Climate Induced Adaptations of Behaviour and Life History of Atlantic Cod (*Gadhus morhua*)

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INTRODUCTION

Atlantic cod (*Gadhus morhua*) stocks inhabit waters over a wide geographic distribution within the North Atlantic. They exhibit a common life history template but with considerable variations in their growth rate and age of maturation [1]. The intraspecific diversity exhibited by North Atlantic cod stocks is not only important in ecology but also for understanding potential differences in adaptation and resilience to climate change.

A primary mechanism through which global temperature change is expected to affect marine species is respiration physiology, due to its consequences for bioenergetics and performance [2, 3]. Resting metabolic rates increase exponentially with temperature, whereas aerobic scope, the maximum capacity to uptake additional oxygen, shows a more complicated pattern with an optimum temperature above which maximum uptake declines [3]. Moderate decreases in aerobic scope can translate into changes in maintenance, growth, activity, and reproduction and are sufficient to cause a loss in fitness and increased mortality [4].

We provide a mechanistic model based on a bioenergetics framework that predicts temperature-induced adaptations for life histories and behaviour of Atlantic cod (*Gadhus morhua*).

METHODOLOGY

We use a mechanistic modelling approach (Fig 1), whereby, temperature dependent physiological functions for respiration [5,6], ecological parameters of mortality and stock specific parameters for harvesting, migrations and temperature seasonality are input within the model (Fig 2).

Dynamic programming [5,6], is used to find optimal strategies of foraging and energy allocation, having consequences for survival, growth and reproduction.

Emergent life history strategies result through evolutionary optimization, and optimal individual strategies are simulated in populations to provide predictions of stock responses to climate change.

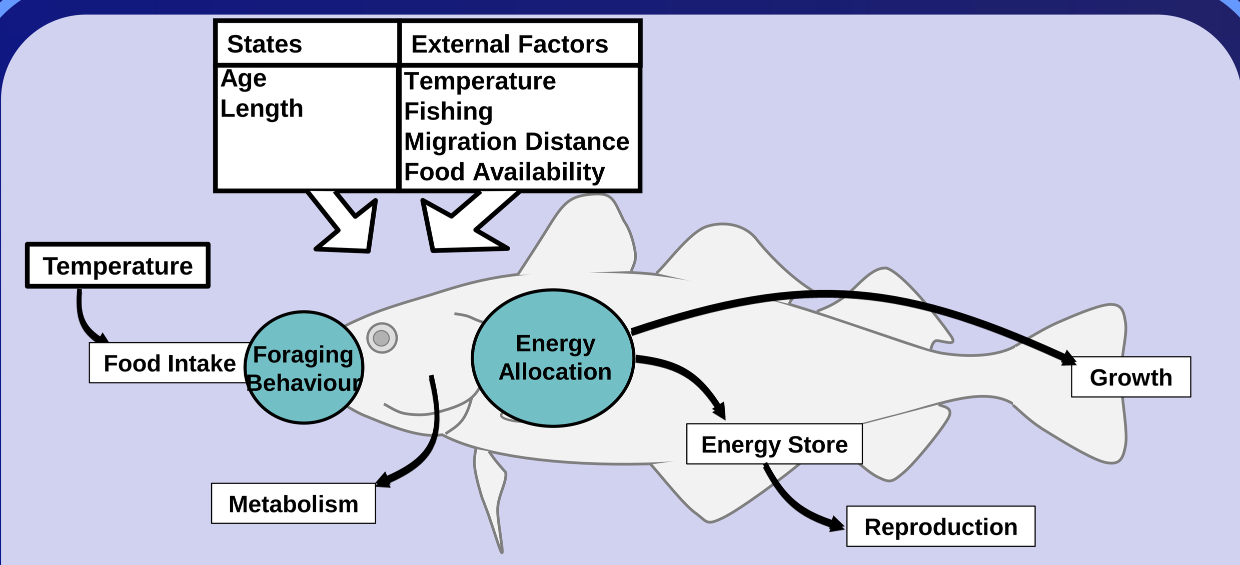


Fig 1. Conceptual diagram of energy allocation in teleost fish (Black lines indicate energy flow)

STOCK-SPECIFIC ASSUMPTIONS

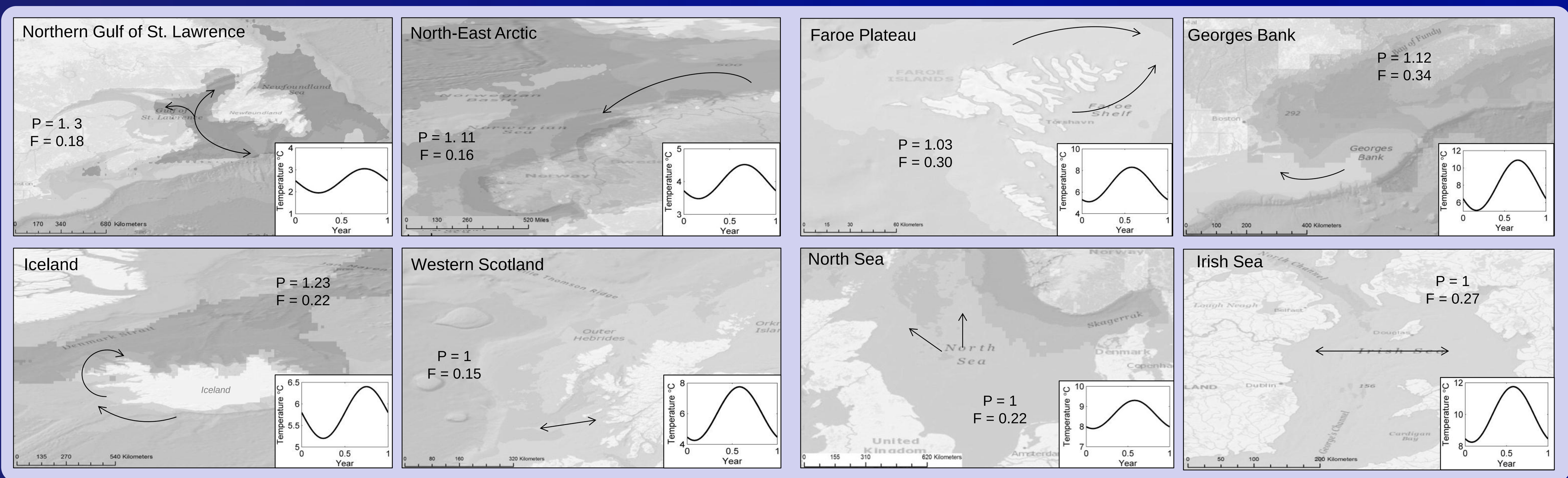
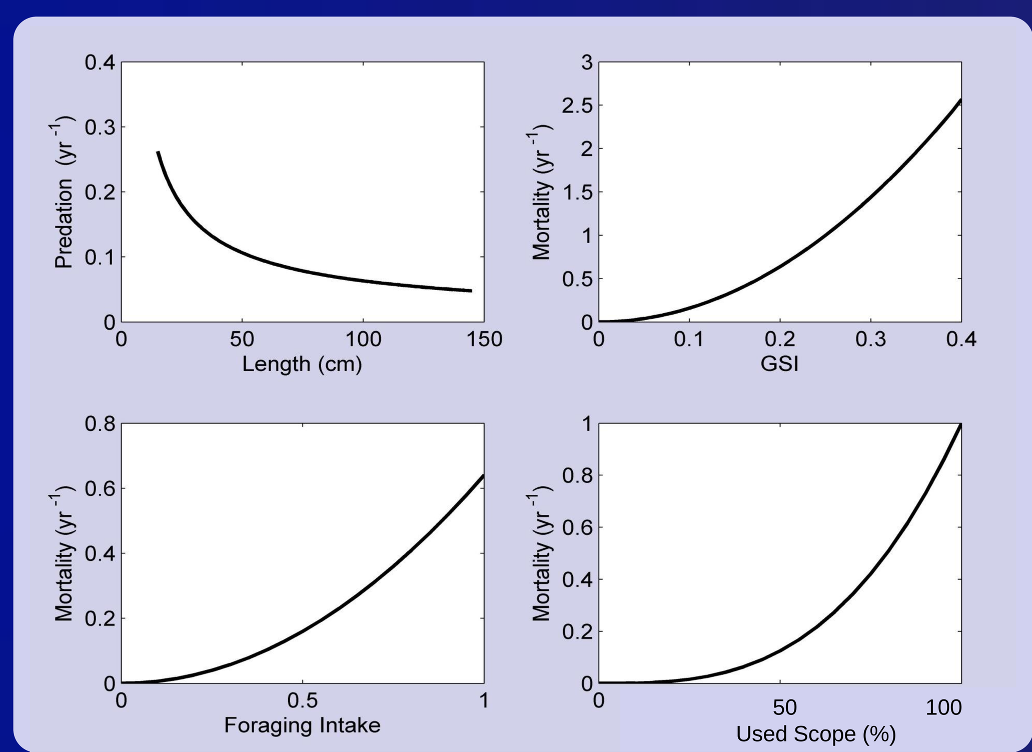


Fig 2. Maps displaying each stocks migration routes, temperature seasonality, habitat productivity value (P), and harvesting mortality (F) used in the model

Capelin Habitat Distribution
Migration Routes

GENERAL ASSUMPTIONS



RESULTS

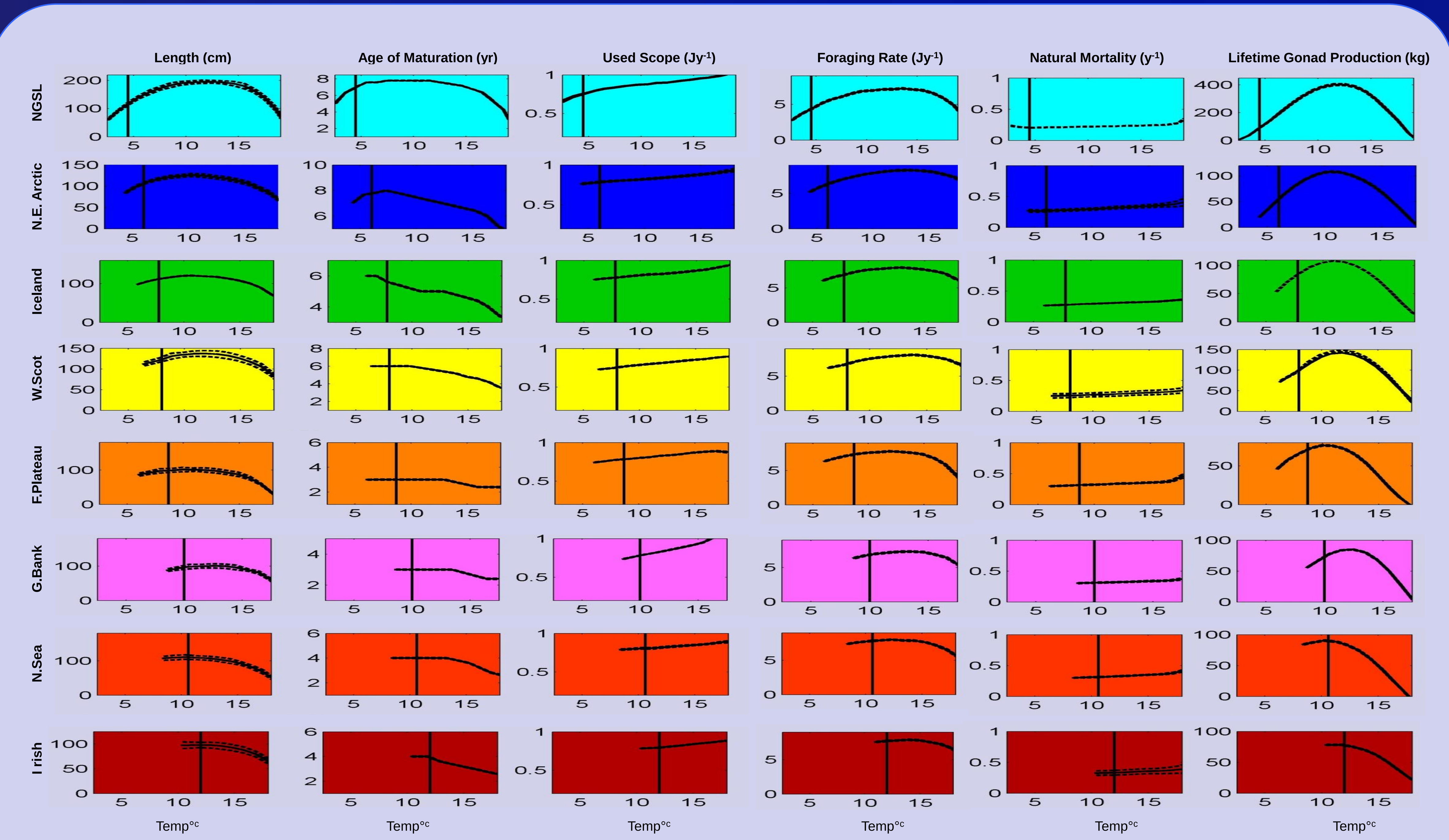


Fig 4. Predicted lifetime trajectories (Age 15 fish) of length, age of maturation, used scope, foraging rate, natural mortality and lifetime gonad production (left to right) for 8 different Atlantic cod stocks (top to bottom). Solid black line denotes the mean value; dashed black lines represent standard deviation. Vertical line denotes IPCC scenario of 2°c increase

Increased temperature influences the life history strategies of Atlantic cod stocks in diverse ways:

1. **Growth Rate** initially increases for cold-water stocks* followed by a subsequent decline. In warm water** stocks a gradual decline in growth rate is observed.
2. **Age of Maturation Decreases** - On an evolutionary time scale, higher temperatures may create a selection pressure towards earlier maturation, except for the NGSL stock.
3. **Used Scope Increases** – Overhead costs, such as specific dynamic action, foraging activity and mortality increase with increasing temperature, encompassing a larger proportion of the aerobic scope.
4. **Foraging Rate Increases** - Emergent patterns in foraging behaviour are observed. The fish forage harder, behaviorally compensating for changes in temperature dependent overhead costs.
5. **Natural Mortality Increases**
6. **Lifetime Gonad Production** initially increases for cold-water*, F.Plateau and Georges Bank stocks, followed by a decline beyond a 4°c increase. In North Sea and Irish Sea cod stocks however, an immediate decline in lifetime gonad production is observed.

*cold-water stocks: Northern gulf of St. Lawrence (NGSL), N.E Arctic, Icelandic and Western Scotland.
**warm-water stocks: Faroe Plateau, Georges Bank, North Sea and Irish Sea

CONCLUSION

Climate warming changes the optimal maturation age, reproductive investment, and foraging strategy beyond what is expected by physiological considerations alone. The model illustrates how climate change effects may influence the life history strategies of cod in diverse ways, and how cod stocks may differ in their response. We incorporate and challenge the concept of physiological performance thresholds by showing how the effect of temperature on adaptations depends on the ecological setting

1. Ratz, H.J. and Lloret, J. 2003. Variation in fish condition between Atlantic cod (Gadhus morhua) stocks, the effect on their productivity and management implications. Fisheries Research. 60: 369-380
2. Pörtner H.O, Knust R (2007) Climate change affects marine fishes through the oxygen limitation of thermal tolerance. Science 315:95–97
3. Pörtner H.O and Peck, M.A. 2010. Climate change effects on fishes and fisheries: towards an cause-and-effect understanding. Journal of Fish Biology. 77: 1745-1779
4. Fry, F. E. J. 1971. The effect of environmental factors on animal activity. In Fish Physiology, 6, pp. 1–98. Ed. by W. S. Hoar, and D. J. Randall. Academic Press, New York.
5. Houston, A.I., and McNamara, J.M. 1999. Models of adaptive behaviour: an approach based on state. Cambridge University Press, Cambridge, UK
6. Clark, C.W. and Mangel, M. (2000) Dynamic state variable models in ecology. Oxford University Press, New York.