Hindcasting North Atlantic plankton production

Riina Klais (Tartu University) riina.klais@ut.ee

Introduction

North Atlantic herring and cod fisheries are driven by climate and fishing. Climate variability affects the spatial distribution of fish, through their temperature tolerance, and drives the inter-annual variability in the availability of food, in particular, the abundance of the expatriate populations of large oceanic arctic copepod *Calanus finmarchicus. C. finmarchicus* dominates the zooplankton biomass and secondary production in many North Atlantic shelf ecosystems: the North Sea, North East Atlantic, and Gulf of Maine/Scotian Shelf regions (Greene et al 2003). It has been hypothesized that climate-associated changes in ocean circulation drive the interannual to interdecadal fluctuations in the abundance of *C. finmarchicus* (Greene and Pershing 2000), and therefore also the resources available for fish populations. Although the observational time series of plankton are still relatively short (up to 50 years in best cases), compared to the long-term cycles of atmospheric and climate variability, e.g. ca 60 years for Atlantic Multidecadal Oscillation; decadal records of climate and plankton variability already allow us to estimate the likely past conditions of prey availability, and explain some of the historic patterns in commercial fishing.

In this report, we use published plankton data, together with long-term reconstructions of past climate variability, to hindcast and visualise the plankton abundance in the NW and NE Atlantic in the past 600 years.

Material and methods

As a proxy for zooplankton production in the NE Atlantic (North Sea) we used the Plankton Index calculated from the Continuous Plankton Recorder data developed first by Beaugrand et al (2003), and recalculated in Beaugrand and Kirby (2010) for the period of 1958-2006. This index is first component of the Principal Component Analysis from the abundances of *Calanus finmarchicus*, *Calanus helgolandicus*, Euphausiids, *Pseudocalanus spp*., the total calanoid copepod biomass and the mean size of female calanoid copepod (Beaugrand & Kirby, 2010); but it is mainly driven by the mean size of copepods, which in turn is mostly determined by the relative abundance of *C. finmarchicus* (Beaugrand et al 2003). Timeseries of Plankton Index (PI) was retrieved from the Fig. 2. in Beaugrand and Kirby (2010).

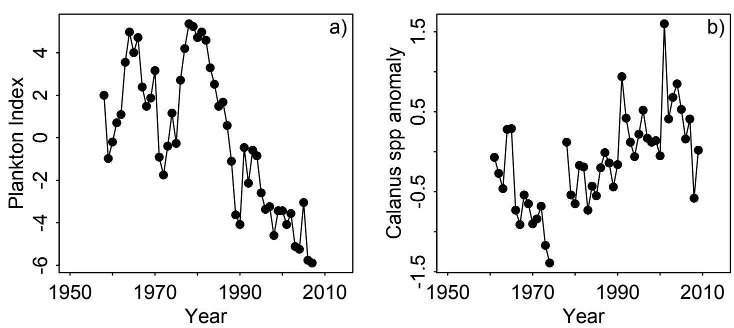

Figure 1. a) Plankton Index in North Sea (Fig. 2. of Beaugrand and Kirby, 2010); b) *Calanus* spp annual anomalies in Gulf of Maine (Greene et al., 2013).

The annual anomalies of *Calanus* spp in the NW Atlantic (Gulf of Maine) was provided by dr Greene, and was published in Greene et al (2013).

Climate proxies

Several long-term reconstructions of northern hemisphere temperature exist, we explored three of them:

1) Northen Hemisphere Temperature anomalies reconstructed for the last 2000 years by Moberg et al (2005);
2) Temperature reconstruction for the North Atlantic Multidecadal Oscillation region by Mann et al (2009) (http://www.ncdc.noaa.gov/paleo/pubs/mann2009b/mann2009b.html);
3) Surface ocean conditions in North-East North Atlantic for the last millennium by Cunningham et al (2013). NE Atlantic Ocean, best choice seems to be the reconstruction by Cunningham et al 2013. Reconstruction is based on 10 different paleoceanographic records in NE North Atlantic, covering the latitudes 56.66 - 69.48 N, and (-18.19)-18.36 E
-Online source https://www.ncdc.noaa.gov/paleo/study/14193

Instrumental records of temperature:

NASA Goddard Institute of Space Studies; GISTEMP Surface temperature. Accessed 11.06.2016. http://cdiac.ornl.gov/ftp/trends/temp/hansen/nhsh.txt . The GISTEMP Team - G. Schmidt,** R. Ruedy,* A. Persin,* M. Sato,** and K. Lo*.

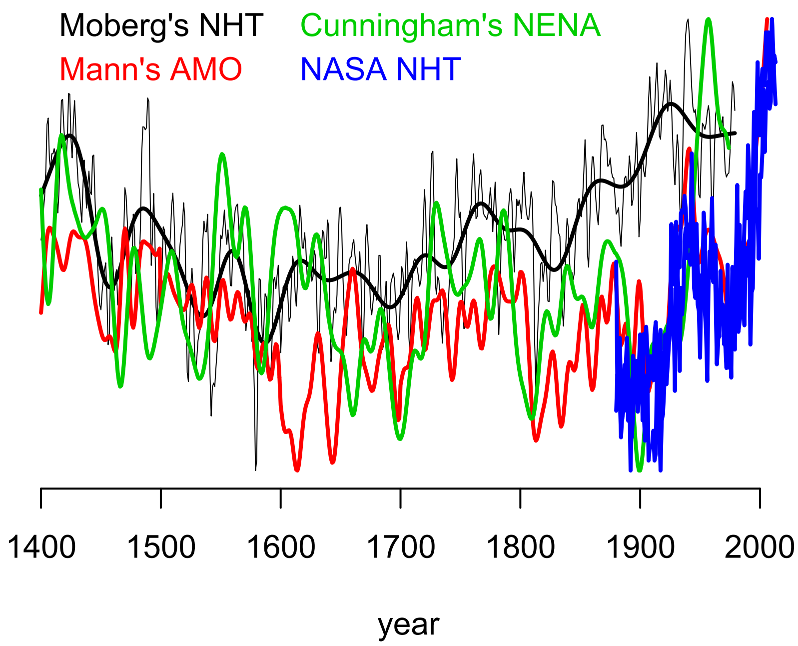

Figure. 2. Climate proxies. Three reconstructions (Moberg et al 2003, black; Mann et al 2009, red, and Cunningham et al 2013 (green) start all before 1400, here shown for the period of 1400-present. Average northern hemisphere temperatures from NASA (blue) start 1880.

How do the long-term temperature reconstructions correlate with Plankton Index in North Sea, and *Calanus* spp. in gulf of Maine?

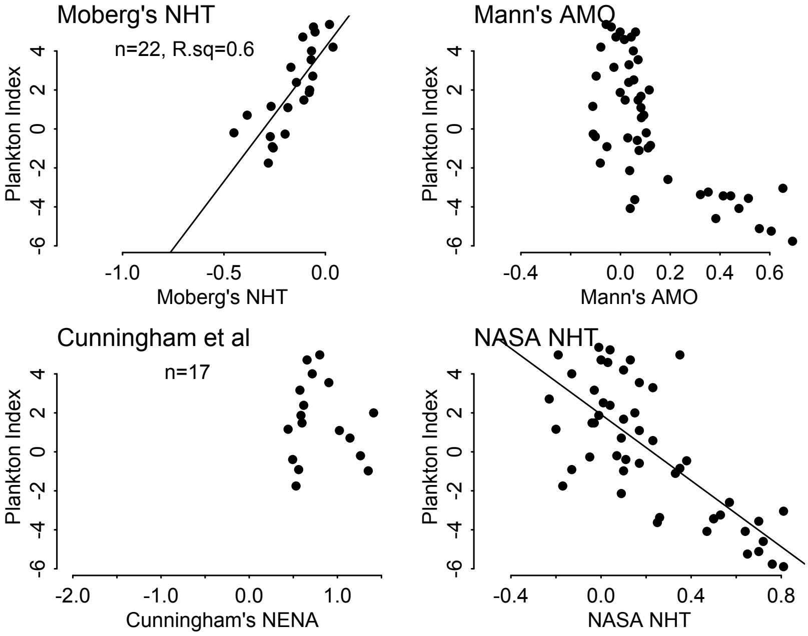

Figure 3. Correlations between Plankton Index and the temperature times series.

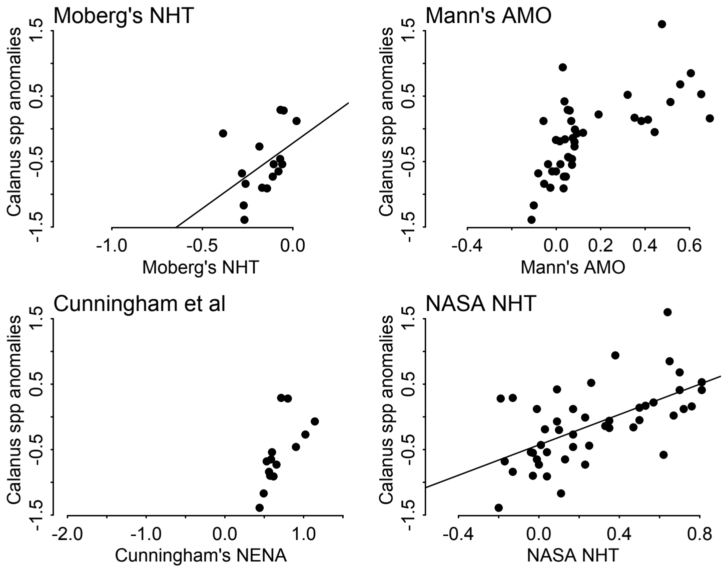

Figure 4. Correlations between *Calanus* spp juveniles and the temperature times series.

Of the three long term proxies, and one instrumental record, the NASA NHT was closest correlated with both, the Plankton Index in North Sea, and *Calanus* spp juveniles in Gulf of Maine, but with opposite sign of the relationship. Hence, it would be preferential to use NASA's NHT for both reconstructions, but it only extended back until 1880, not 600 years. Therefore, we next explored which of the long-term proxies was closest associated to NASA NHT:

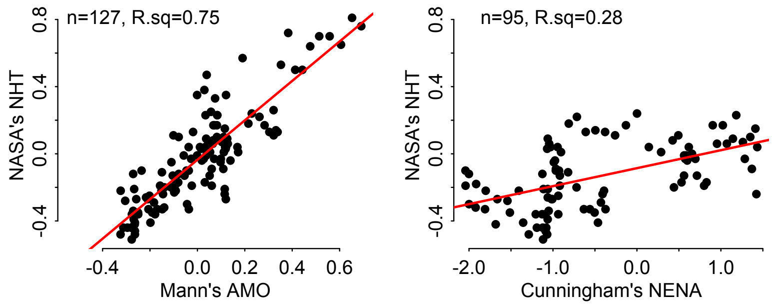

Figure 5. Correlations between NASA NHT and long term temperature proxies – Mann's AMO, and Cunningham's NENA

It appears that Mann et al (2009) reconstruction is linearly linked to NASA's NHT over the period of 1880-2006, while correlation to Cunningham's reconstruction, though still positive, is weaker.

Therefore, to use the linear correlation between NASA NHT and Plankton Index in extending the Plankton Index back until 1400, we first extrapolated the NASA NHT for the 1400-2006 period, using the linear correlation between NASA NHT and Mann's AMO temperature values. This essentially meant only adjusting the mean level of Mann's AMO time series to that of NASA NHT, other than that, the pattern is identical to Mann's AMO (Fig. 6).

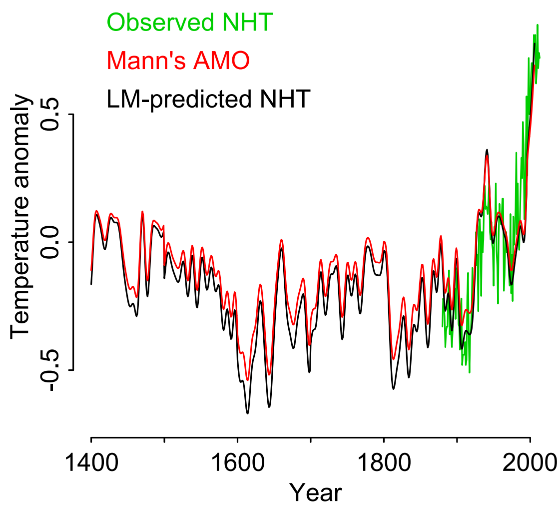

Figure 6. Adjusting Mann's AMO to the mean level of observed NASA NHT.

The linear predictors from the model of Plankton Index ~ NASA NHT (lower right plot in Fig. 3), and from the *Calanus* spp ~NASA NHT (lower right plot in Fig. 4), were then used to reconstruct the North Sea Plankton Index, and Gulf of Maine *Calanus* spp abundance for the period of 1400-2006 based on the extended NASA NHT instead of observed NASA NHT. Reconstructed plankton time series are presented in Fig. 7.

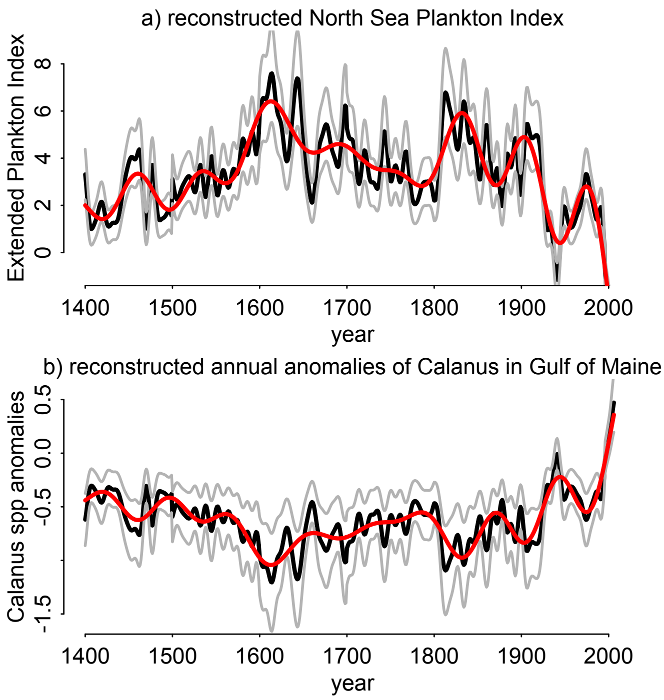

Figure 7. The extended North Sea Plankton Index a) and annual anomalies of *Calanus* spp juveniles in Gulf of Maine (b). Black line – annual values, grey lines are confidence intervals, and red line the generalized additive model smoother.

Conclusions

Reconstruction of zooplankton abundance for NW and NE Atlantic Shelf areas was done for two regions – North Sea in NE Atlantic, and Gulf of Maine region in NW Atlantic. The biological proxies for the plankton abundances identify similar properties of the zooplankton – the abundance of large arctic copepod *Calanus* spp, and hence the quality and quantity of the food. Strong assumption was made that contemporary links between northern hemisphere temperature and plankton abundance hold also in the past. Since the links between large bodied zooplankton and northern hemisphere temperatures (or North Atlantic Oscillation) were with an opposite sign for the two studied regions, the long term reconstructions are mirrored – milder periods are ought to reduce the Plankton Index in the North Sea, while they are associated with higher abundance of *Calanus* in the Gulf of Maine region. This contrasting pattern was also noted and discussed in Greene et al (2003), and explained by the contrasting patterns in currents, and transport of the expatriate populations of *C. finmarchicus* from the Arctic Ocean in to the two regions.

References

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