalising predictions
- Joint activites planned with PICES SG-CEP
  - Theme session at Climate Change Impacts Conference in Washington 2018?
  - -Joint meeting

Seasonal-to-Decadal Prediction of Marine Ecosystems





## Decadal prediction of some elements of marine ecosystems is possible

# Ask not "how do we predict something?" Ask "what can we predict?"

Seasonal-to-Decadal Prediction of Marine Ecosystems

Mark R Payne

mpay@aqua.dtu.dk

DTU Aqua National Institute of Aquatic Resources





# Feel the fear and do it anyway



# Wouldn't it be loverly... if we knew where the fish were going to be?

Seasonal-to-Decadal Prediction of Marine Ecosystems



#### **The Challenges of Surveying Mackerel** 20"W



Seasonal-to-Decadal Prediction of Marine Ecosystems

#### Temporal variability



# Assessing predictive skill





## **Anomaly Persistence Forecasts**





# **Probability of Observing Eggs**





### "Prediction is difficult, especially if it involves the future

### Niels Bohr



**Seasonal-to-Decadal Prediction of Marine Ecosystems** 

# **Biological Model Diagram**

- Environmental correlates
  - -SST
  - -NPP
  - -Daylength
  - -Bathymetry
- Sampling parameters
  Volume filtered
  Gear type

- Response variables
  - -Presence-Absence
  - -Daily Egg Production
- Model types
  - -Binomial GAM
  - -Zero-inflated Poisson GAM
  - -Random forest



### "Prediction is difficult, especially if it involves the future fish"

### (with apologies to) Niels Bohr



**Seasonal-to-Decadal Prediction of Marine Ecosystems** 



# **Biological Model**

- Environmental correlates
  - -SST
  - -NPP
  - -Daylength
  - -Bathymetry
- Sampling parameters
  Volume filtered
  Gear type

- Response variables
  Dresence Absence
  - -Presence-Absence
  - -Daily Egg Production
- Model types
  - -Binomial GAM
  - -Zero-inflated Poisson GAM
  - -Random forest

# What limits predictive skill?



Hawkins & Sutton, BAMS 2009

# **Predictive model skill**

Prob. presence pred. correct Prob. absence pred. correct



Seasonal-to-Decadal Prediction of Marine Ecosystems

# **Forecasting Model**



# **Forecast skill**

(Probability of presence prediction being correct, Northern Region)



Seasonal-to-Decadal Prediction of Marine Ecosystems

Mark R Payne (mpay@aqua.dtu.dk)

# "The great tragedy of science the slaying of a beautiful hypothesis by an ugly fact."

- Thomas Henry Huxley

# So what goes wrong?



# Inter-annual variability in SST is simply not influential enough

Seasonal-to-Decadal Prediction of Marine Ecosystems



# Essentially, all models are wrong, but some are useful

- George E. P. Box

### ...and verify our hypotheses.





Higgs Boson Proposed 1964 Verified 2011-13

CMS detector, Large Hadron Collider



# 

# The role of prediction in science

Seasonal-to-Decadal Prediction of Marine Ecosystems

### Prediction is practical...





Map produced by Halley showing path of predicted eclipse

"Halleys Eclipse" 3 May, 1715





Existence of Neptune predicted by Le Verrier, 1846. Verified after less than an hour's search

### Prediction can open our minds....





Einstein's Theory of General Relativity predicted bending of light by gravity, 1915. Verified 1919

"Cheshire cat" cluster



## **Continuous Plankton Recorder (CPR)**





Deploying a CPR, 80 years later

Sir Alister Hardy deploying one of the first continuous plankton recorders, *c.* 1928

Seasonal-to-Decadal Prediction of Marine Ecosystems



# Fisheries management has learned to live with uncertainty



**Seasonal-to-Decadal Prediction of Marine Ecosystems** 



## ...and at longer time scales...





# What determines predictive skill?



Seasonal-to-Decadal Prediction of Marine Ecosystems



# Where does the improved skill come from?



Seasonal-to-Decadal Prediction of Marine Ecosystems



# Mackerel spawning distribution case study

Seasonal-to-Decadal Prediction of Marine Ecosystems



# **NE Atlantic Mackerel Surveys**



(Scomber scombrus)

#### Mackerel Egg Survey (MEGS)

Tri-annual Egg Survey

Jan-June, Gibraltar - Iceland

~ 2000 hauls, 250 Vessel days

Used in stock assessment

€3-5 million per survey

Ensuring full coverage of stock is challenging

Can we forecast the distribution?

Seasonal-to-Decadal Prediction of Marine Ecosystems





## **Environmental Niche Model**





# **Predicted Egg Counts for MEGS 2016**



**Seasonal-to-Decadal Prediction of Marine Ecosystems** 



# **Predictions for MEGS 2016 June (Period 6) Details**



Seasonal-to-Decadal Prediction of Marine Ecosystems

The most exciting phrase to hear in science, the one that heralds new discoveries, is not '*Eureka!*' but '*That's funny...*'



# - Isaac Asimov



Seasonal-to-Decadal Prediction of Marine Ecosystems



# The quiet revolution in weather forecasting



Bauer Thorpe and Brunet, Nature 2015

Seasonal-to-Decadal Prediction of Marine Ecosystems



# **Distribution Range of Bluefin Tuna**







Fromentin et al. 2013 Fish. Oceanogr.

Rare/absent in E. Greenland & Irminger Sea

**Seasonal-to-Decadal Prediction of Marine Ecosystems** 



# **Availability of Thermally Suitable Habitat**



### Area of suitable habitat increased by size of France

Seasonal-to-Decadal Prediction of Marine Ecosystems

# Outline



Prediction

& Science

Physical Predictability NEW YORK CAPE REINGA I BOB SLARD I BOB SLARD

Biological Predictability



Case Studies



Future Directions

Seasonal-to-Decadal Prediction of Marine Ecosystems



## ...on the seasonal scale...

Include NMME skill map as a supplement here

NMME Ensemble SST skill, 6 months lead

Seasonal-to-Decadal Prediction of Marine Ecosystems



## But that's about as far as we got ...



1 out of 49 recruitment-environment correlations "survived" 10 years

Myers, Rev. Fish Biol. Fish. 1998



#### 15 out of 1250 fish stocks incorporate environmental information in tactical management

#### Skern-Mauritzen et al, Fish Fish. 2015

Seasonal-to-Decadal Prediction of Marine Ecosystems



# **Bluefin Tuna Habitat Predictability**



Seasonal-to-Decadal Prediction of Marine Ecosystems