Abundance and horizontal distribution of Northeast Atlantic mackerel in the Nordic Seas summers 2007-2013

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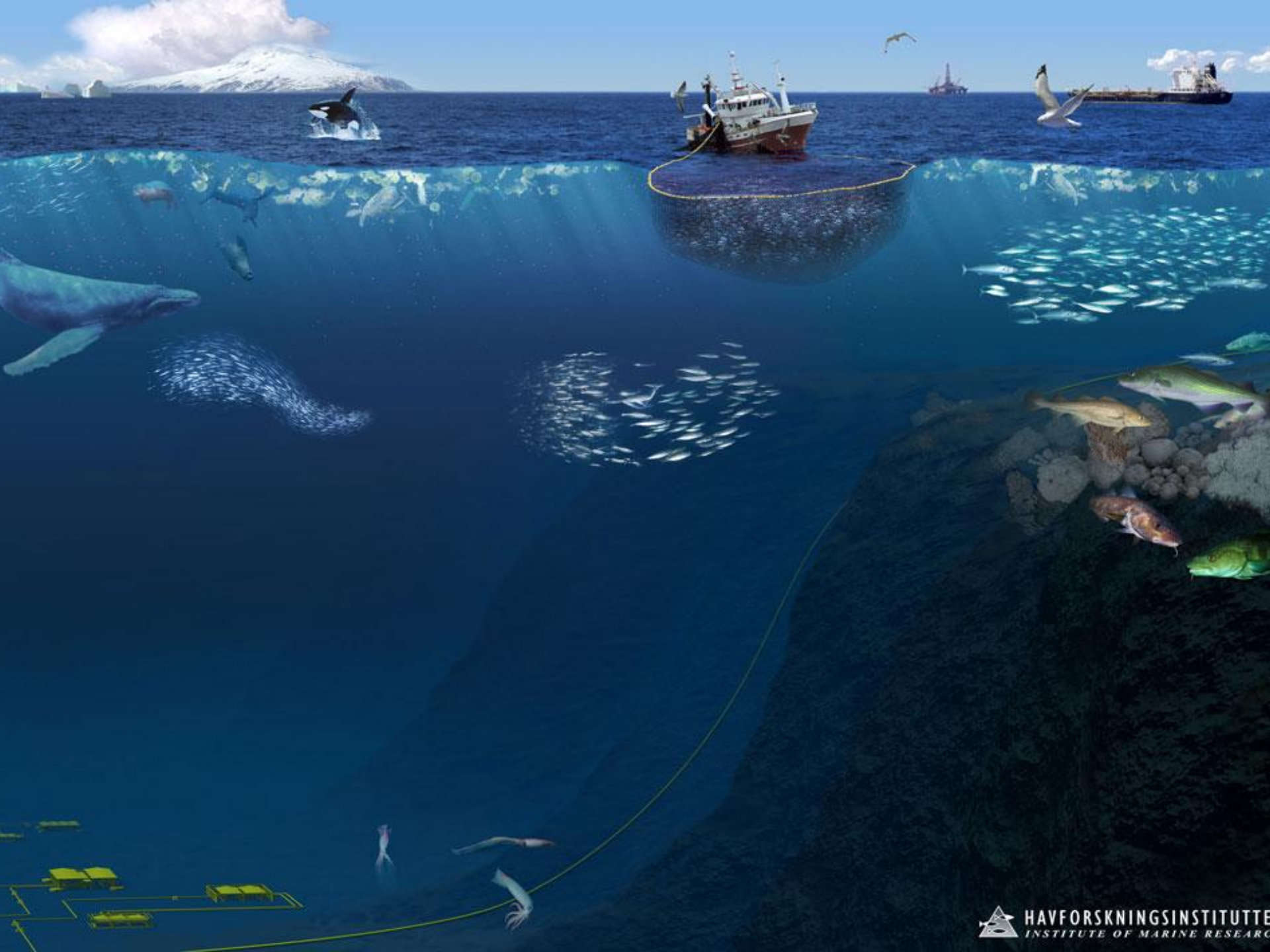
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The principal pelagic fish player in the Northeast Atlantic ecosystems

Northeast Atlantic mackerel (*Scomber scombrus*)

- Most commercially valuable fish species in North Atlantic Ocean
- Key ecological role as predator, competitor and prey in the North Sea, Norwegian Sea and massive coastal waters in the NE Atlantic
- Abundant and presently a robust fish population
- Massive distribution and annual long-distance migration patterns
- Explosive, highly adaptive and opportunistic highly migratory schooling pelagic fish

Major objectives

•Quantify abundance, distribution and spatial coverage of mackerel in the Norwegian Sea and surrounding waters July-August 2007-2013 based on extensive and coordinated national and international survey effort

• Quantify inter-annual variation in spatial coverage, centre of gravity and length, weight, age-dependent migration patterns.

• Reveal how in situ temperatures in the upper water column may affect the observed distribution patterns of NEA mackerel

•Reveal how zooplankton concentrations and distribution may affect distribution patterns of mackerel

Research and fishing vessels hand in hand

Several international large oceanic vessels including both research vessels and chartered modern fishing vessels from Norway, Iceland and Faroe Islands performed dedicated mackerel and ecosystem research during summers 2009-2013

Table 1. Survey year, ship name, nationality and time period of chartered and research vessels participating each year from 2007-2013.

Survey Year	Ship name	Nationality	Time period
2007	M/V "Libas"	Norway	15. July - 6. August
2007	M/V "Eros"	Norway	15. July - 6. August
2008	M/V "Eros"	Norway	29. July - 6. August
2008	R/V "Magnus Heinason"	Faroe Islands	2. – 12. July
2009	M/V"Libas"	Norway	15. July - 6. August
2009	M/V"Eros"	Norway	15. July - 6. August
2009	R/V "Magnus Heinason"	Faroe Islands	1.- 15. July
2009	R/V "Arni Fridriksson"	Iceland	4. -24. August
2010	M/V "Libas"	Norway	15. July - 20. August
2010	M/V "Brennholm"	Norway	15. July - 6. August
2010	M/V "Finnur Fridi"	Faroe Islands	9. - 23 July
2010	R/V "Arni Fridriksson"	Iceland	20. July – 12 August
2011	M/V "Libas"	Norway	18. July - 10. August
2011	M/V Finnur Fridi	Faroe Islands	8. - 18. August
2011	R/V "Arni Fridriksson"	Iceland	3. -31. August
2012	R/V "G.O. Sars"	Norway	2. – 20. July
2012	M/V "Brennholm"	Norway	6. - 27. July
2012	M/V "Christian í Grótinum"	Faroe Island	3. – 18. July
2012	R/V "Arni Fridriksson"	Iceland	12. July -10. August
2013	M/V "Libas"	Norway	4.-29. July
2013	M/V "Eros"	Norway	4.-29. July
2013	M/V " Finnur Fridi"	Faroe Islands	2.-17. July
2013	R/V "Arni Fridriksson"	Iceland	12. July – 9. August

Pelagic trawl gears used 2007-2013

Table 2. The different trawl types used onboard the participating vessels from the three countries (FO=Faroe Island, IS=Iceland, NO=Norway) in the ecosystem surveys in 2007-2013, and their specifications.

Pelagic trawl type	Country	Year	Horizontal opening (m)	Vertical opening (m)
Egersund trawl	NO	2007, 2010, 2011	60	40
Wide body 500	IS	2010	23	16.5
Multpelt 832	IS, FO,	2011-2013	65	30
Multpelt 832	NO	2012-2013	65	30

Toolbox 1

- International standarized pelagic trawl (Multpelt 832)
- Multifrequency echosounder (18, 38, 70, 120, 200, 330 kHz) 10-500 m depth coverage
- Multibeam sonars (long-range + short range) 0-50 m depth of primary scientific focus
- Standarized plankton sampling (0-200 m depth)
- SEABIRD / SAIV CTD oceanographic profiles (0-500 m depth)
- Thermosalinograph at ~6 m depth

Toolbox 2

- Ocean current measurements (ADCP)
- Survey logging system mapping important activities
- Modern laboratory fascilities onboard the vessels for analyzing all pelagic fish samples, plankton and oceanographic samples and depth profiles.
- Marine mammal observations

Systematic and predefined pelagic trawl stations from 2007 to 2013

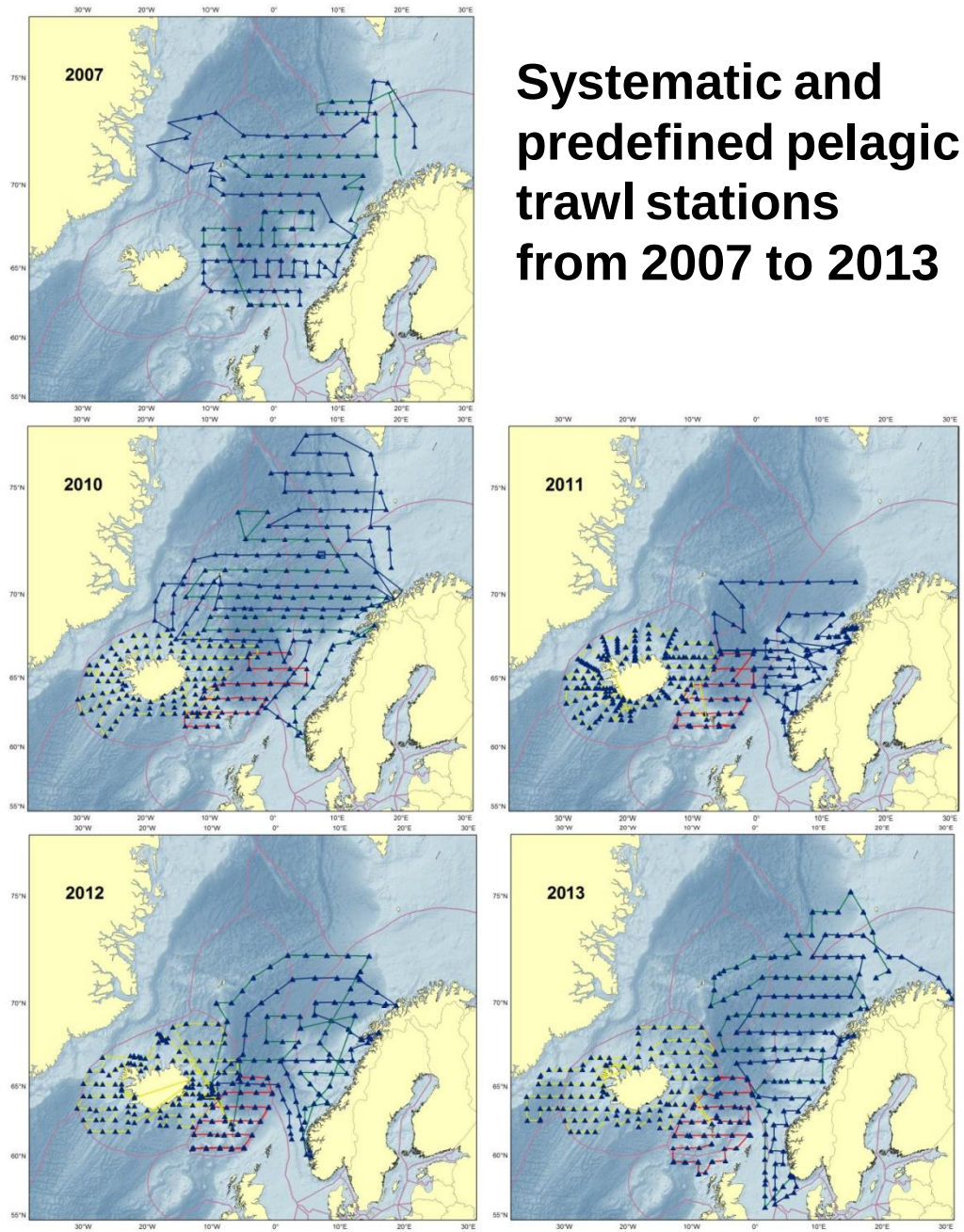


Figure 1a-e. Systematic predefined survey stations including pelagic trawl stations conducted onboard two (2007), three (2011) and four (2010, 2012, 2013) highly equipped vessels from Norway (blue lines), Faroe Islands (red lines) and Iceland (yellow lines).

Results

Average catch index (kg/km²) from pelagic trawling for NEA mackerel in July-August 2007-2013

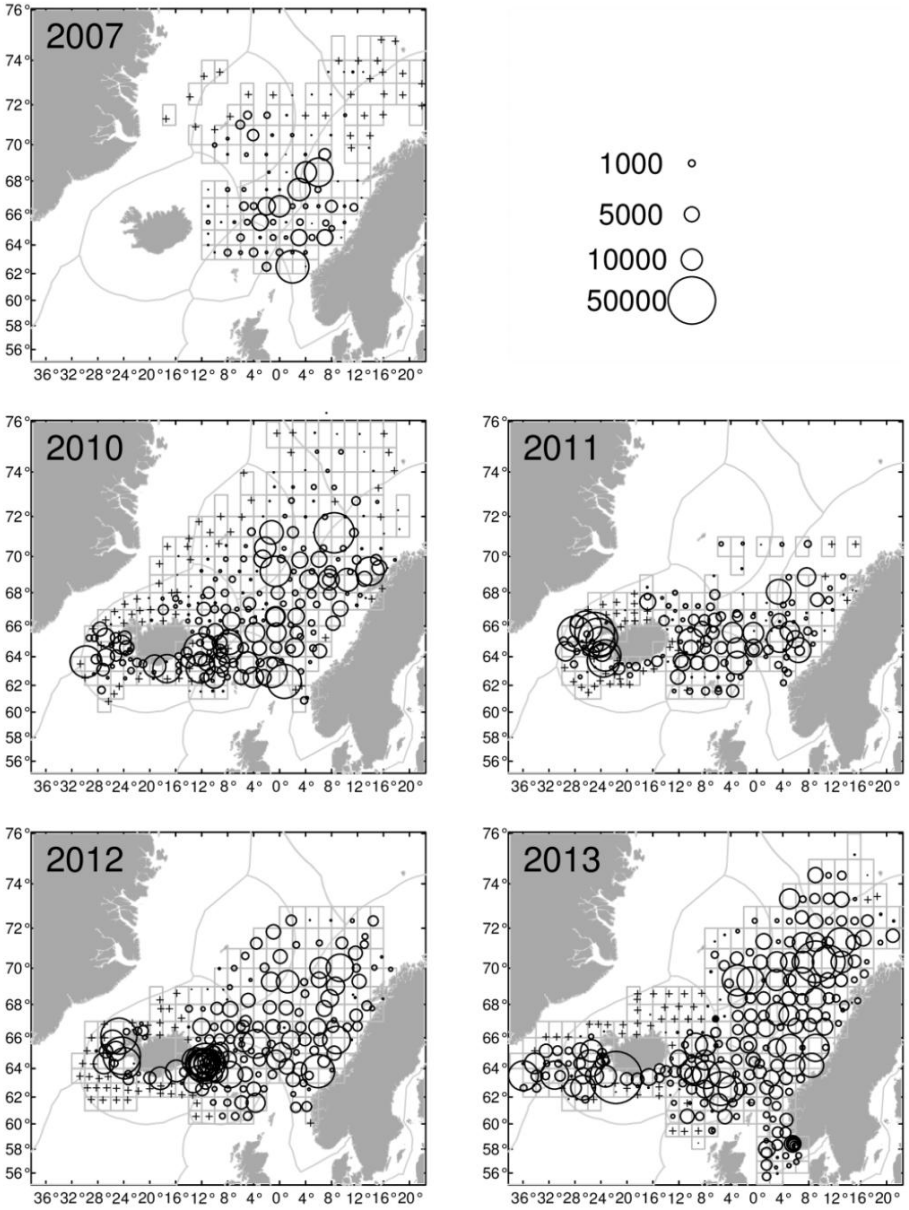


Figure 2a-e. Average catch index (kg/km^2) presented as circels ranging from >1000 kg/km^2 to >50000 kg/km^2 for NEA mackerel in July-August 2007, 2010, 2011, 2012 and 2013. The spatial coverage varied from 0.926 million km^2 in 2007 to 2.410 million kg/km^2 in 2013.

Average catch index (kg/km²) from pelagic trawling for NEA mackerel in July-August 2007-2013

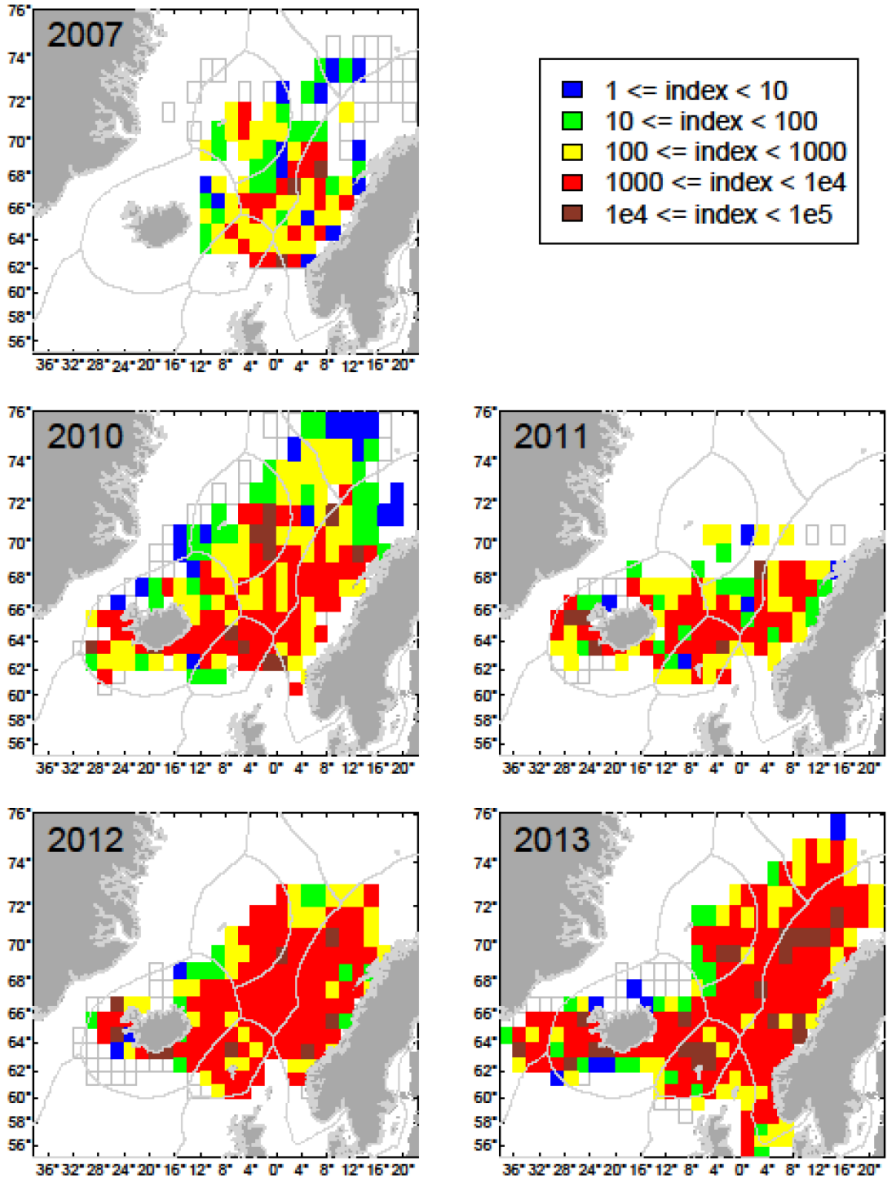
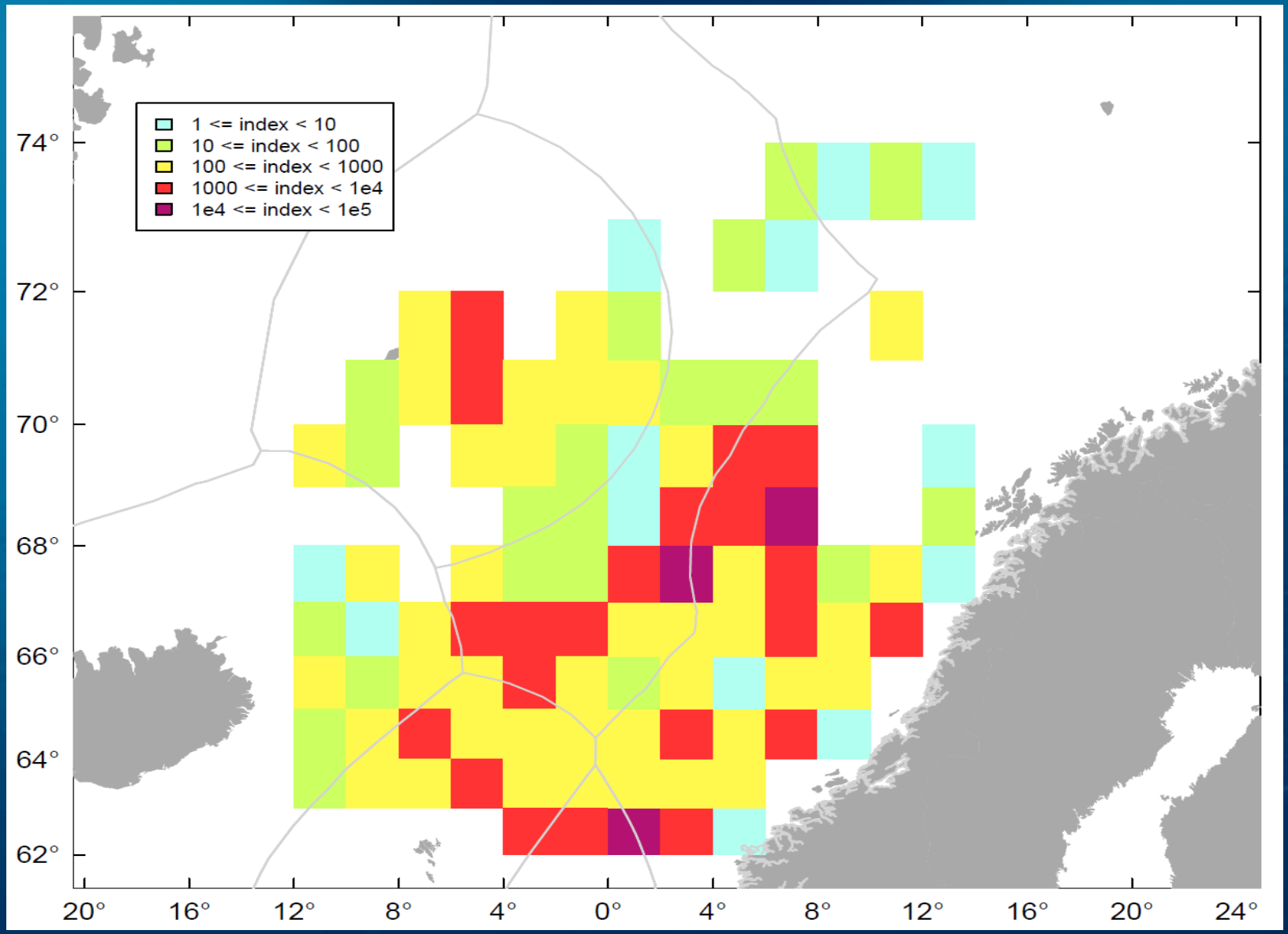
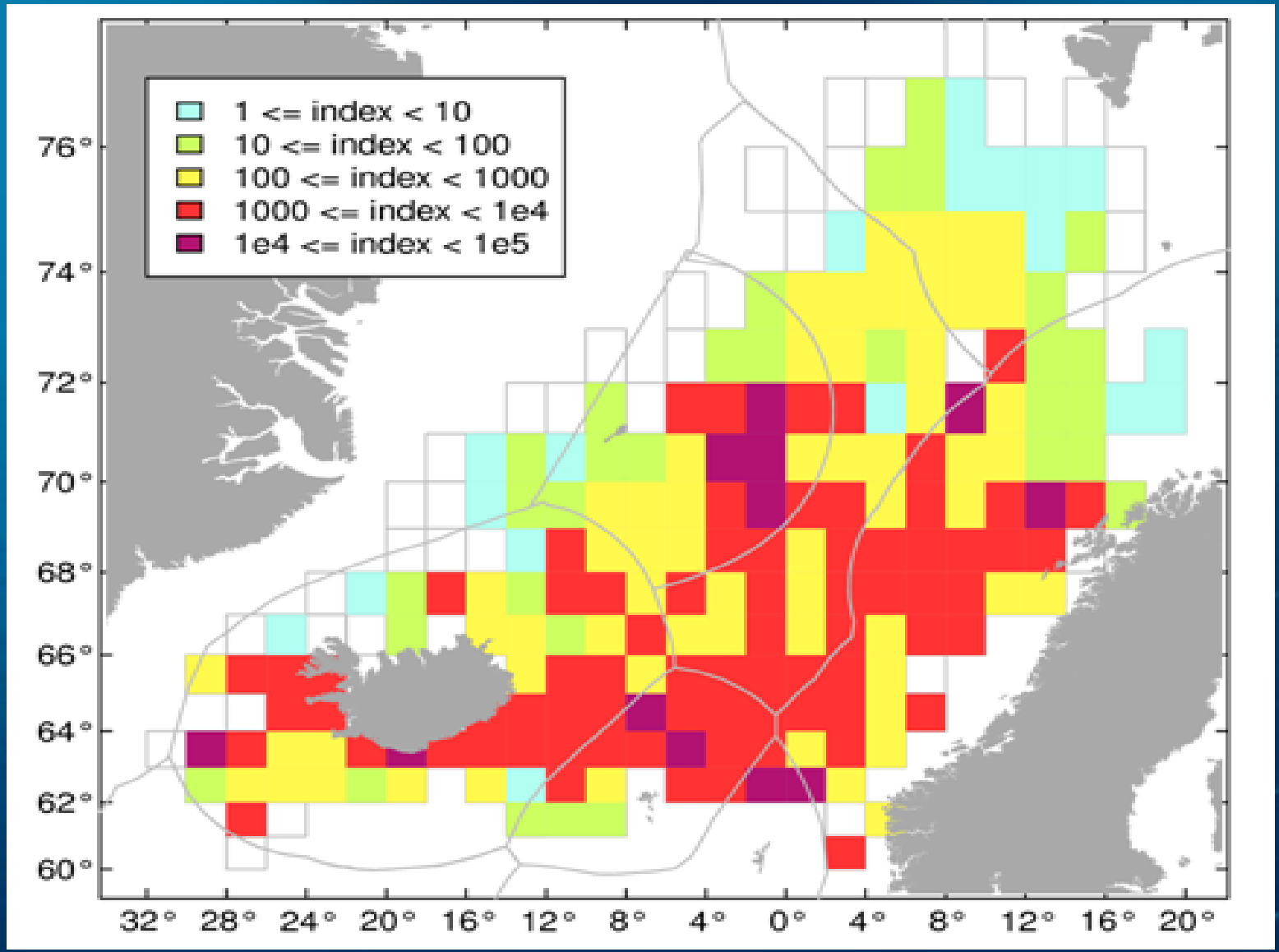


Figure 2. Graphical representation of average catch index (kg/km^2) for NEA mackerel in July-August in (**a**) 2007 with spatial coverage of 0.926 million km^2, (**b**) 2010 with spatial coverage of 1.750 million km^2, (**c**) 2011 with spatial coverage of 1.290 million km^2, (**d**) 2012 with spatial coverage of 1.528 million km^2, and (**e**) 2013 with spatial coverage of 2.410 million km^2.

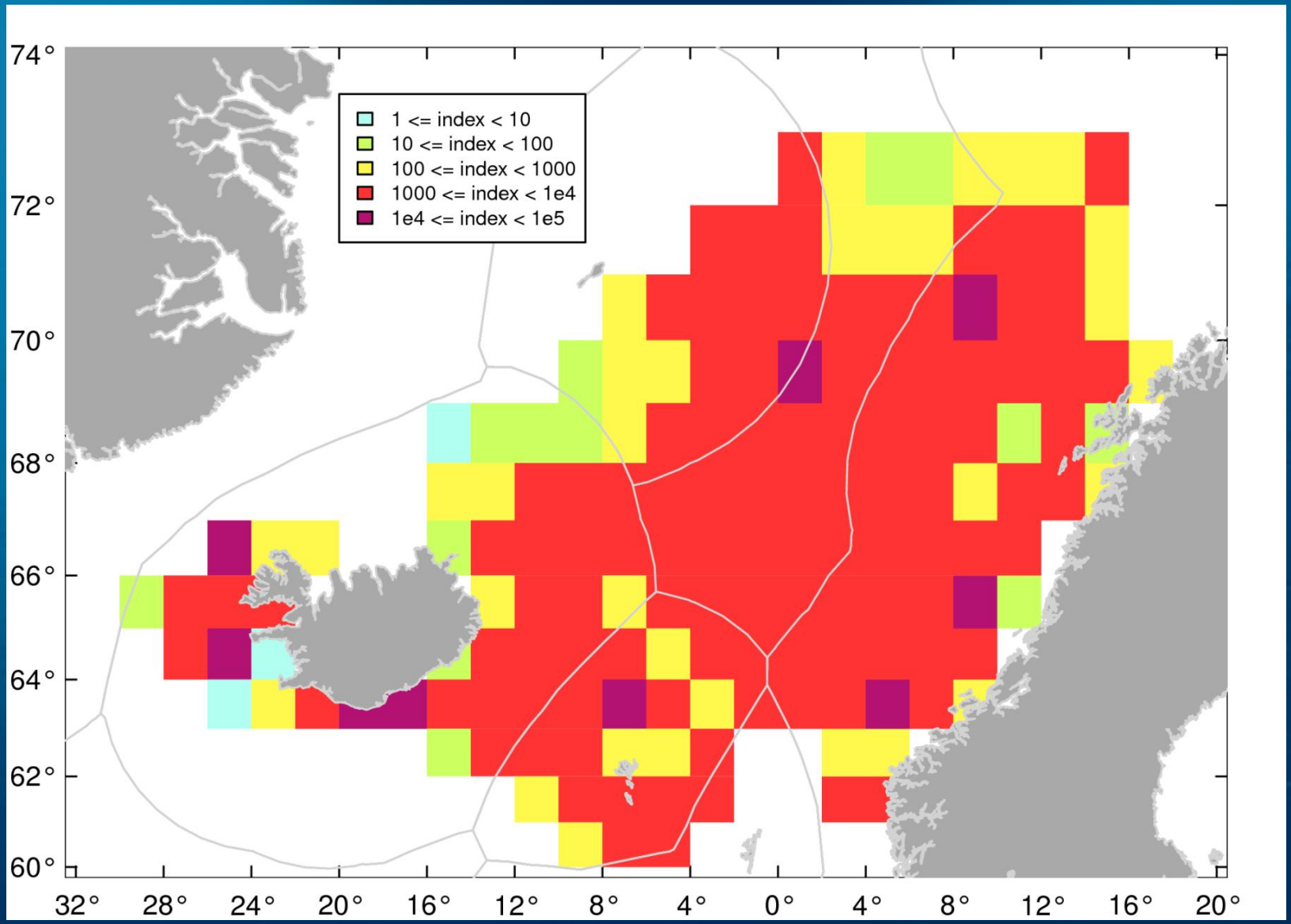
Rectangle average catch index (kg/km^2) as colour level plot for mackerel summer 2007



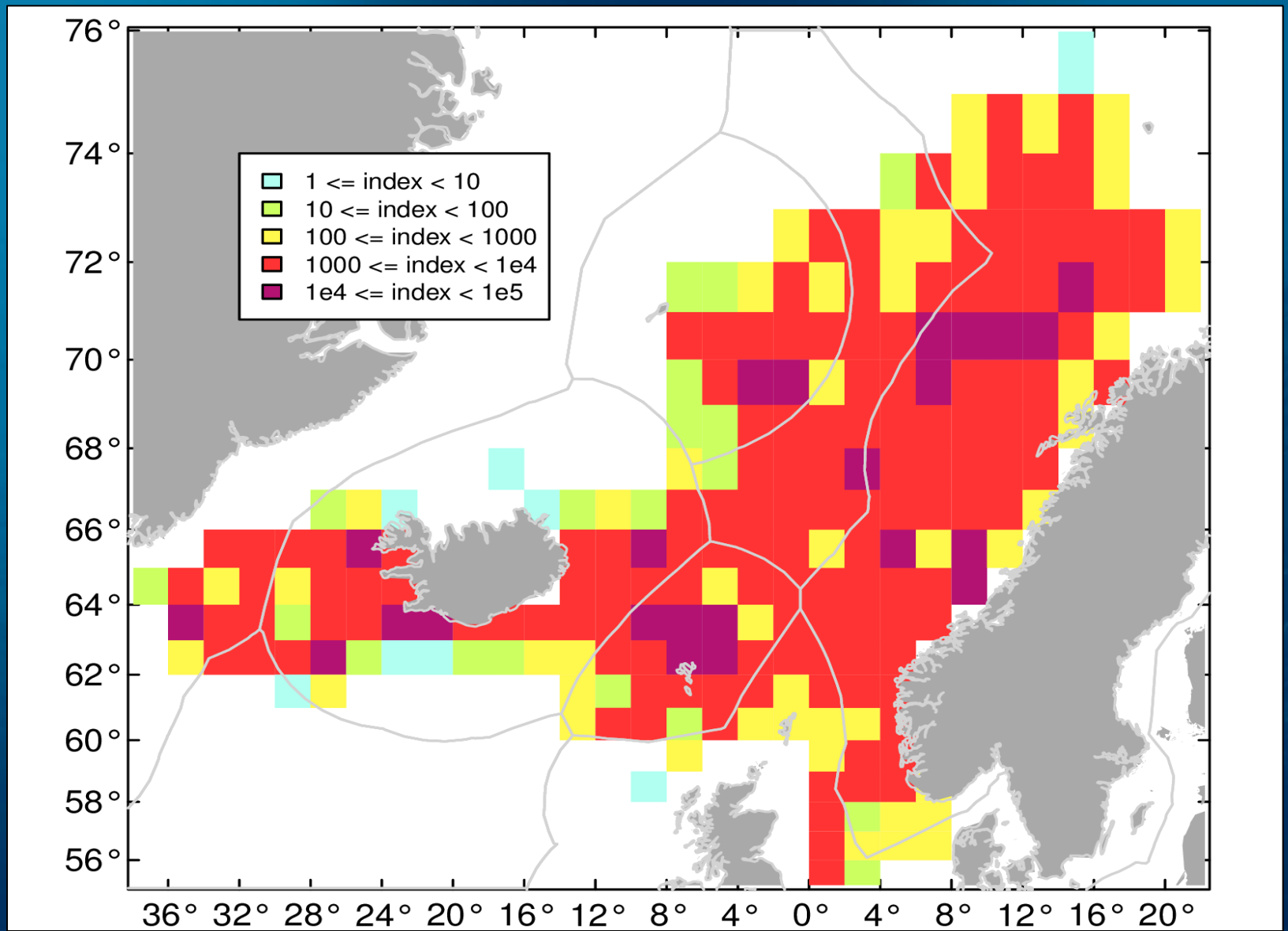
Rectangle average catch index (kg/km^2) as colour level plot for mackerel summer 2010



Rectangle average catch index (kg/km^2) as colour level plot for mackerel summer 2012



Rectangle average catch index (kg/km^2) as colour level plot for mackerel summer 2013

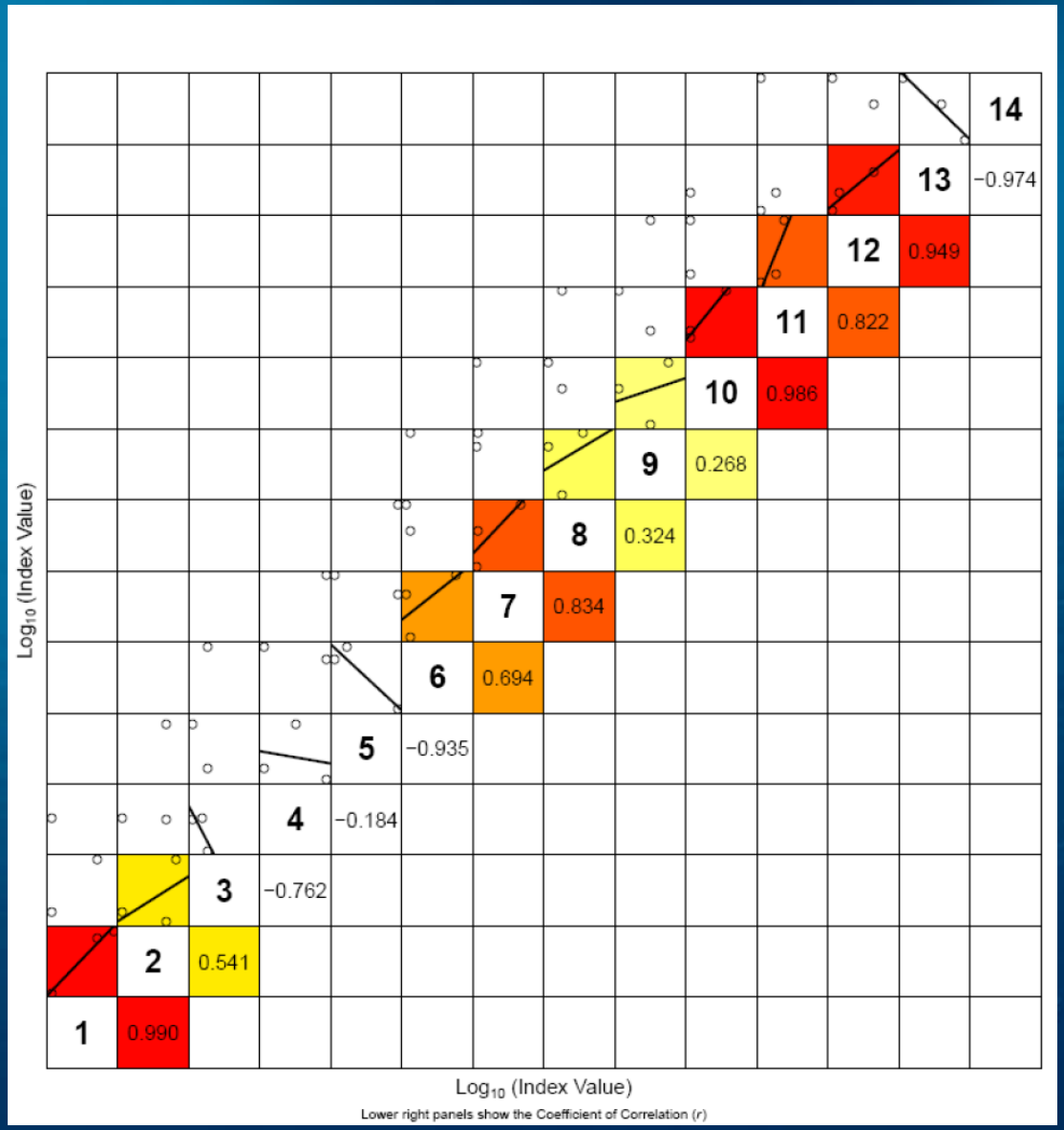


TB, SSB, Habitat range and mean density

Table 3. Estimated total biomass (spawners and juveniles) and spawning stock biomass (SSB) of northeast Atlantic (NEA) mackerel in the Nordic Seas from the swept area approach with pelagic trawling (Multpelt 832 pelagic sampling trawl), the coefficient of variation (CV), habitat range and mean density of mackerel during the summers 2007, 2010 2011, 2012 and 2013. In July-August 2011 our results on estimated biomass is based on too limited geographical coverage, because we had only three vessels rather than four vessels available during the 2011 IESNSS survey.

Year	Total biomass (mill. tonnes)	SSB (mill. tonnes)	CV	Habitat range (mill. km^2)	Mean density (tonnes km^{-2})
2007	1.6	1.25	0.23	0.99	1.61
2010	4.9	4.52	0.14	1.75	2.80
2011	3.1	2.45	0.10	1.20	2.58
2012	5.1	4.56	0.10	1.50	3.39
2013	8.8	7.87	0.09	2.41	3.65

The internal consistance in the age at age data from the swept area indices using a CLR model



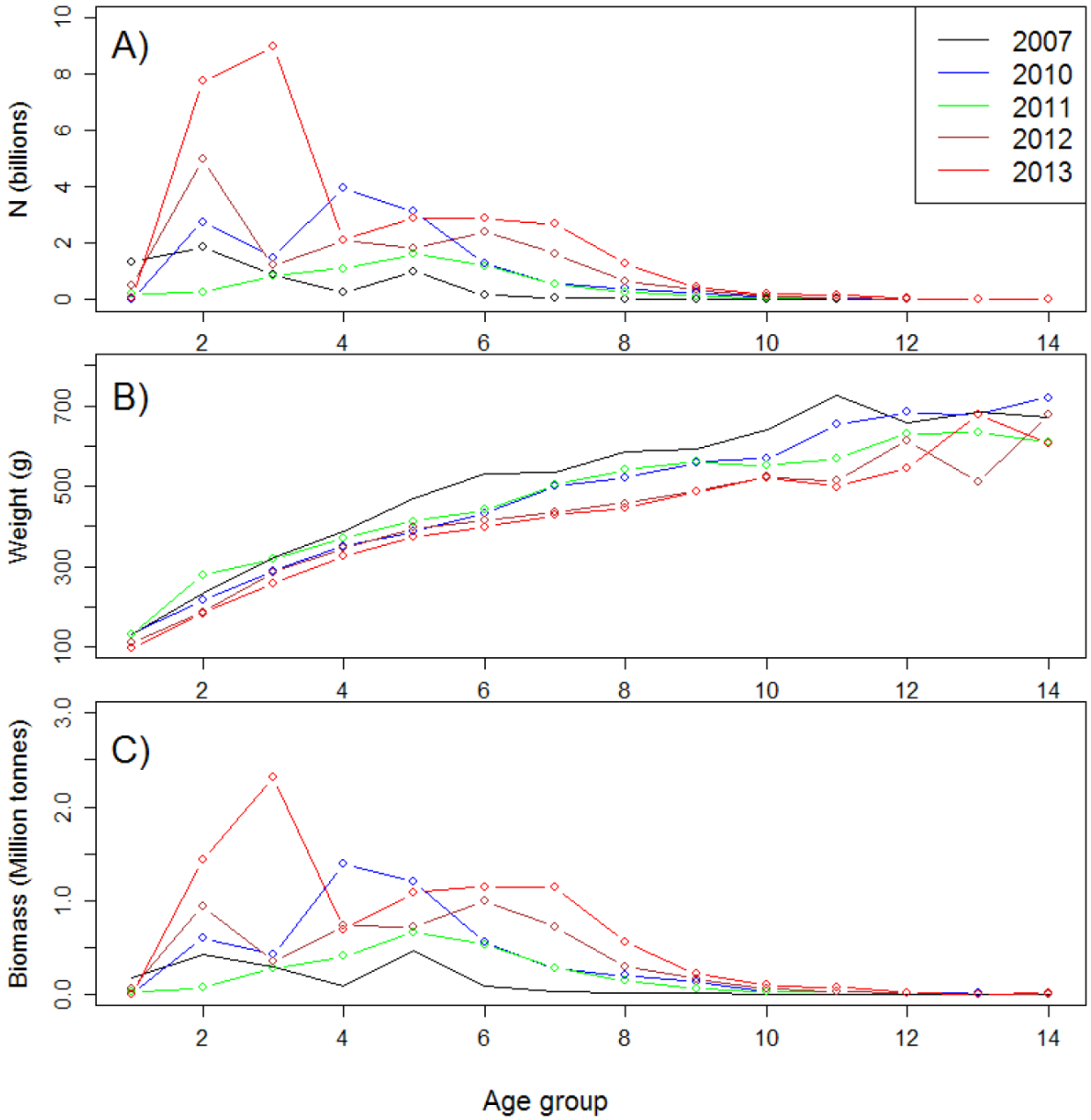


Figure 5. The swept-area estimates of (a) number of mackerel (log-scale) at age for the year classes 1999-2011 (indicated on the graph), (b) mean whole body weight at age and (c) total biomass at age from the IESSNS survey in 2007, and 2010-2013.

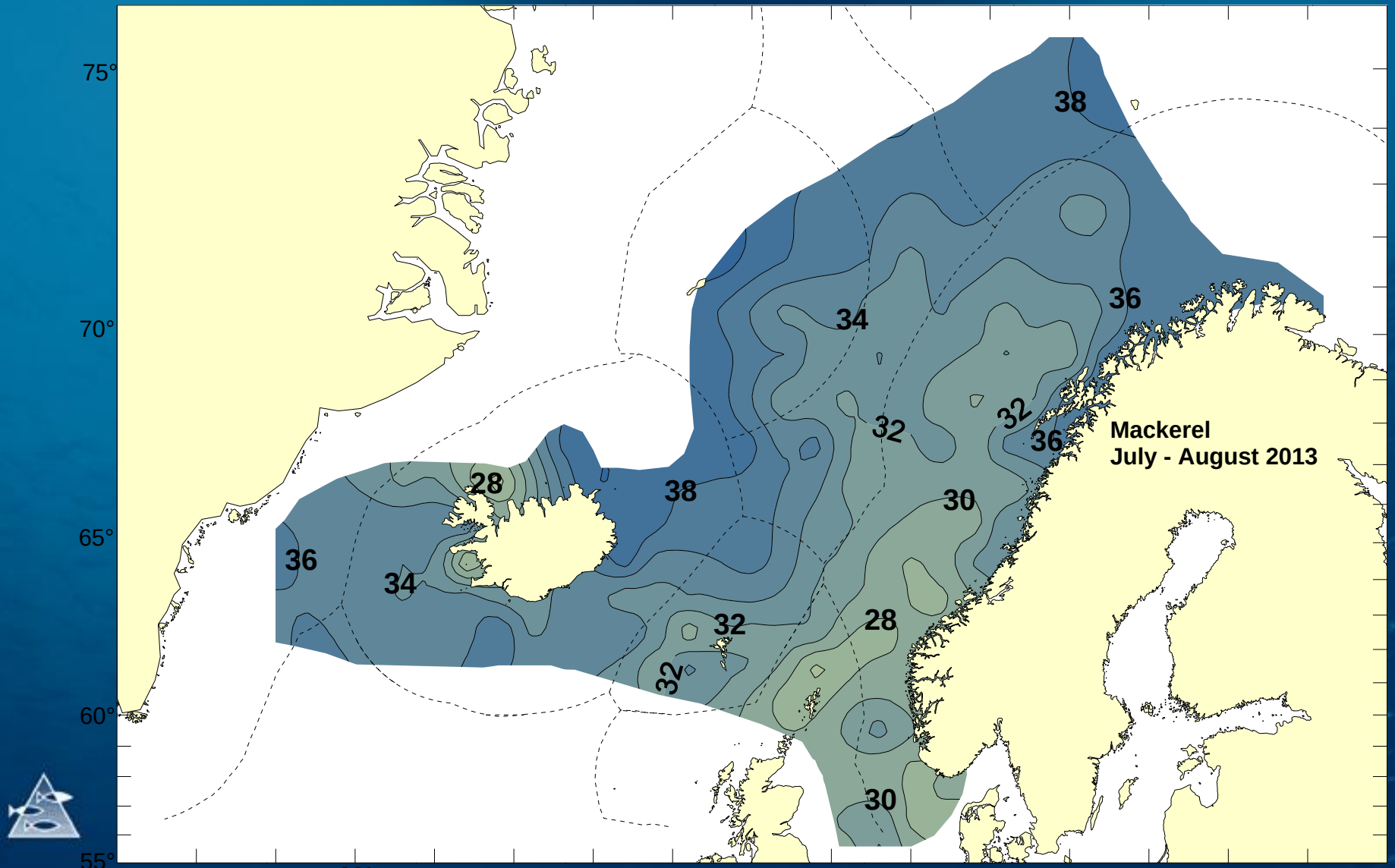
Swept area age groups estimates N(billions) Weight (g) Biomass (Million tonnes

No day-night differences in catchability from the standarized swept area methodology

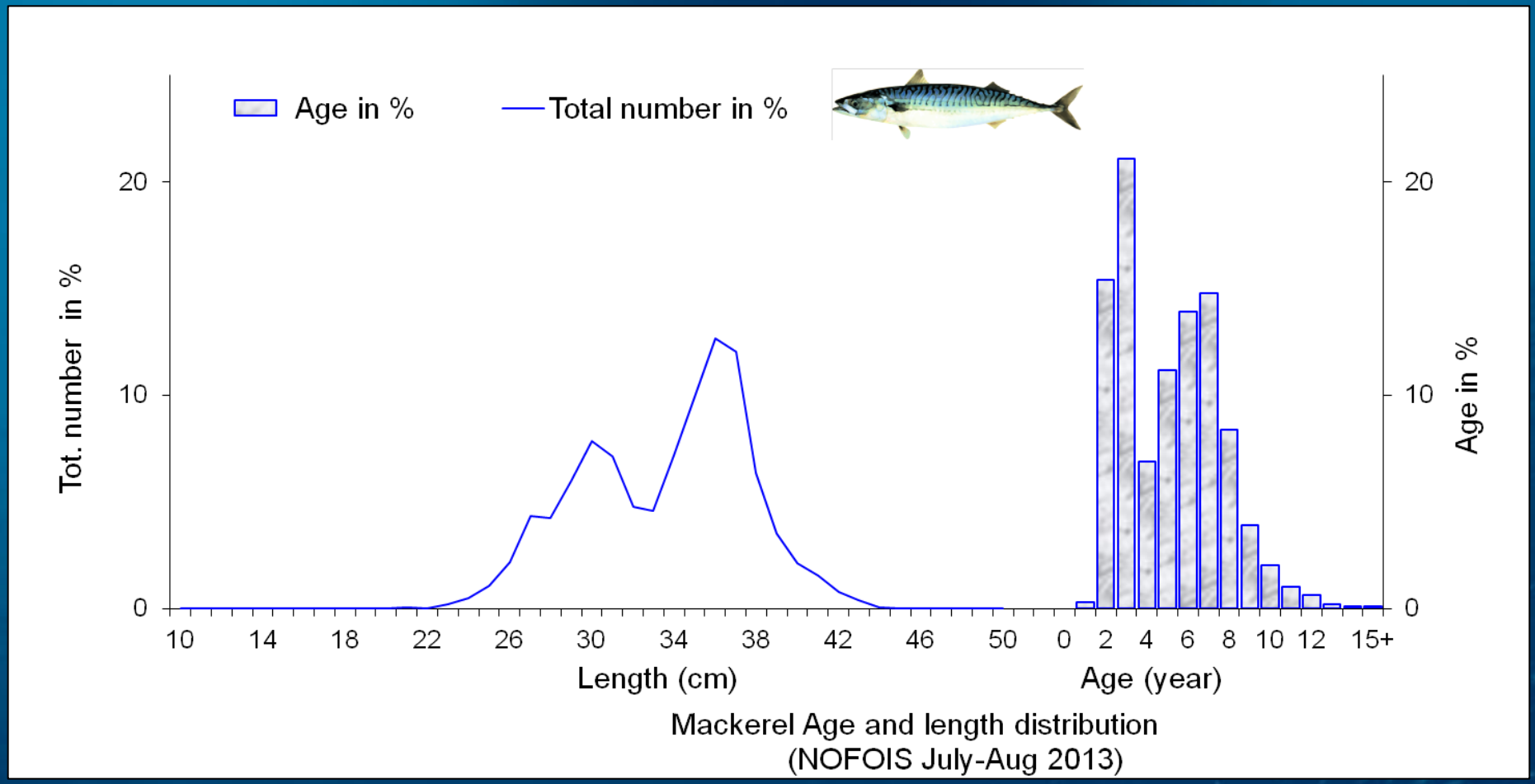
Table 4. The effect of including the effect day-night differences in catchability in the linear model. Model 2 is model 1 with the day-night covariate included. AIC is Akaike information criterion, df the degree of freedom and LogLik the log likelihood values for the models.

Model	df	AIC	LogLik	p-value
Mod 1	58	439.8	-161.9	
Mod 2	59	438.9	-160.4	0.0843

Significant length, weight and age dependent feeding migration pattern

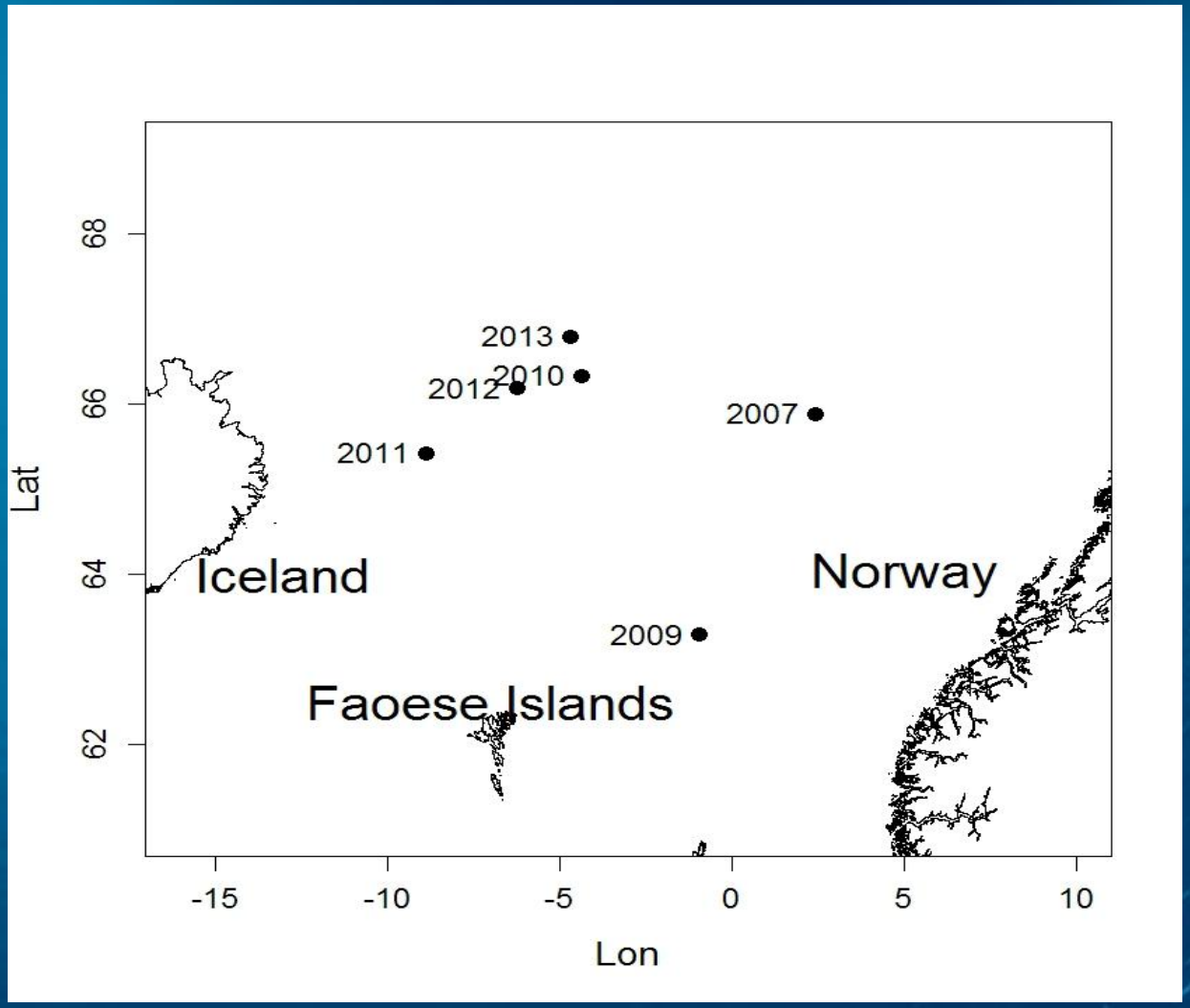


Mackerel age-length distribution July-Aug 2013



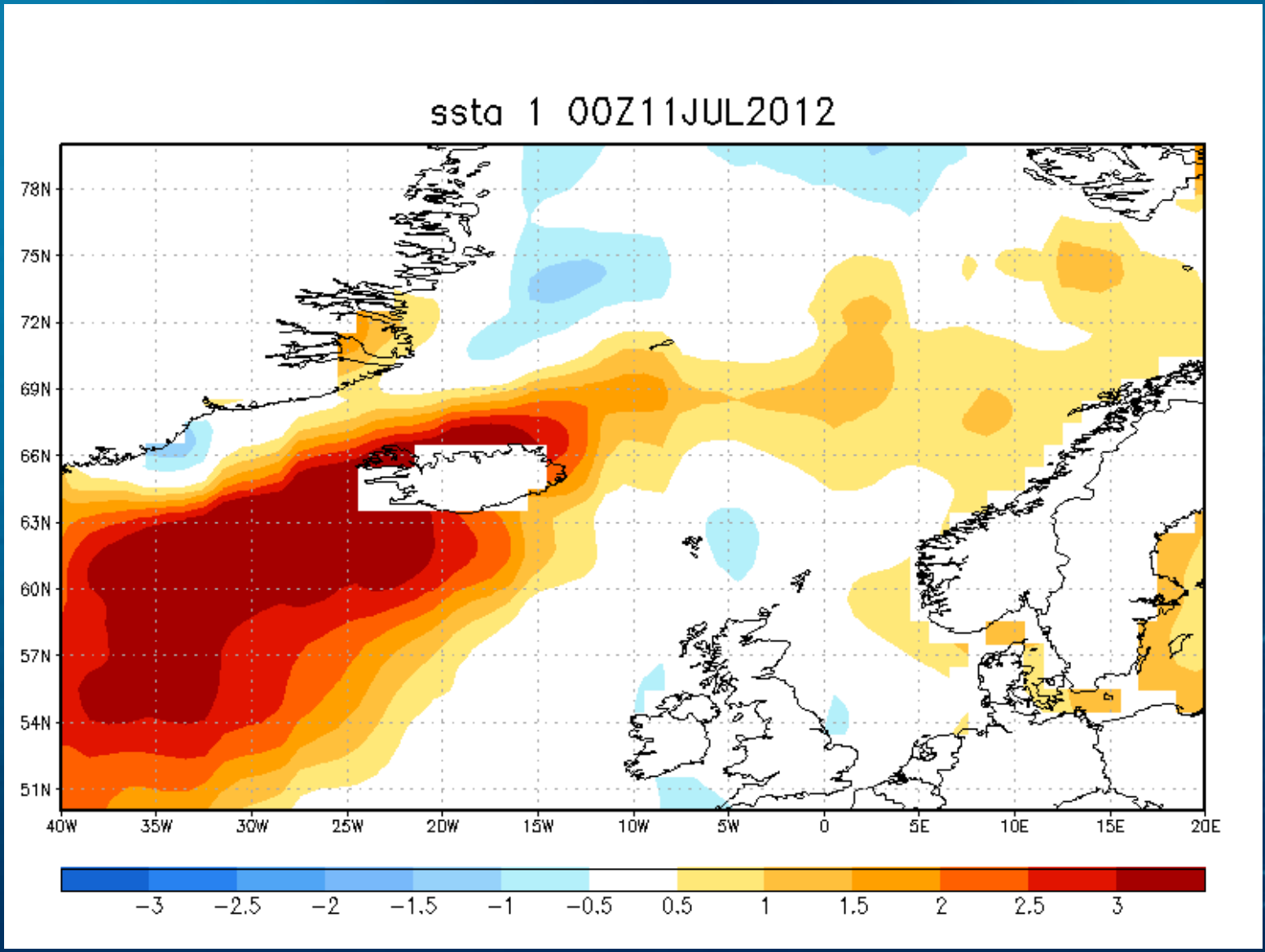
Several abundant year classes present in the samples for 2013: 2005, 2006, 2007, 2008, 2010 and 2011 year classes constitute ~85% of all measured mackerel during the international IESSNS survey

NEA mackerel Centre of Gravity (CoG)



Mackerel Centre Of gravity (CoG) is moving towards northwestern and northern waters 2007-2013

Sea surface temperature annomalies (SSTA) for mid-July 2012 compared to the average during the last 20 years of observations



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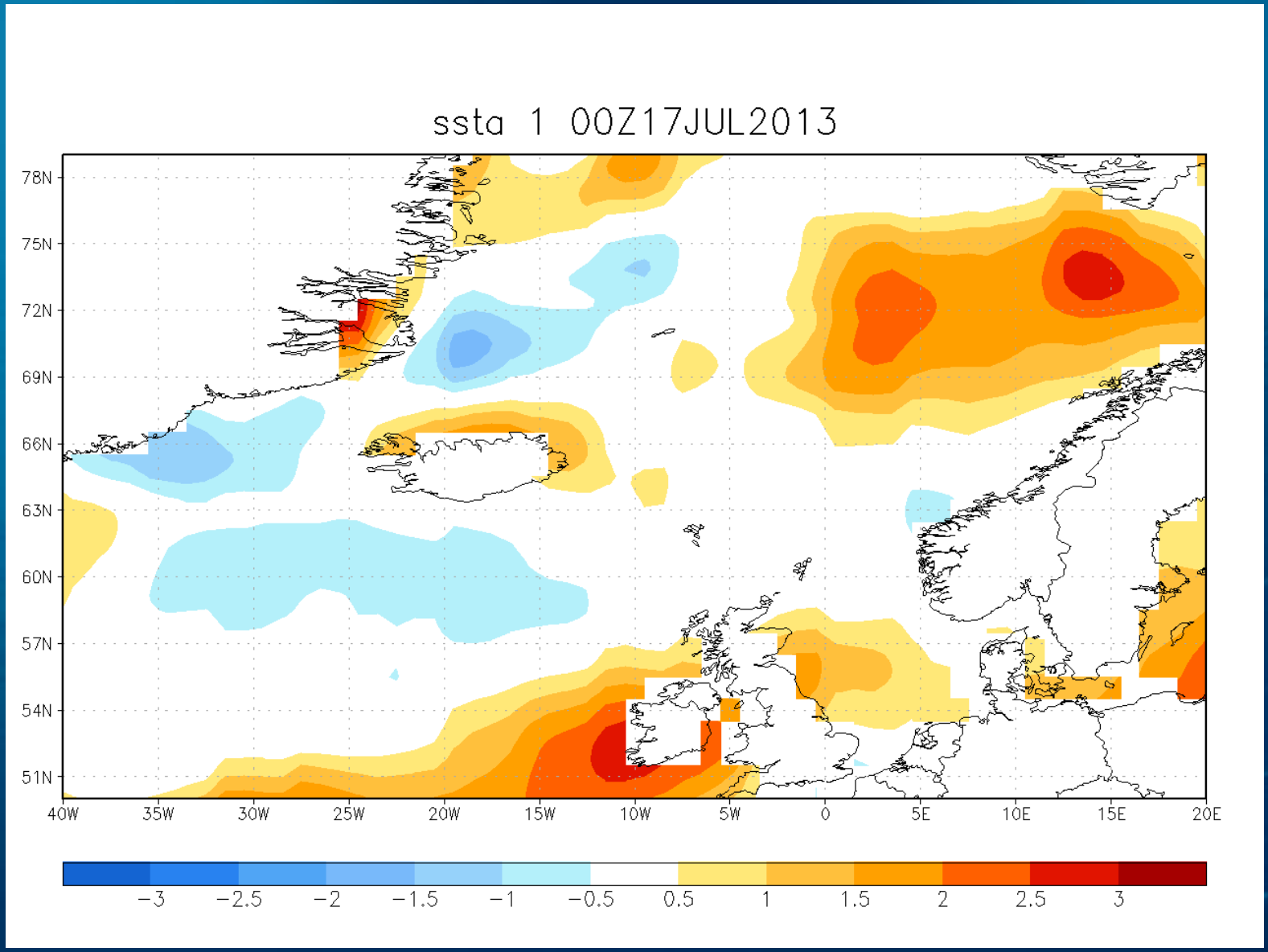
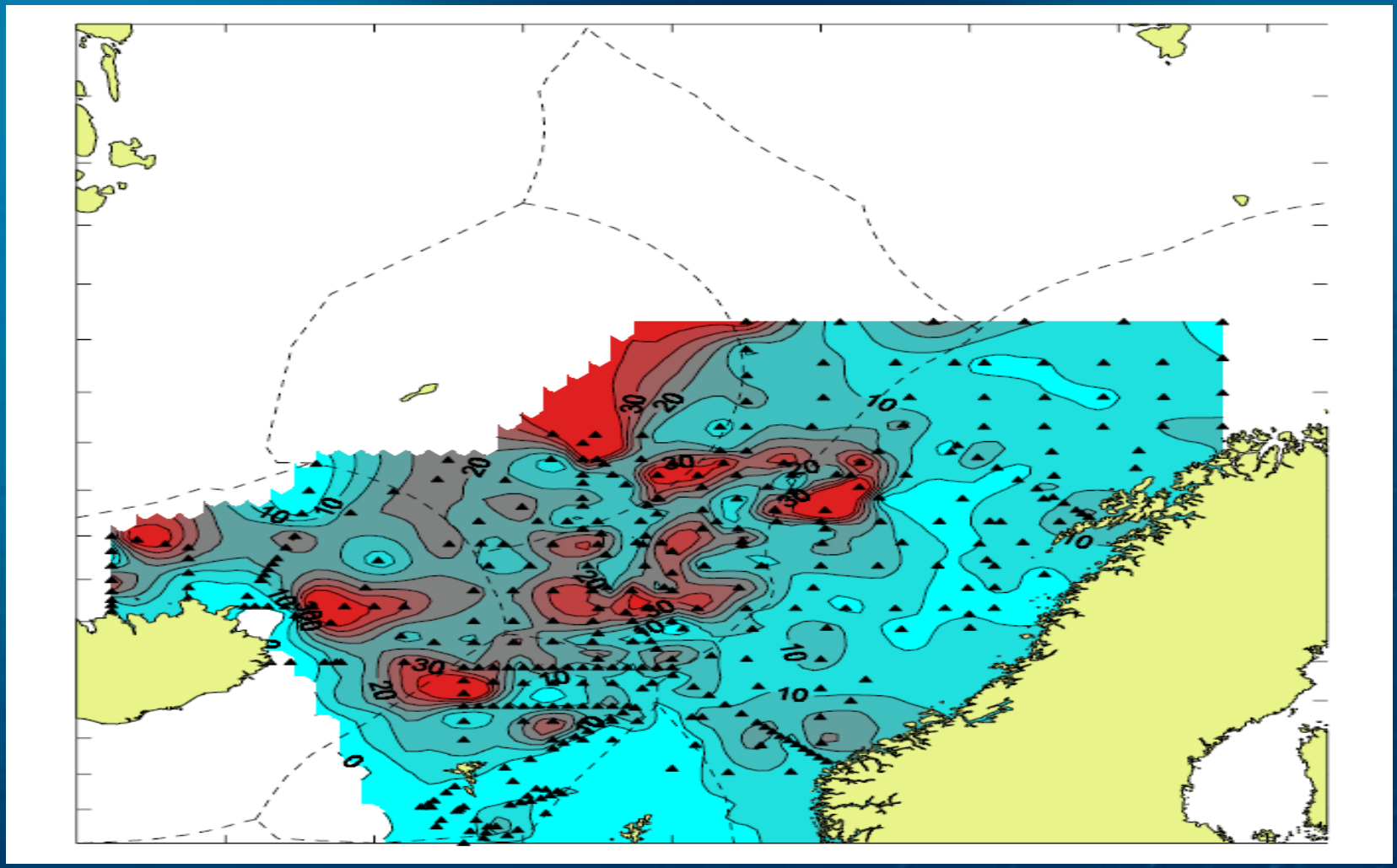
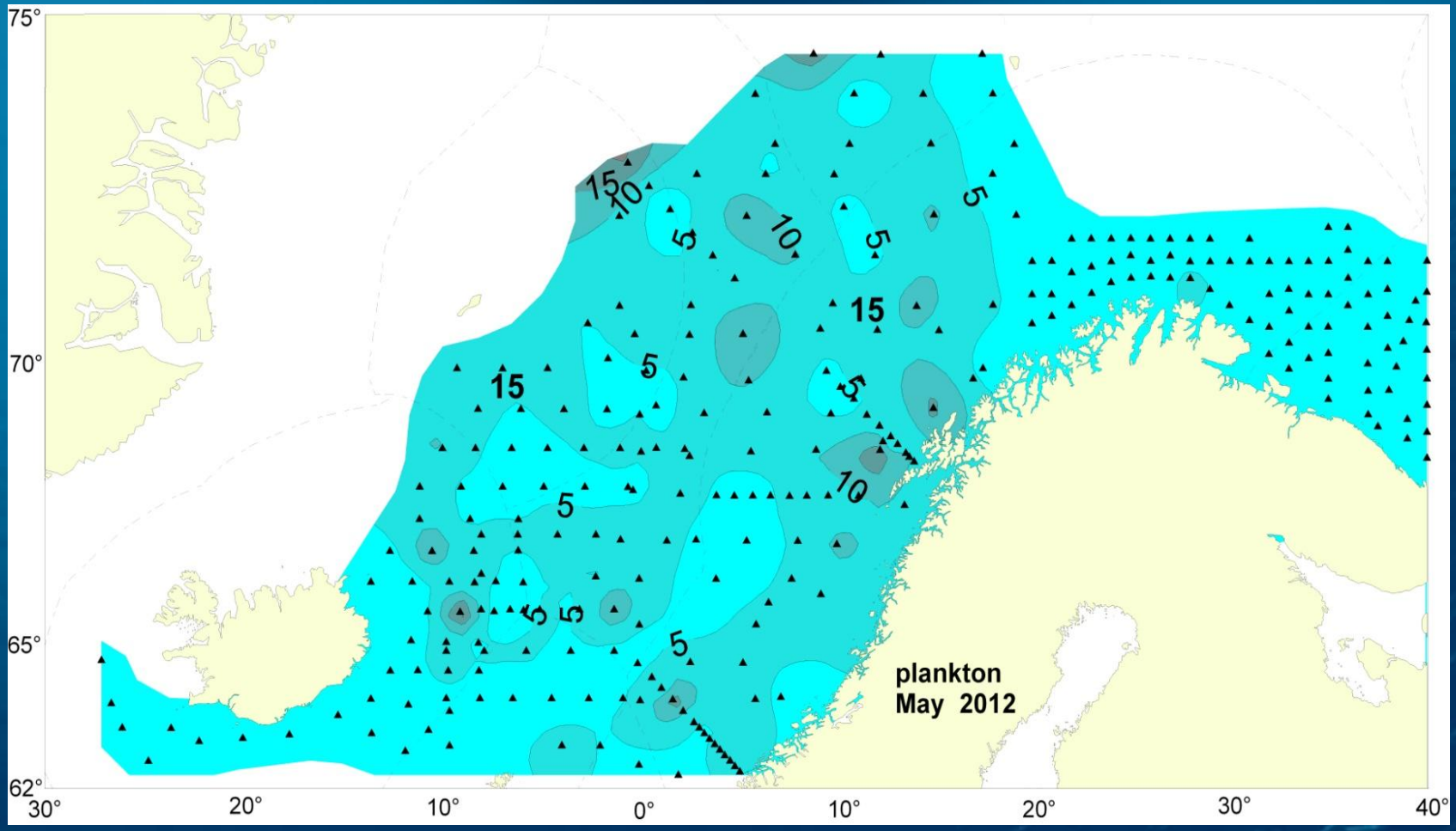


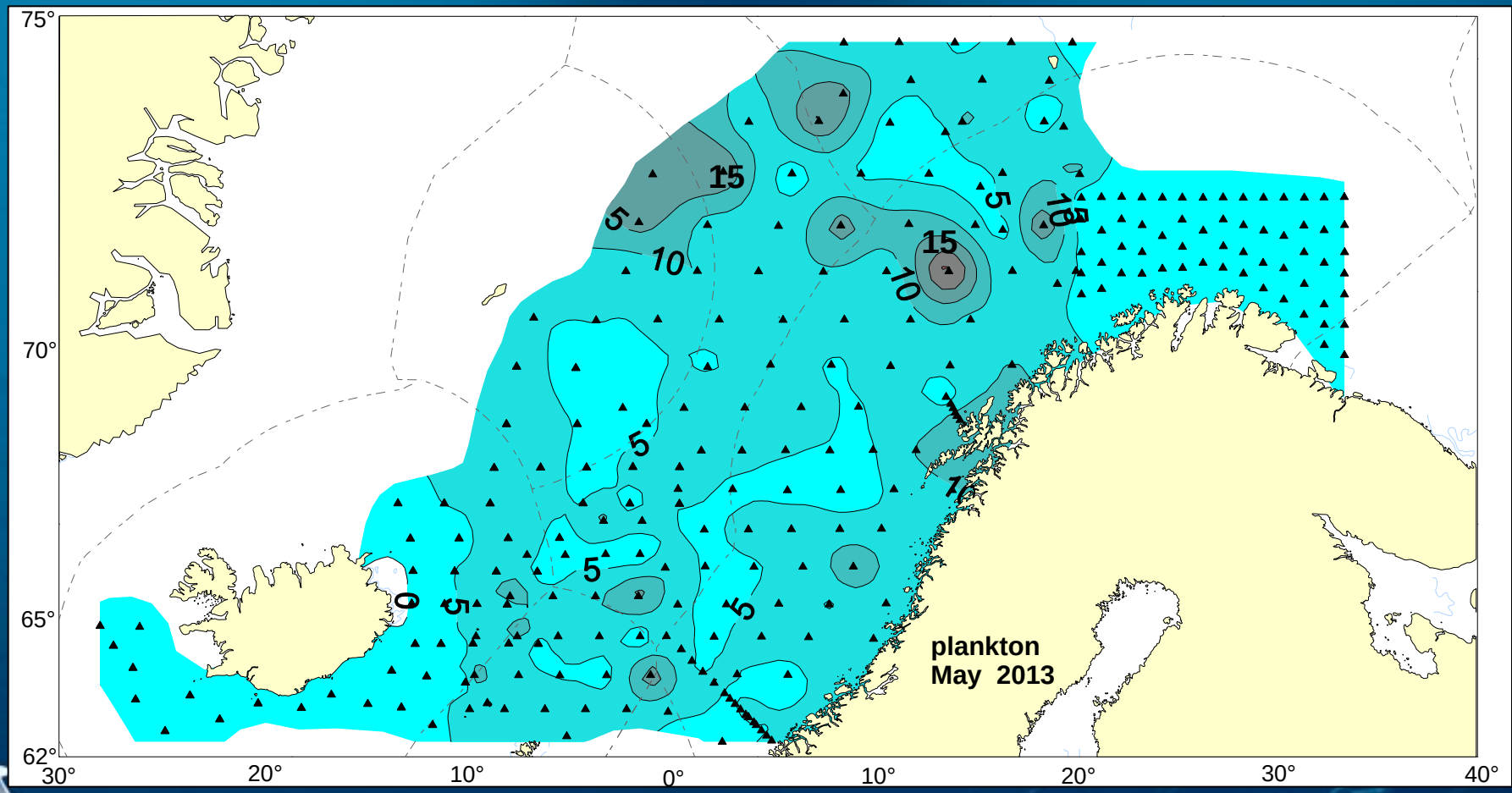
Plankton concentrations and distribution in May 2000



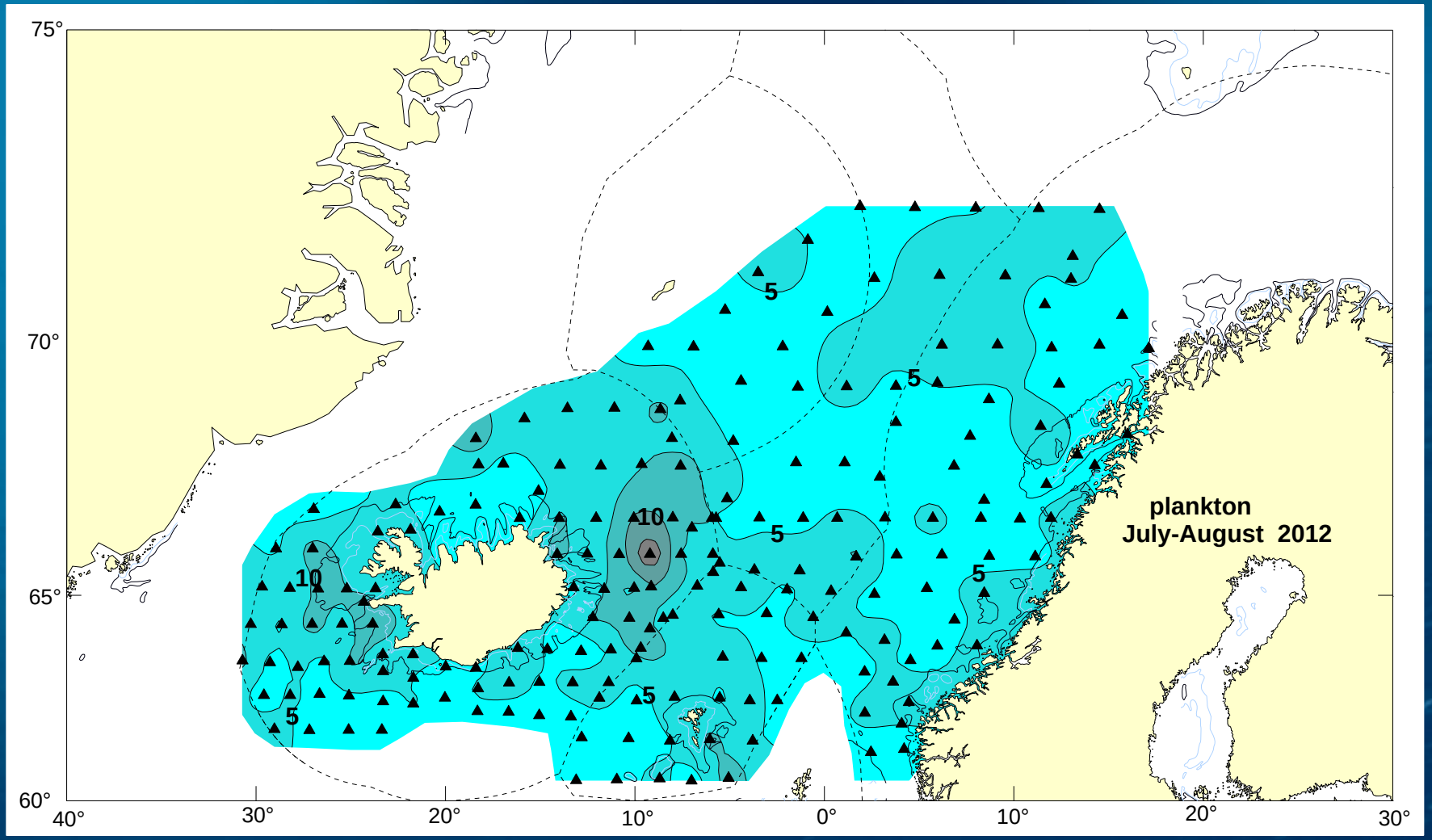
Plankton concentrations and distribution in May 2012



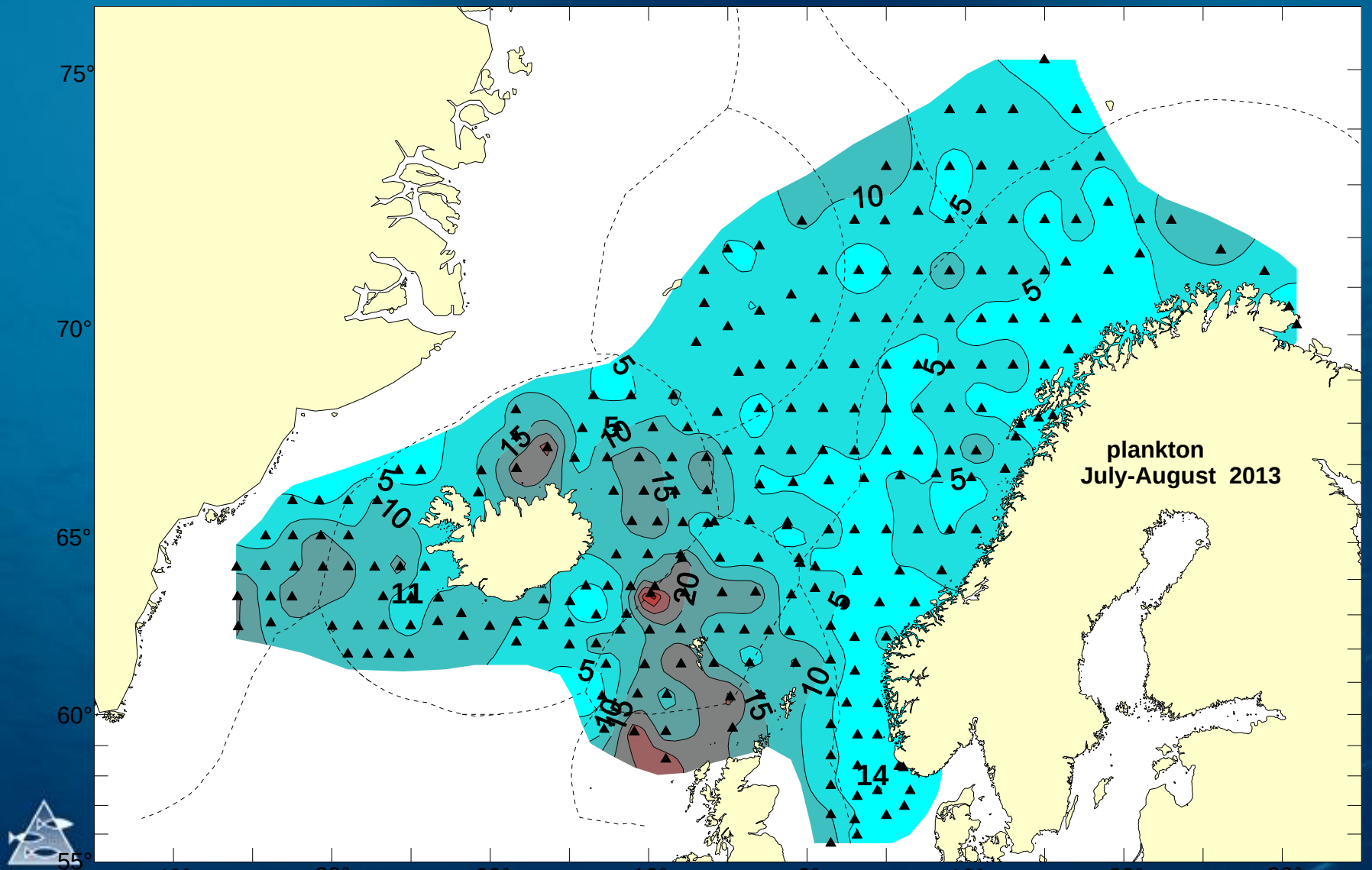
Plankton concentrations and distribution in May 2013



Plankton concentrations and distribution in July 2012



Plankton concentrations and distribution in July 2013



Main conclusions

- The NEA mackerel stock has been very robust during the last years with indications of strong increase in stock size
- NEA mackerel estimated to be 1.6 million tonnes in 2007, 4.8 million tonnes in 2010, 5.1 million tonnes in 2012 and 8.8 million tonnes in 2013
- Substantial changes in the overall distribution and migration pattern of mackerel in the Norwegian Sea and surrounding waters during the feeding season in summer and autumn over the last few years.
- Information from national and international research surveys and commercial mackerel catches show that the mackerel stock has greatly expanded to the west, northwest and as far north as Svalbard (Spitzbergen) in late September 2013!

Holy mackerel: why is this happening?

Possible combined reasons and drivers for mackerel constantly swimming into new territories

1. **Increased population size of NEA mackerel in recent years. Very strong recruitment from the 2002, 2005, 2006 and 2010 year classes and also strong 2007, 2008 and 2011 year classes!**
2. **Significantly warmer waters compared to 10-20 years ago**
3. **Lower and more dispersed plankton abundance and distributions at present compared to 10-20 years ago**
4. **Significantly increased intra-specific competition and possibly inter-specific competition between the large planktivorous fish species in the Northeast Atlantic**