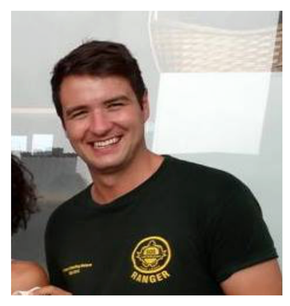

Sandeel Growth: The consequences of climatic warming on morphology and phenology

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Introduction

- Sandeel (*Ammodytes sp.*) life history makes this family of fish particularly susceptible to the consequences of climate change (Heath *et al.* 2012).
- As sea temperature rises an individual's assimilation rate first increases then drops off dramatically and maintenance costs rise exponential = REDUCED FISH GROWTH (Jobling 1994).
- Survival therefore becomes heavily dependent on the temporal synchronization of sandeel emergence and the spring bloom in secondary production.
- This study introduces a deterministic individual based bioenergetics model for juvenile lesser sandeel (*Ammodytes marinus*) in the North Sea.
- The aim was to disentangle the physical-biological interaction processes of food availability and sea bottom temperature to provide a more mechanistic understanding of how climatic warming of the oceans is likely to effect the growth and survival of this key prey species.

The model

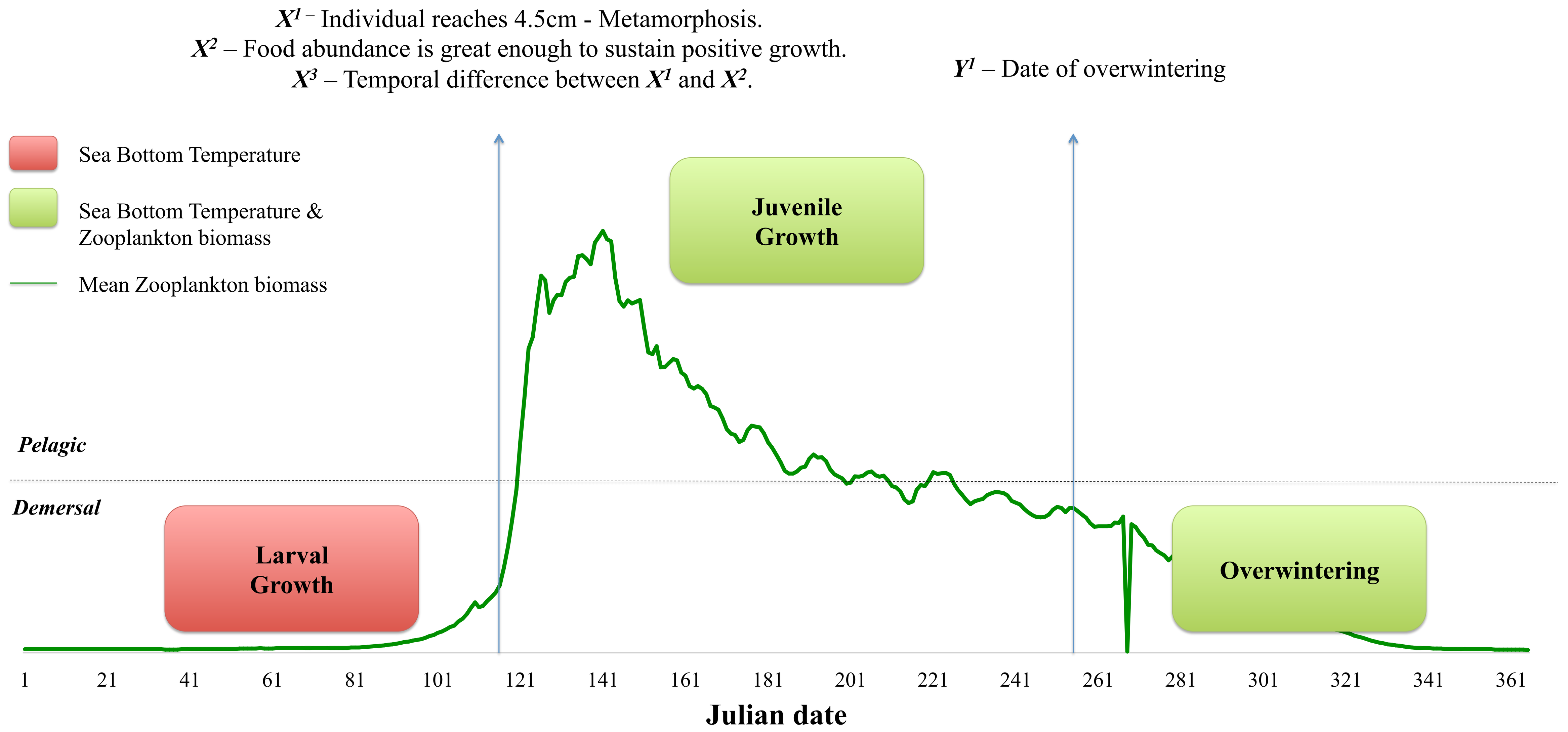
Deterministic individual-based model that is based on Broekhuizen 's (1994) compensatory growth model.

Parameter values taken from Heath *et al* (1997) or based on empirical studies.

Two main assumptions:

(1) An individual partitions net assimilate to either structural or reserve tissue.
(2) The fish modulates its physiology in response to an instantaneous ratio of reserve to structural tissue and aims to achieve an ideal ratio of 1.5:1 (Kleiber 1961).

Theoretical thresholds are imposed to separate the three main sandeel growth phases.



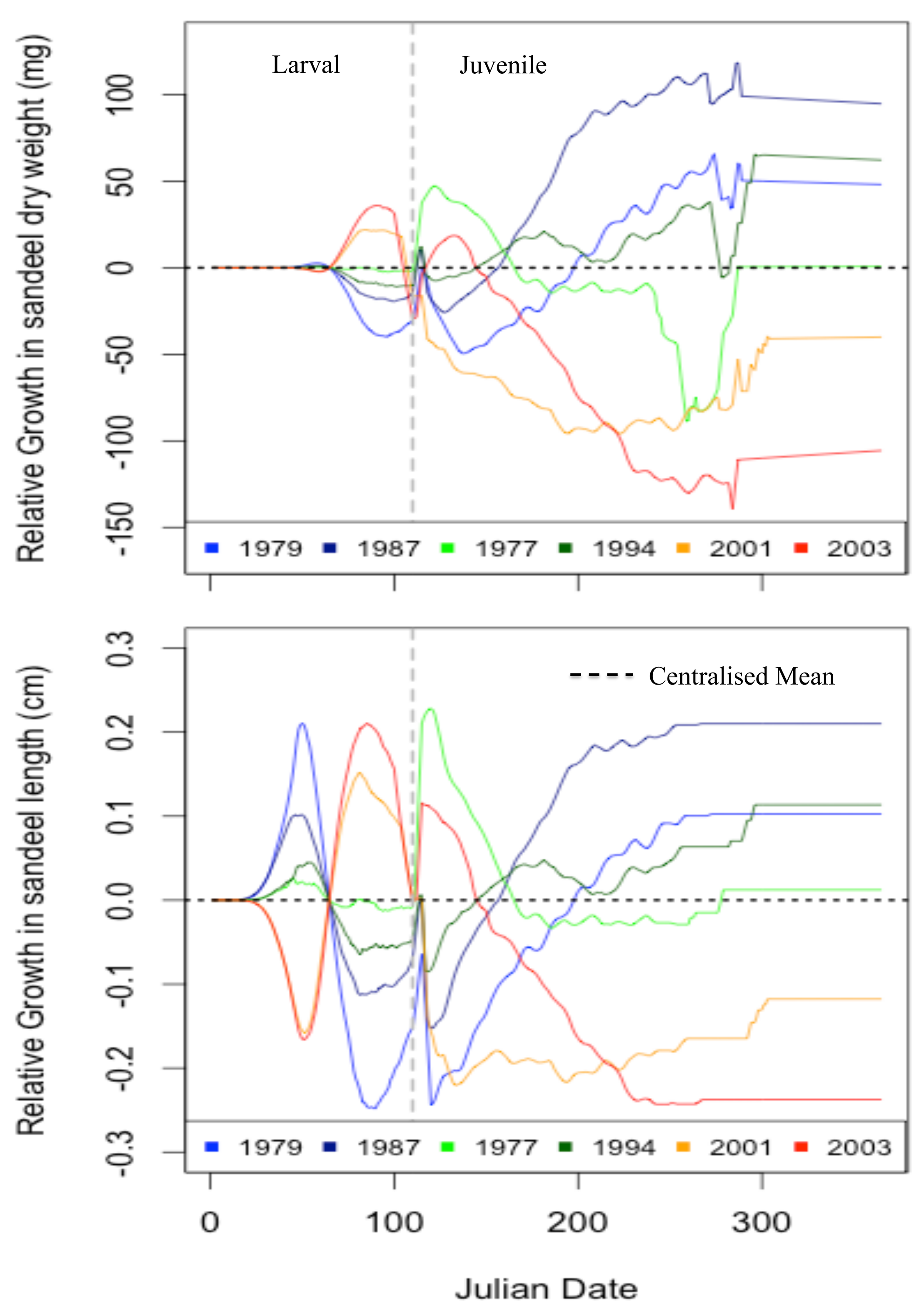
Input Parameters

Sea Bottom Temperature (SBT) (°C) – MET data (1973-2003) from the Marr Bank region (Depth 65m, 56° 15' N; 01° 15' W) of the North Sea.

Zooplankton biomass (mg d m^{-2}) – taken directly from locally parameterized runs of a 1-Dimensional Biophysical Model (Sharples 1999) for the Marr Bank region (see Scott *et al*. 2006).

Yearly conditions:
1979: Low Temp, Low Food.
1987: Low Temp, High Food.
1977: Average Temp, Low Food.
1994: Average Temp, High Food.
2001: High Temp, Low Food.
2003: High Temp, High Food.

A **Mean** year is also calculated and used as a comparison.



Results

Warmer temperatures are shown to accelerate larval growth leading to temporal mis-matches in X^1 and X^2.

In 2001 & 2003, X^1 occurs 15 and 14 days earlier than X^2 resulting in respective losses of 21% and 18% of their total reserve tissue.

Little variation in X^3 is observed across all other conditions.

Colder conditions (1979 & 1987) support a greater juvenile growth rate, resulting in a fish at Y^1 that is both long and fat.

Greater food availability during cold and average years results in increases in dry weight.

Warmer conditions (2001 & 2003) are shown to cause a slower juvenile growth rate.

In fact, in 2003 when food availability is high, the individual is shorter and thinner at Y^1 than under all other conditions, demonstrating that a 1°C increase in average SBT is sufficient to offset the potential benefits of greater food.

Overwintering weight loss (ΔO) is shown to be driven by both body size and SBT.

In 1979 and 1987, ΔO peaks at 9.5% and 17.5% respectively.

In 2001 and 2003, ΔO peaks at 12.7% and 17.2% respectively.

ALL POINT TO A CLIMATE DRIVEN DECLINE IN SANDEEL BODY CONDITION.

Wider Ecological Picture

- Declines in sandeel body condition are likely to reduce individual survival and potentially delay the onset of maturity.
- On a community level, declines in body condition will reduce it's nourishment value to predators, potentially leading to seabird breeding failures (Wanless *et al.* 2005; Furness *et al.* 2002; 2007), declines in the weight of commercial fish species (Engelhard *et al.* 2008) and the body condition of marine mammals (Santos *et al.* 2006).
- Poor reserve accumulation will also have economic consequences, with the fat content of fish presumably reducing the value of catch for processing into fishmeal or oil (ICES 2002).

References
Broekhuizen, N. *Function Ecology,* **8**, 770-782 (1994).
Engelhard, G.H., van der Kooij, J., *et al. Marine Ecology Progress Series*, **369**, 213-227 (2008).
Furness, R.W. *ICES Journal of Marine Science*, **59**, 261-269 (2002).
Furness, R.W. *Journal of Ornithology*, **148**, 247-252 (2007).
Heath, M., Scott, B., Bryant, A.D. *Journal of Sea Research*, **38**, 413-436 (1997).
Heath, M., Neat, F.C, *et al. Aquatic Conservation: Marine & Freshwater Ecosystems,* **22**, 337-367 (2012).
ICES Document CM 2002/ACFM: 1-555pp.
Jobling, M. *Fish Bioenergetics (Fish & Fisheries Series)* (1994). Springer.
Santos, M.B., Pierce, G.J., *et al. Marine Mammal Science*, **20**, 1-27 (2004).
Scott, B.E., Sharples, J., *et al. Top Predators in Marine Ecosystems* (2006). Cambridge University Press.
Wanless, S., Harris, M.P. *Marine Ecology Progress Series*, **294**, 1-8 (2005).