Large-scale shifts in the North Atlantic bio-geography forced by the subpolar gyre

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And many good people 😊
Important components of the food web

Ocean → shelf influence

Phytoplankton

Zooplankton

Nutrients

Mackerel

Blue whiting

Seabirds

Physics (SPG)
The subpolar gyre

The Labrador Sea convection

Subtropical Gyre

Subpolar Gyre

(Hatun et al., Science 2005)
The Subpolar Gyre

Salinity in the Irminger Current (obs.)

Salinity at the Ellett Line (obs.)

Gyre index (GI)

Record high T and S

Weak.

Strong
The Subpolar Gyre

Simulated temperature

Extended Ellett Line

1993

Grønland

Subpolar Gyren

1998

Large mid-1990s changes!
The main signals

Open Ocean = Inter-decadal trend + Sub-decadal variability
East-West silicate gradient

Sub-arctic: fresh, much silicate

Lusitanean: saline, poor in silicate

Climatological June concentrations, 50m depths

(source: WOA09)
Nutrients

Silicate decline

~ 40% reduction in potential diatom production

Silicate cons.

Year


Irminger Current

Svinøy

Gimsøy

Gyre index

(winter conc.)

(courtesy: Francisco Rey and Jón Ólafsson)

In Prep.
The central Labrador Sea

Silicate decline

Likely an impact on higher trophic levels

winter convection water collected in May

(courtesy: Kumiko Azetsu-Scott)
The Rockall region
(Ocean Color/satellites)

Monthly Chlorophyll (mg/m³)

Phytoplankton

SeaWiFS

(May-Sept. 2002-2005)

SeaWiFS-based chlorophyll in selekt

0.01
0.1
1
10
1995
2000
2002
2005
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2

Monthly Chlorophyll (mg/m³)

Annual chl average

Gyre index
(shifted 1 yr →)

1995
1997
2000
2002
2005
Phytoplankton

Long-term changes

The Continuous Plankton Recorder (CPR)

Phytoplankton Color Index (PCI) (1958-2005)

Much more phytoplankton (greeness) after 1995!

The Subpolar Gyre and plankton - Space

(a) Sea Surface Height
   Hátún et al., Science, 2005

(b) Sea Surface Temperature
   Beaugrand, Science 2002

(c) Phytoplankton

(d) Calanus finmarchicus
   (Hátún et al., PIO, 2009)
The Subpolar Gyre and plankton
- Time

(1955-2005)

Weak gyre
Weak

Strong

Sea Surface Height
Sea Surface Temperature

But silicate decline?

Phytoplankton (PCI)

Calanus finmarchicus

(Hátún et al., PIO, 2009)
Diatom decrease in the east

A 30-year diatom decline
maybe reinforced by the gyre

Graph showing diatom data over the years from 1972 to 2002, with a trend line indicating a decline. The Gyre index is shown on the graph. The text also mentions that the decrease might be reinforced by the gyre.

(Alvarez-Fernandez and Hátún, Submitted to PIO)
Phytoplankton in the central subpolar gyre

- Ratios to total phytoplankton abundance
- Estimated ratios

Diatom ratio decreases
Dinoflagellate ratio increases

As expected from the silicate decline

(L. Zhai et al., 2014)
On-shelf zooplankton - characteristic sub-decadal variability

(Hátún, et al – submitted to PIO)

Mainly C. finmarchicus

South Iceland shelf

Hypothesis:
A north-eastward extended subpolar gyre limb in the Irminger Sea improves the biological productivity southwest of Iceland – both oceanic and potentially on the shelf.
The Subpolar Gyre and on-shelf biological production

Zooplankton (on-shelf)

Gyre index (detrended)

Strong gyre $\rightarrow$ high production
Statements on Plankton

• More subtropical influence after 1995
• More phytoplankton (greeness) after 1995
• General decline in diatoms and increase in dinoflag.
• Higher abundance of warm-water zooplankton species after 1995 (not shown)
• Lower abundance of sub-arctic zooplankton species (*Calanus finmarchicus*) after 1995
• Clear sub-decadal variability:
  NAO+ → Strong gyre → more *Cal fin* off- and on-shelf
Blue whiting

Spawning

Feeding area

(Hátún et al., PIO, 2009)
A threefold stock-size increase

Largest fishery in the North Atlantic!

SST (in Rockall Areal)

Stock size (← shifted 3 years)

(Hátún et al., PIO, 2009)
Spatial Shifts
(Catches – all nations)

Cold (1990-1996)


Spawning distribution

Migration

(Hátún et al., PIO, 2009)

(Hátún et al., CJFAS, 2009)
Cold years – Faroe-Shetland Ch.
Warm years – Iceland-Faroe region

Possibly more suitable food
So what about blue whiting recruitment?

(Ferreira, Hátún, Payne, Makenzie, Visser, submitted)
Atmosphere-gyre details

Wind stress curl

Wind stress - arrows (NCAR/NCEP)

Cyclonic (Curl >0)

Anticyclonic (Curl <0)

UK

Greenland
Atmosphere-gyre details

Subpolar Gyre

Subtropical Gyre

WSC = 0
Atmosphere-gyre details

- Subpolar Gyre
- Subtropical Gyre
- "Inter-gyre region"

WSC = 0
Recruitment and wind stress curl

(Ferreira, Hátún, Payne, Makenzie, Visser, submitted)
Western and Eastern source waters

Metric based on altimetry

~ 7 Sv
(Pingree, 2002)
An along-Continental Slope perspective

(Data availability) Decompose onto a S-axis

(b) Hydrography

(Hátún et al. 2009, CJFAS)
Salinity

Hydrographic Pulses

Salinity @ 300m

Shetland

Porcupine

Distance [km]

Year

Porcupine

Salinity
Hydrographic Pulses

Salinity, currents

Distance [km]

Year

Salinity @ 300m

Weaker NAC

Porcupine

Shetland
Hydrographic Pulses

Salinity, currents and recruitment

A new boom?

('prediction' made at an ICES meeting in Santander 2011)
The post-2006 mackerel expansion

(Pacariz, Hátún and others, In Prep.)
A narrow ‘corridor’

International mackerel surveys
Average mixed layer depth
(from HYCOM)

'Corridor'
Empty Iceland Basin?
– a richer ‘corridor’

Silicate summer concentrations (µM)

Iceland Basin

Limiting at 2 µM

Extended Ellett Line
The post-2006 westward mackerel expansion is induced by the west-high, east-low nutrient gradient, together with the recent strong nutrient decline in the North Atlantic.
Subpolar conditions (large gyre) might improve on-shelf conditions in the east as well.
Poleward pulses

Simulated salinity anomaly (time-lat. plot)

Northward transport

1 Sv = $10^6$ m$^3$/s

MICOM

Kittiwakes in Shetland

Lagged 1-2 years

Faroe cod

Weight and Recruitment

UK
Subpolar gyre and puffins - South Iceland

Gyre index

Shifted 5 years →

Puffin catches (Vestmannaeyjar)

(Diagram showing changes in silicate and diatom levels over time, with shifted gyre index indicating strong and weak conditions.)
Messages

• The North Atlantic subpolar gyre regulates ecosystems in the NE Atlantic.

• Critical aspects: The relative contribution of eastern and western waters, and the Rockall-Hatton plateau topography

• The Extended Ellett Line is a key section for monitoring these changes

(FP7 2007-2013), Grant agreement n.308299
NACLIM www.naclim.eu
A link to the Newfoundland Basin

(Bersch et al. 2007):
‘...shift in subarctic surface and intermediate water masses between the West European Basins (/Iceland Basin) and the Newfoundland Basin’

(Hátún, et al., 2005)
Statements by Herbaut and Houssais (2009):

...contrary to the suggestion of Hátún et al. (2005) and Bersch et al. (2007), this acceleration of the gyre does not force the changes in the eastern North Atlantic.

...salinity changes in the eastern SPG are mostly due to the set-up of an “intergyre gyre” in response to the wind-stress anomalies rather than to an enhancement of the gyre circulation due to the buoyancy flux.
The ’Inter-gyre’ gyre
(simulated stream-function)

(Eden and Willebrand, 2001)
NAC shifts in the Newfoundland Basin

Simulated salinity (MICOM, upper layers)

Depth (m)
NAC shifts in the Newfoundland Basin

First EOF (after linear detrending)
Wind stress curl
(Herbaut and Houssais, 2009)

Covariance between the NAC position and the influx of western water

Simulated Transport

Yes

No

PC

NAC position and western water influx

Year


0 1 2 3 4 5 6

Transport [Sv]
2d. The Subpolar Gyre and Long-finned Pilot Whales
(Globicephala melas)
SST (in Rockall Area)

Pilot whales in the Faroe Islands

(Hátún et al., PIO, 2009)
Long-term whale migration

The gyre-ecosystem link over three centuries!

(Hátún et al., PIO, 2009)
SeaWiFS-based chlorophyll in selekt

Chlorophyll Chl, 2002-2005

Geolocators

Harris et al, 2009

Puffins

Heyst

Chl, 2002-2005

[0.01, 10]
Unexpected: strong winter → earlier bloom

Phenology

Timing of spring bloom
(Average, 1998-2011)

Iceland

Mid-May

Rockall

Late March

NAO+, strong gyre
- Mid-April

NAO-, weak gyre
- Mid-May

(Courtesy: Sofia Ferreira)
Atlantic Climate Indices (and proxies)

- AMO
- SST (NE Atl.)
- Central England Temperature (CET)
- GI
- NAO
Silicate in Faroese water

Nutrients

On-shelf

Off-shelf

Si (µM)

1997 1999 2001 2003 2005 2007 2009 2011 2013
Kittiwakes – Breeding Success

Average over 15 colonies in Shetland

#Chicks/nest

Year

(Nature Communications, almost ;-)
Poleward pulses and the Shetland Kittiwakes – Breeding Success

Sverdrup Transport (inverted)

Potential for Prediction!

(Nature Communications, almost ;-)
The gyre warps biological provinces

(Source: Ekman, 1953)
The gyre warps biological provinces

(Source: Ekman, 1953)
Diatoms

Northern Iceland Basin

Mid-1990s increase in dinoflagellates

(Alvarez-Fernandez and Hátún, Submitted to PIO)
5. Predictability
10.5 months lead
Start in June

Seasonal forecasting system.
US National Multi-Model Ensemble (NMME)
Amongst the highest predictability potential in the World

Stronger convection again in 2012 and 2014: We predict(ed) increased production 😊