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Fish distribution and declining cod productivity in inner Danish Waters: new insights from using a systems approach

Grete E. Dinesen, Stefan Neuenfeldt, Alex Kokkalis, Andreas Lehmann, Josefine Egekvist, Peter Munk, Kasper Kristensen, Karin Hüssy, Josianne G. Støttrup

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Introduction - Background

This study was initiated in response to repeated outcries from coastal fishermen regarding disappearance of cod from inner Danish in the past 15 years. This issue became a priority with the fisheries managers, but has proven highly complex with ecological and socio-economic consequences. Thus, the Systems Approach Framework (SAF) was adapted to guide a sustainable integrated coastal management (ICM) process to investigate potential relationships of changes in cod distribution with coastal cod fishery.

Introduction - Objectives

The overall objective of this study was to investigate declines in coastal cod fisheries in inner Danish waters perceived by local fishermen using a systems approach framework.

The aims were to:

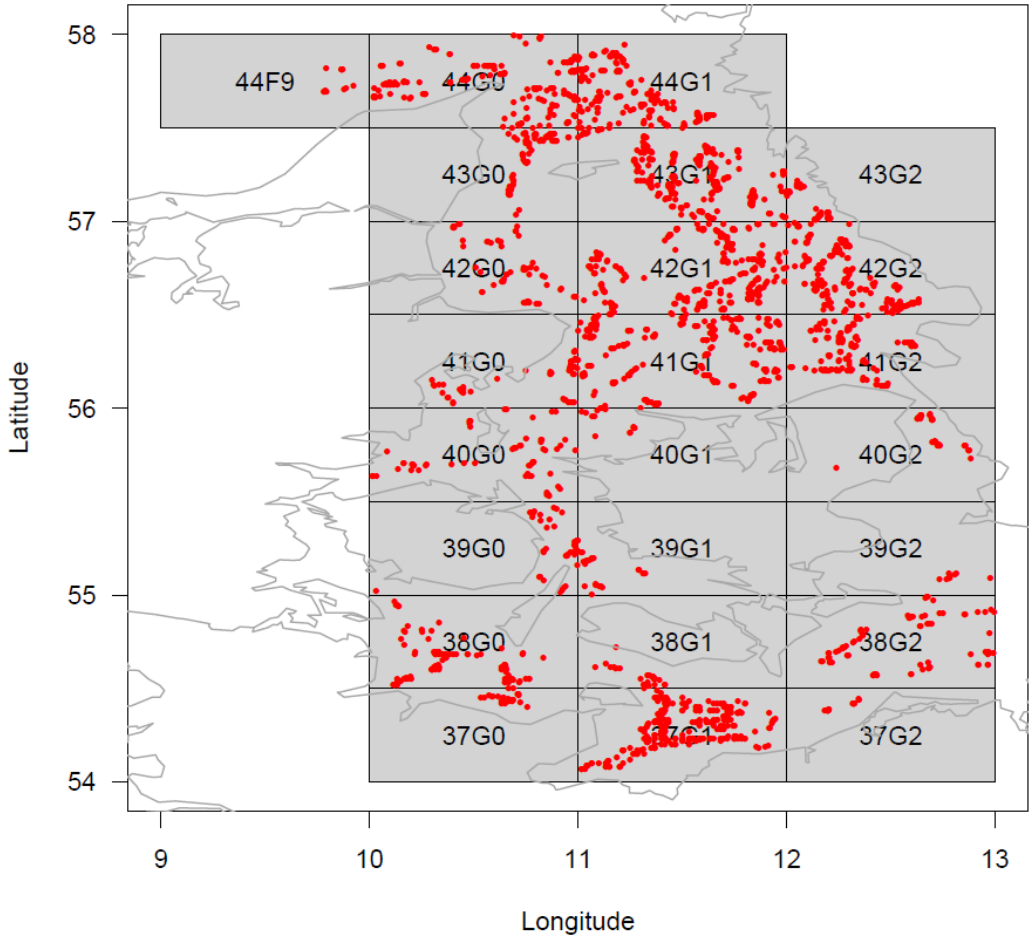
i) Identify spatial and temporal changes of cod distribution as perceived by fishermen,

ii) Validate perceived changes empirically and identify potential drivers,

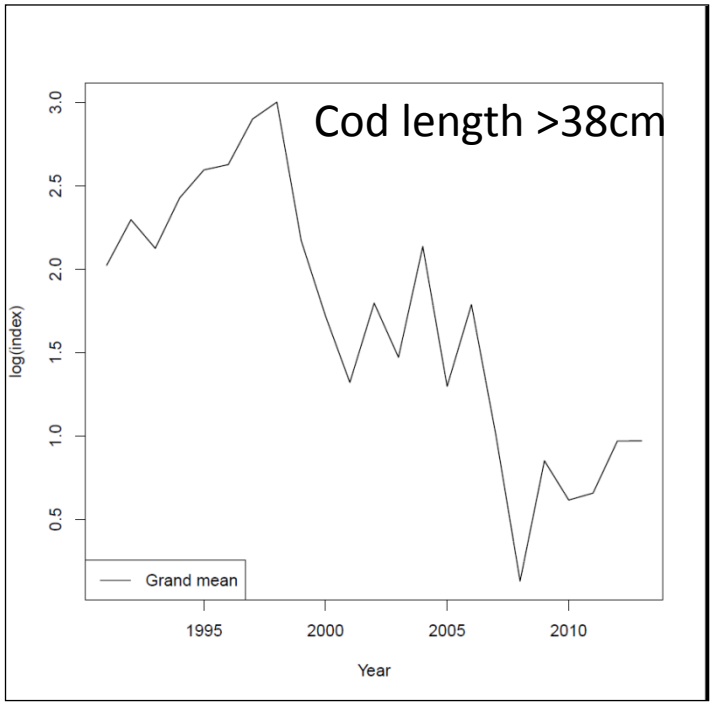
iii) Evaluate potential impact of changes in cod populations on coastal fisheries,

iv) Providing scenarios for sustainable integrated management.

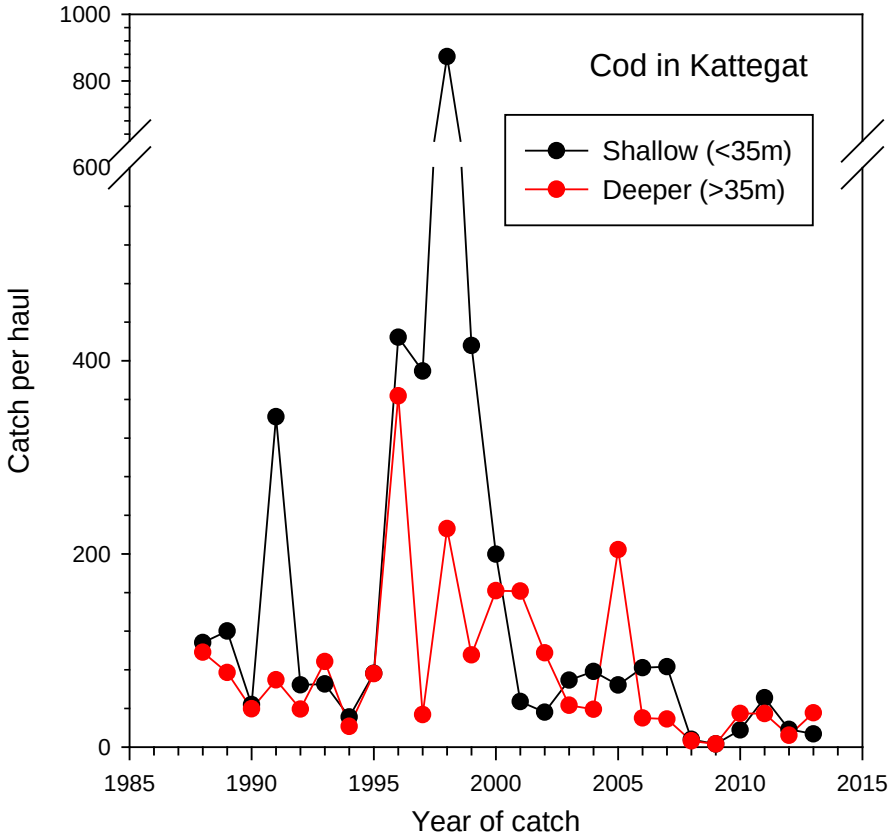
Material and Methods – System Design



Kattegat survey stations (left) and development in adult fishable cod stock (below).



Results – Issue identification



Støttrup et al. 2014

Stakeholder meetings:
with Danish fisheries organisations and Danish fisheries managers.

Key Policy Issue identified:
Declining stocks of cod in inner coastal waters.

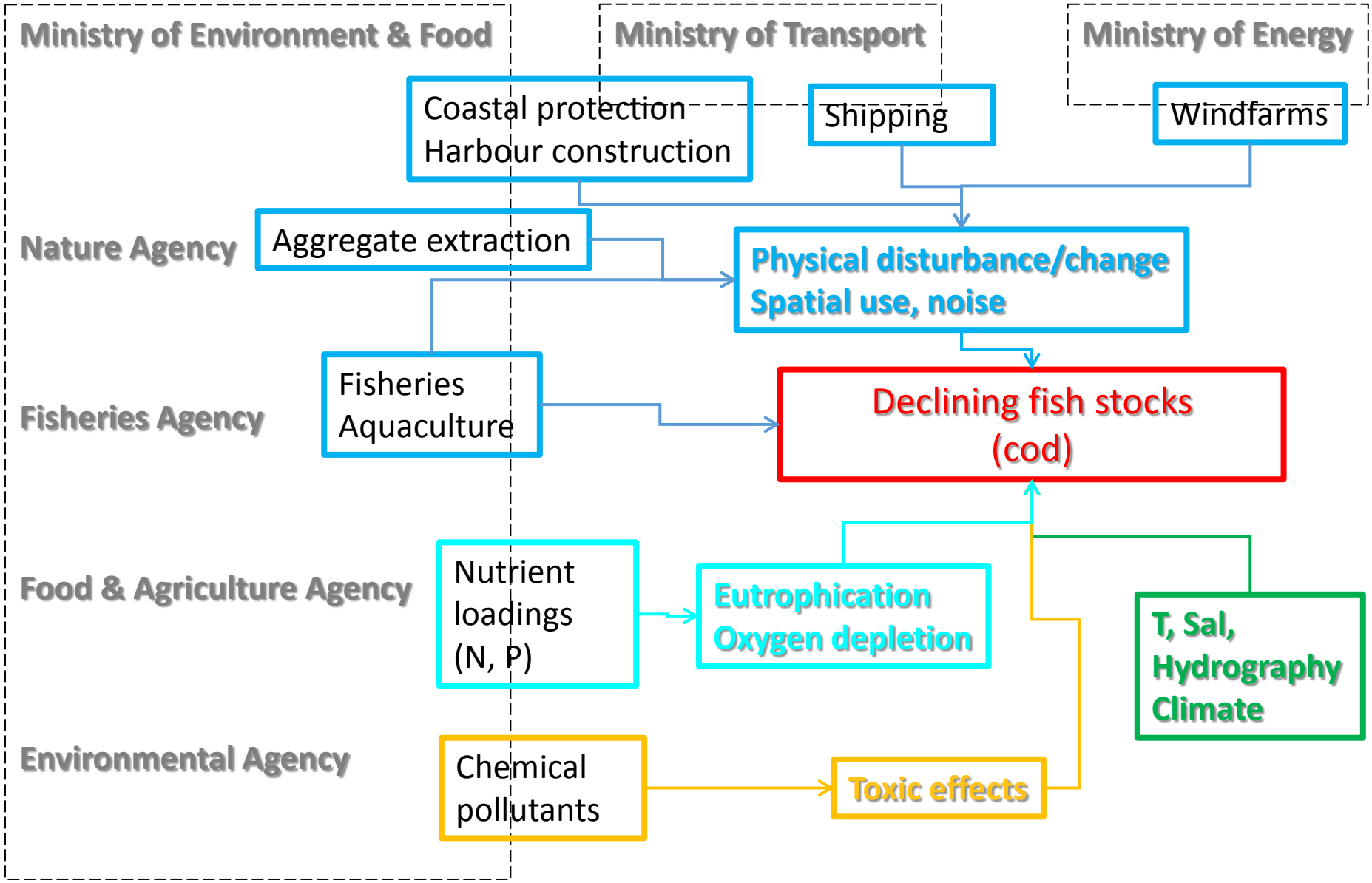
Virtual system selected:
Skagerrak-Kattegat & Western Baltic Sea

Results – DPSIR & CATWOE

DPSIR	Description	Study Site specific
Driver	Needs of human society (food, water, fuel, shelter, etc.)	Fish food provision
Pressure	HA that stress the environment (increasing loading with nutrients)	Long term climate change: (i) increasing average bottom sea water temperature in summer and autumn, and (ii) increased frequency of hypoxia events
State	Changes in condition of the environment - ecosystem (increasing nutrients, phytoplankton, primary production, shift from fish to mussels, change of macro vegetation – regime shifts)	Declining/disappearing cod stocks in several (but not all) coastal areas
Impact	The 'undesirable disturbance' (e.g. harmful algal blooms, water quality/clarity),	Ecological: species/regime shift Social- economic: decline in income in local fishing communities, especially in rural areas
Response	Response of society to losses of Ecosystem services - measures to mitigate the Driver and Pressure e.g. WFD targets for nutrient reductions	Fishery laws at trans-regional level (EU, ICES) and national level: change in quota systems (2007), quota allocation, fishing closure regulations, Social-economic: industrialization of fishery from small to large vessels, loss of income from landings, deteriorated/abandoned small rural harbours, (and possibly loss of employment of fishermen and in related trades)

CATWOE	Description	Study Site specific
Customers, beneficiaries/victims	• Who is on the receiving end? • What problem do they have now? • How will they react to new management options? • Who are the winners and losers?	• Fishermen, employment in related trades • Loss of income, employment opportunities • Losers: Small scale coastal fishers and their communities • Winners: few off-shore/large-scale fishing companies (short term)
Actors	• Who are the actors who will 'do the doing', carrying out your solution? • What is the impact on them? • How might they react?	• Depends on identification of increasing sea water temperature and/or hypoxia as a responsible pressures and potential mitigation measures: FLST/NAER (change of quota and fishing area allocation).
Transformation	• What are the inputs and where do they come from? • What are the outputs and where do they go to? • What are the steps in between?	Awaiting results from the ESE model: spatial and temporal stock assessments and annually adjusted quota and fishing area allocation There are no steps in between
Worldview	• What is the bigger picture into which the situation fits (may differ among stakeholders) • What is the real problem for each stakeholder • What is the wider impact of any solution?	Commercial fishing industry: loss of local income, professions, professional knowhow and local area-specific knowledge Recreational fisheries: loss of cultural heritage, decline in membership in organizations, loss of knowhow
Owners	• Who can help or stop you? • What will cause them to get in your way? • What will lead them to help?	NAER/FLST/EU/ICES Lack of trans-boundary political cooperation and coordination Change of national and international fisheries policies and regulations
Environment	• What are the external constraints and limitations affecting the success of the solution? • What are the ethical limits, laws, financial constraints, limited resources, regulations? • How might these constrain your solutions? • How might you get around them?	Further increase in bottom sea water temperature and slow/no/inappropriate management responses The main pressure(s) is not manageable Perhaps no (short-term) solution to the issue – management solutions have to be adaptive and iterative at an annual time interval

Results – Mapping of key elements



Results – Issue Identification

Social and Economic stakeholders/components relevant for the issue

Social:

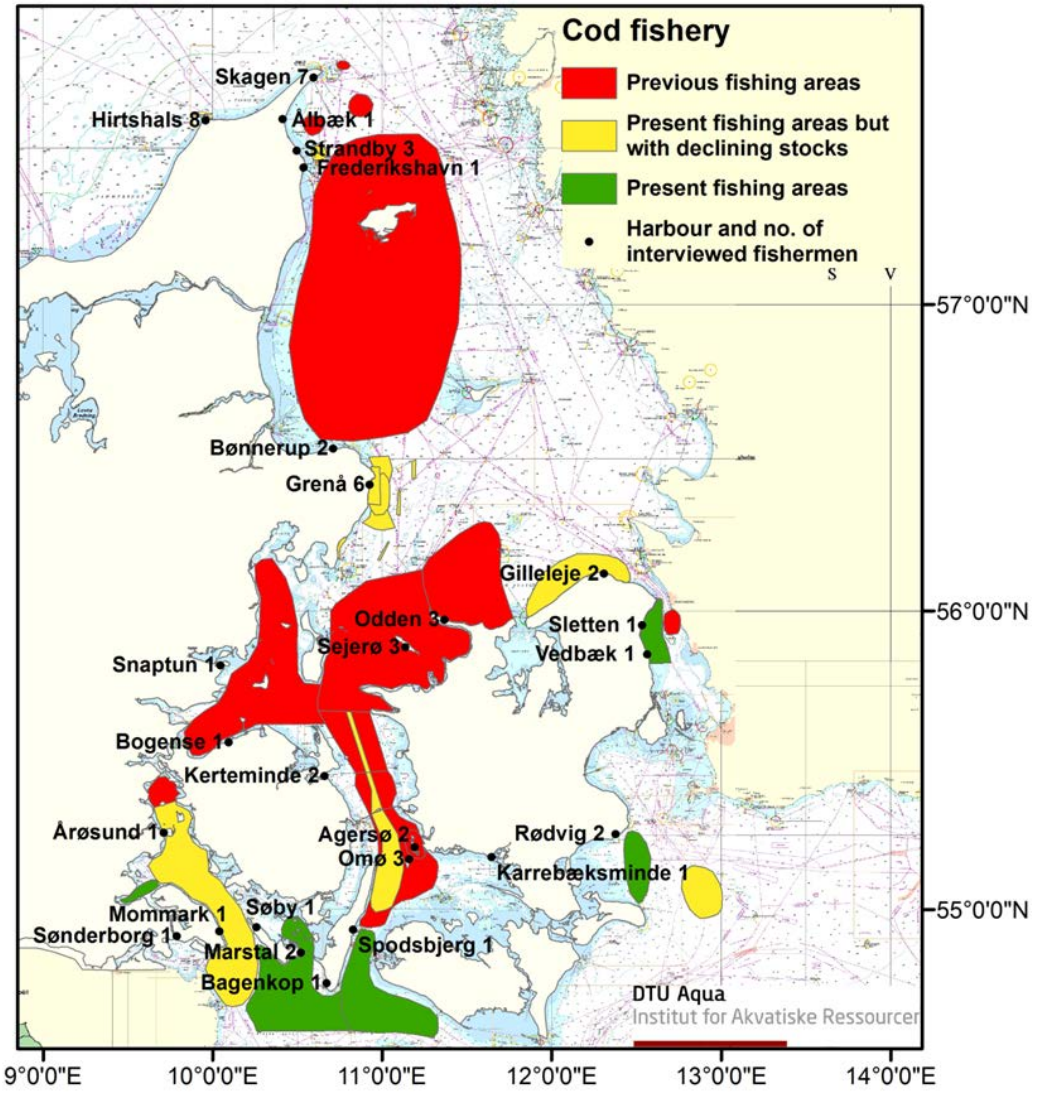
Rural fishing harbors and their communities, cultural heritage (bartering, availability of fresh fish), interest groups, e.g. NGOs (nature conservation, recreational activities).

Economic:

Rural fishing harbors and their communities (landings, local fish production, income, employment, tourism for recreational fishery) and WFD/NATURA 2000/MSFD target implementation (e.g. commercial fish stocks, nutrient loadings, spatial use, substrate use, biodiversity, food webs).

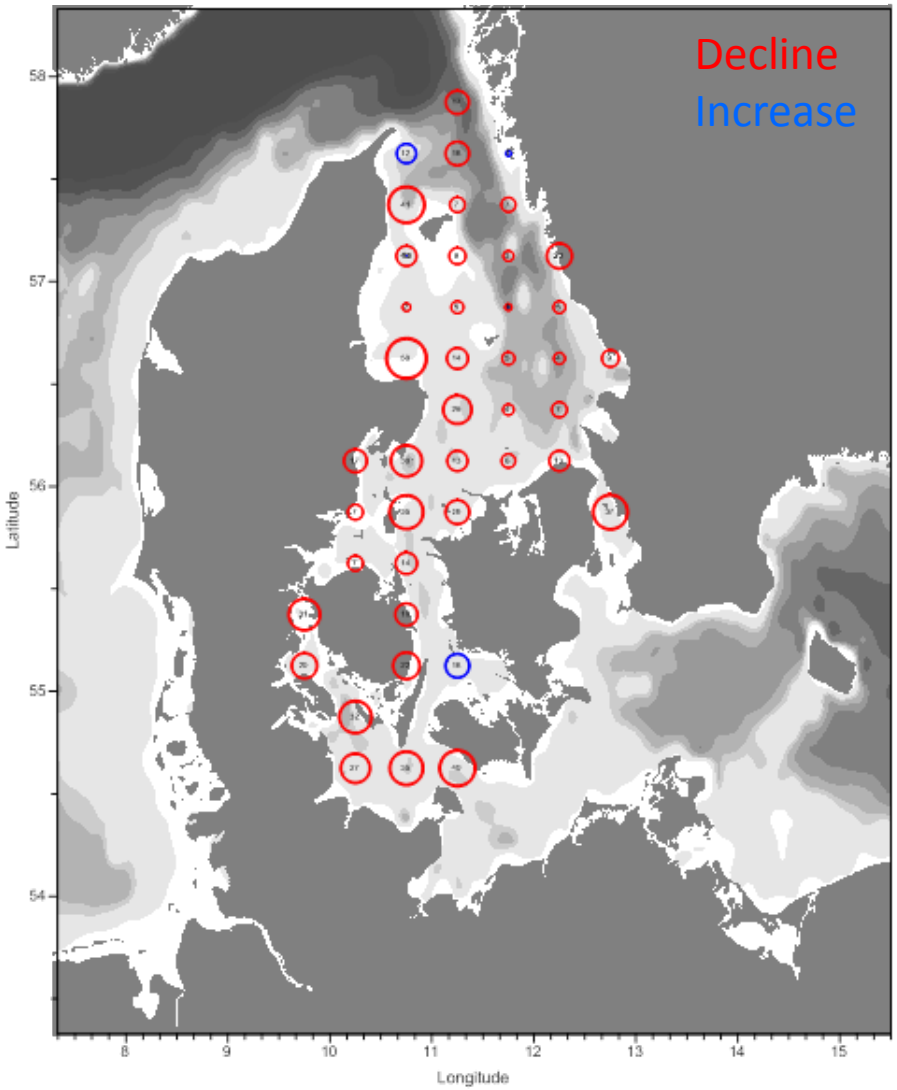
Results – System Design

Interviews of 74 coastal fishermen from 30 harbours were used to identify perceived spatial changes in the coastal cod fishery.

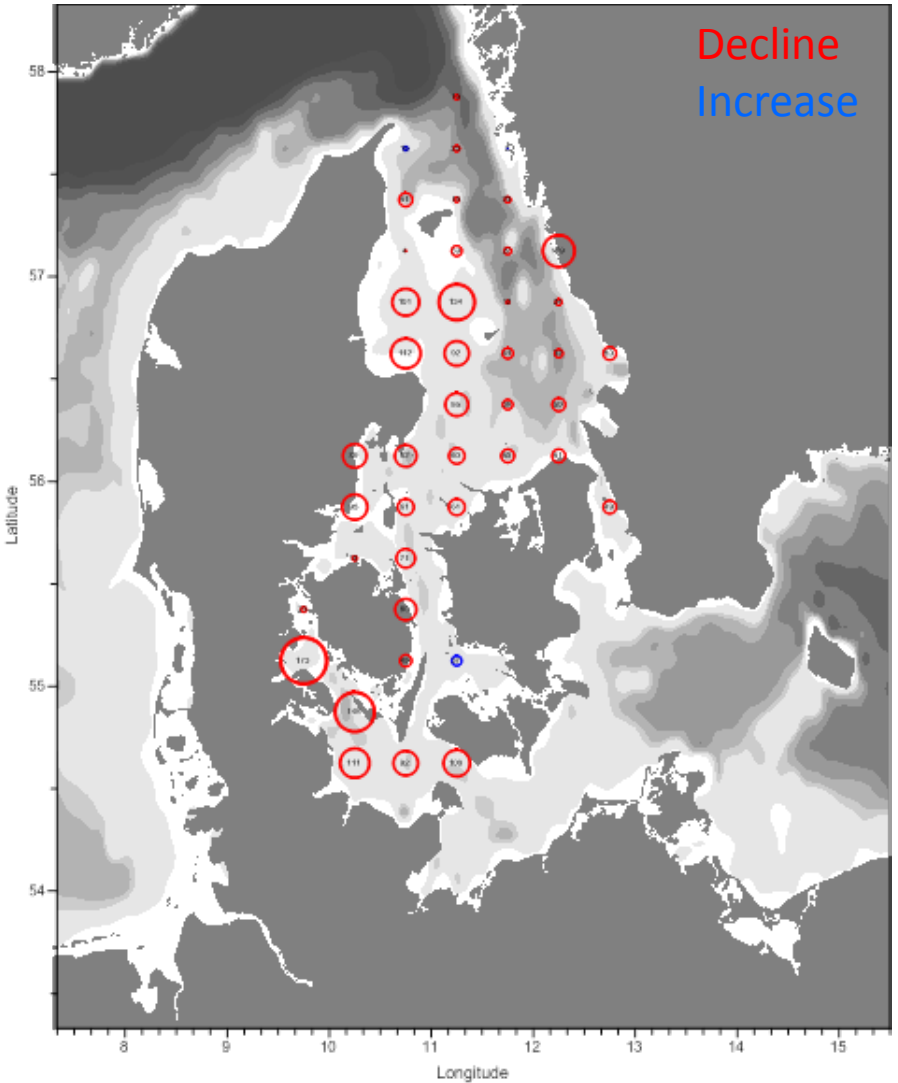


Results – System Formulation

Survey data: cod catches 1994-2015, absolute changes.



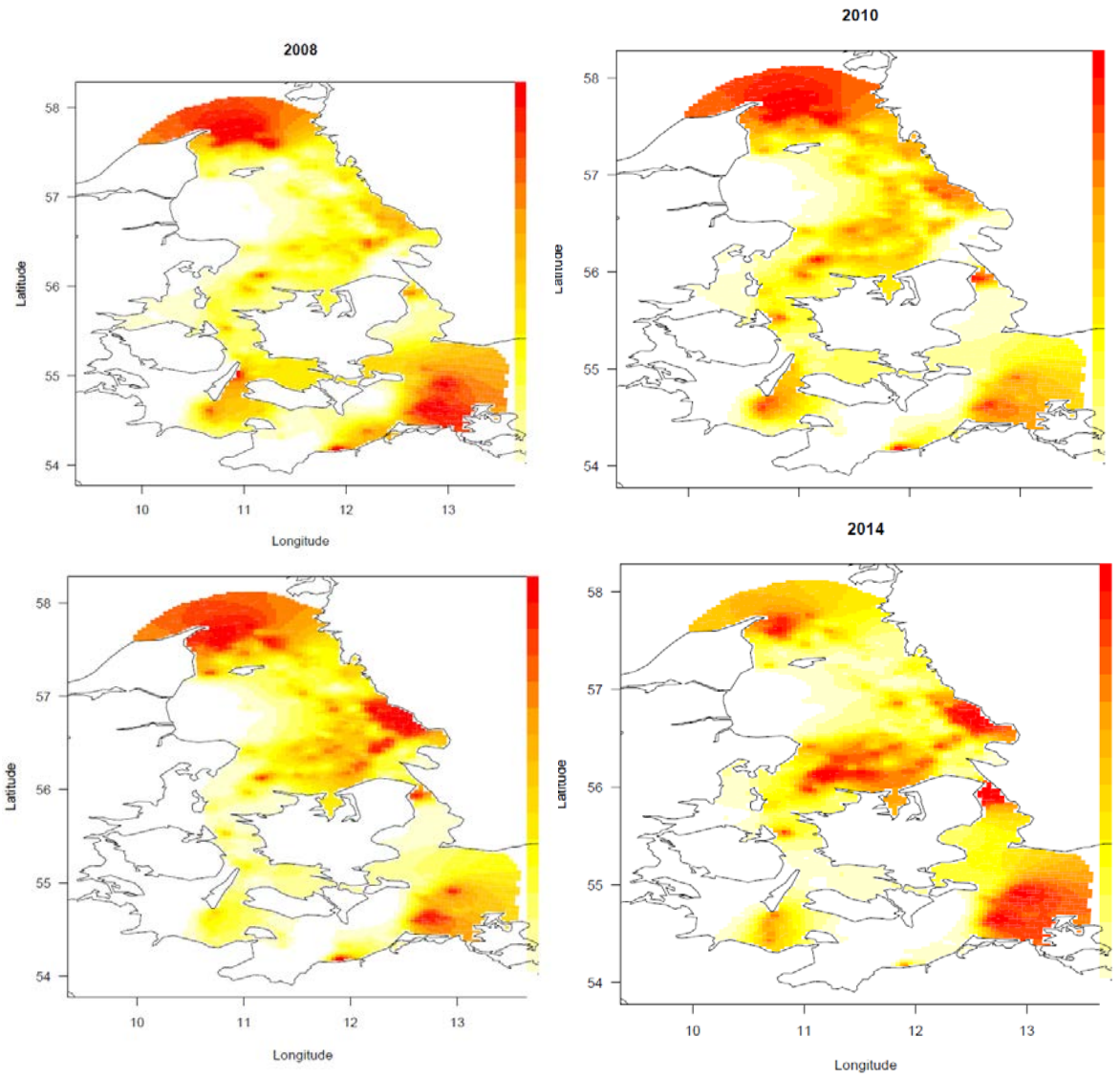
Survey data: cod catches 1994-2015, relative changes.



Results – System Formulation

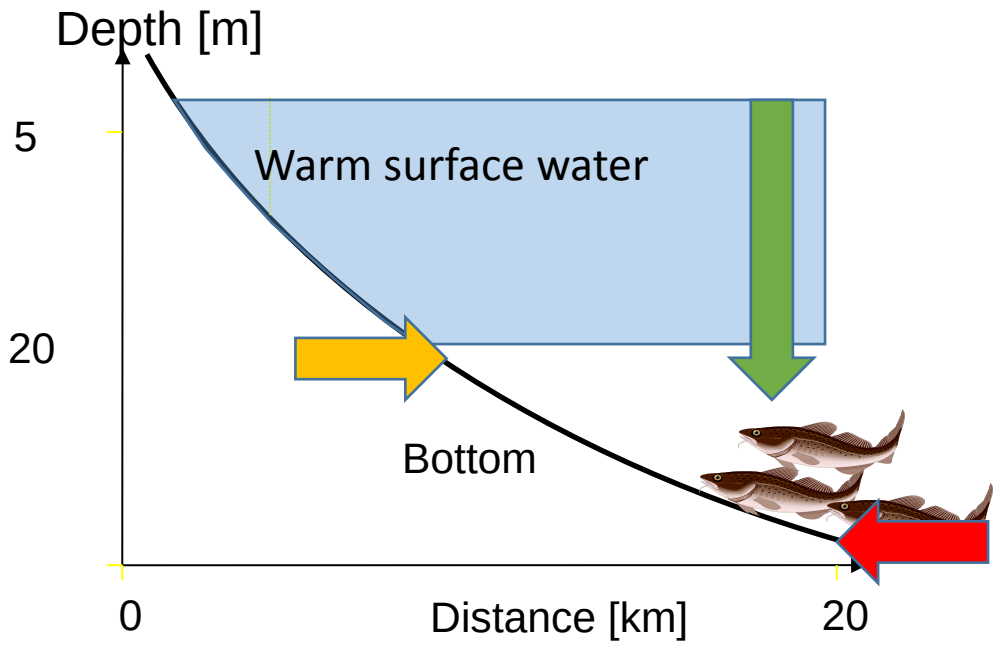
GeoPop modelling of inter-annual changes in the spatial distribution of cod in inner Danish waters (1991-2016):

- No significant correlation with eutrophication or environmental variables.



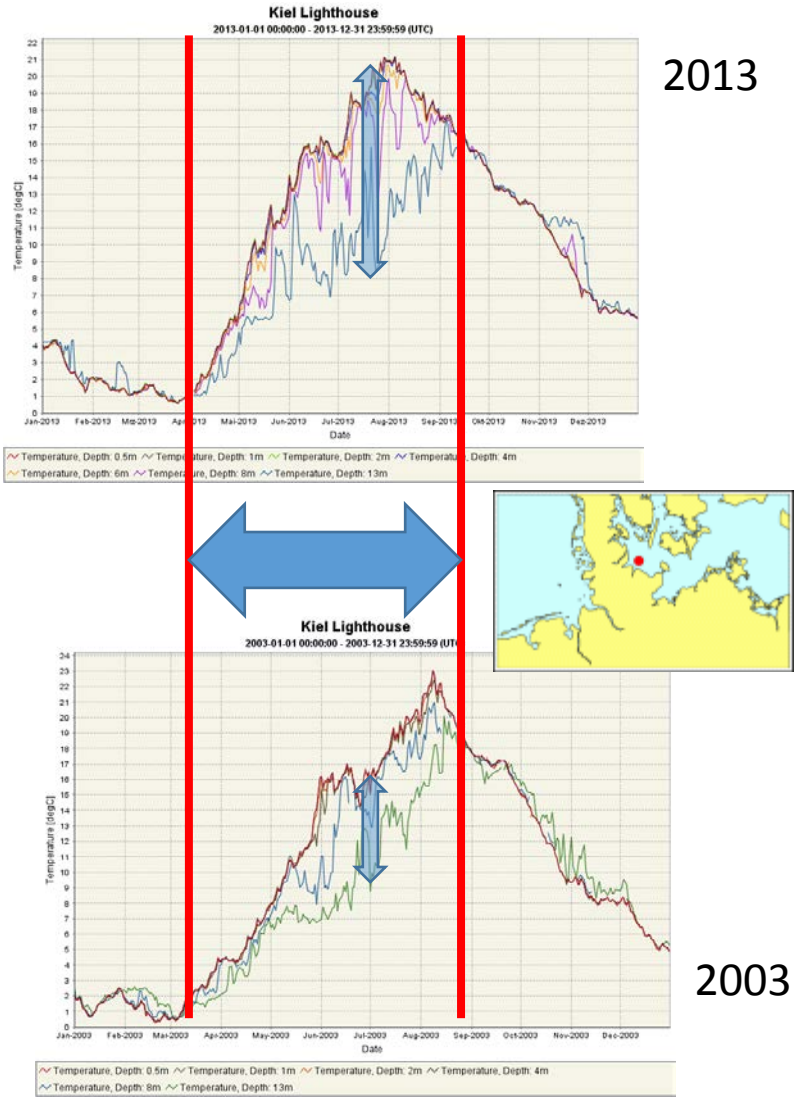
Results – System Formulation

Behavioural hypotheses for cod case



1. **Cod spawn in spring/summer and return to the coast afterwards**
2. **Their migration is stopped where they encounter warm surface water (>12°C, >14°C, >15°C)**
3. **Downward expansion of the surface layer forces cod further away from the coastal areas**
4. **Hypoxia forces cod upwards from deeper areas**

Results – System Formulation



2013

2003

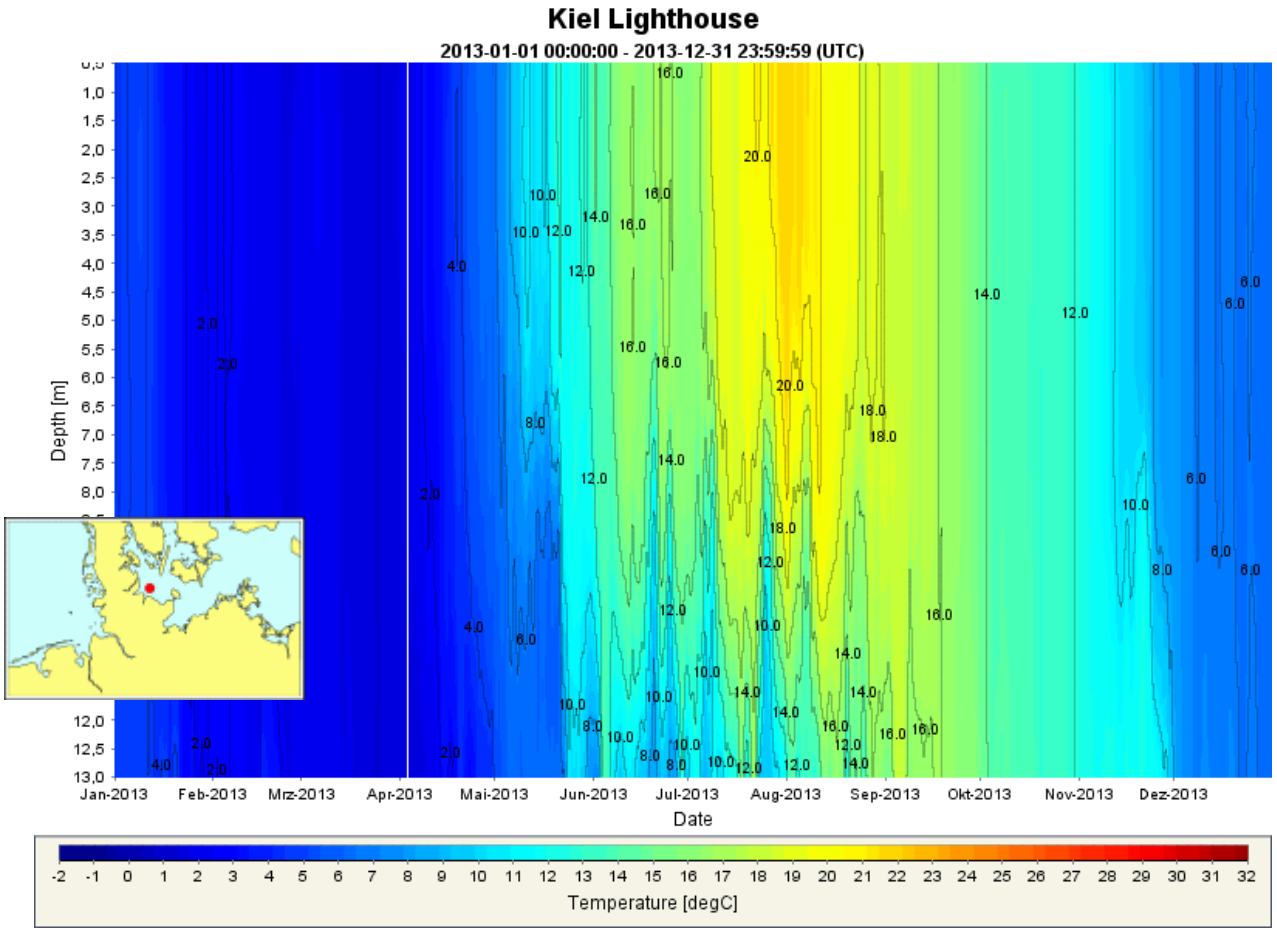
Water column temperatures at the Kiel lighthouse

- Temperature gradient due to summer warming between April and October, e.g. at 8 m depth up to 20 °C,
- There is some between-year variability both in **duration** of the warming period, and also in **intensity** (thermal gradient),
- **First hypothesis: During the last decades, there has been an increasing trend in duration and intensity of summer warming in the Baltic Sea,**
- BONUS INSPIRE collaboration: applying a high-resolving hydrodynamic model to reconstruct the spatio-temporal extent of the surface layer during the last 40 years (by Andreas Lehmann, GeoMar, Kiel).

Source: http://www.bsh.de/de/Meeresdaten/Beobachtungen/MARNET-Messnetz/Stationen/kiel.jsp

Results – System Formulation

Isopleth diagram of temperature at the Kiel lighthouse in 2013



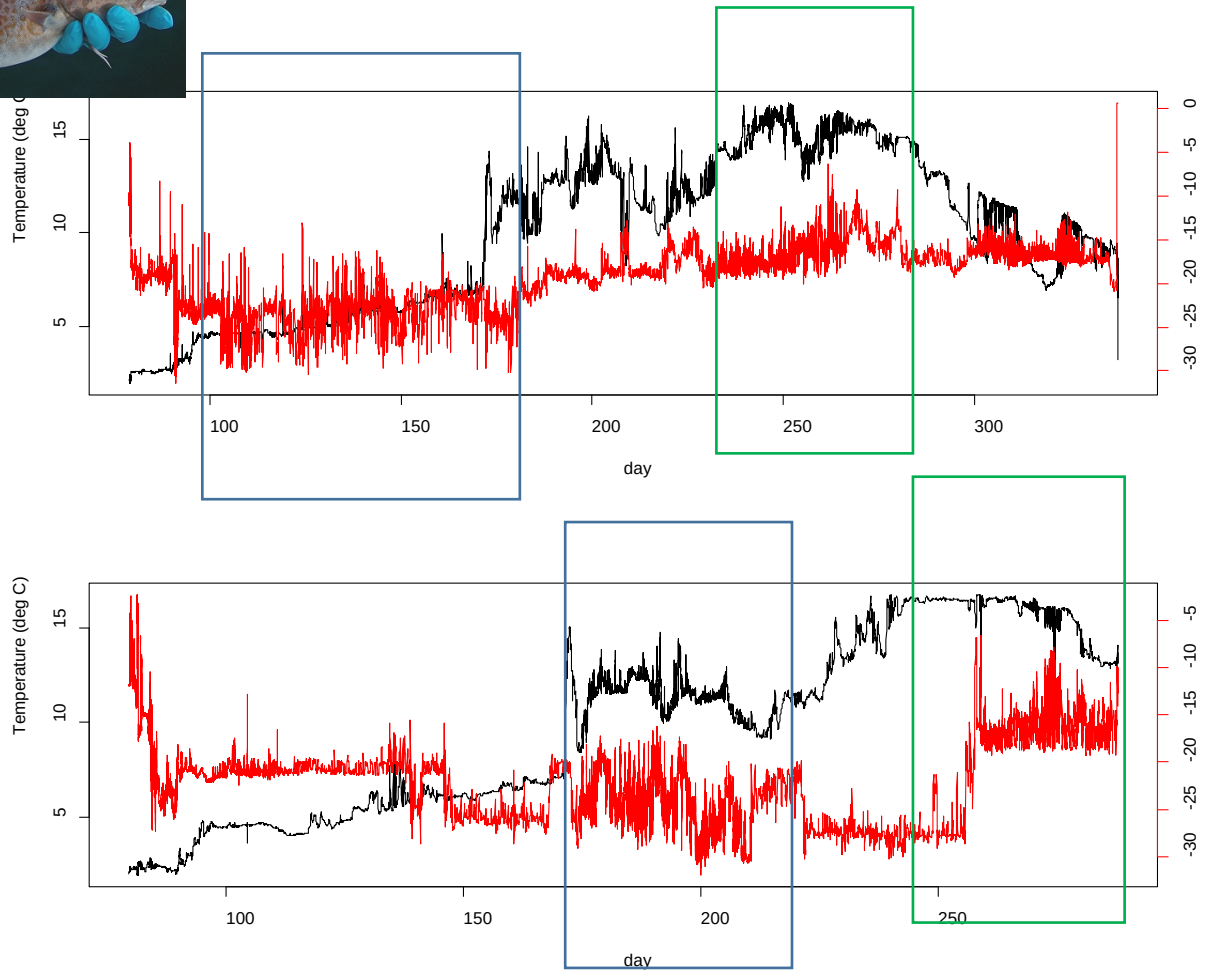
- **Hypothesis: During the last decades, there has been an increasing trend in *duration* and *intensity* of *summer warming* in the Baltic Sea (April-October)**

- **BONUS INSPIRE** collaboration: applying a high-resolving hydrodynamic model to reconstruct the spatio-temporal extent of the surface layer during the last 40 years, 1979-2016 (by Andreas Lehmann, GeoMar, Kiel)

Source: http://www.bsh.de/de/Meeresdaten/Beobachtungen/MARNET-Messnetz/Stationen/kiel.jsp

Results - System Formulation

Behavioural observations from Data Storage tagged cod in the Western Baltic



RED: depth, BLACK: temperature

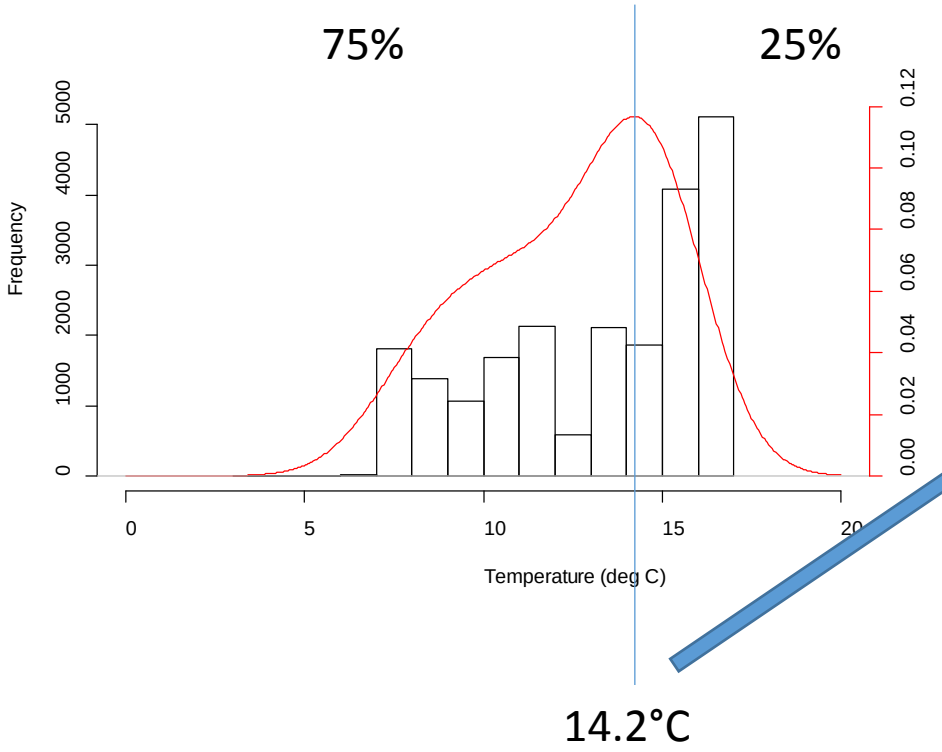
Hypotheses:
Temporally distinct periods of vertical activity at different maximum depths.

BLUE RECTANGLES:
Spawning close to the Arkona basin center or in Cadet trench

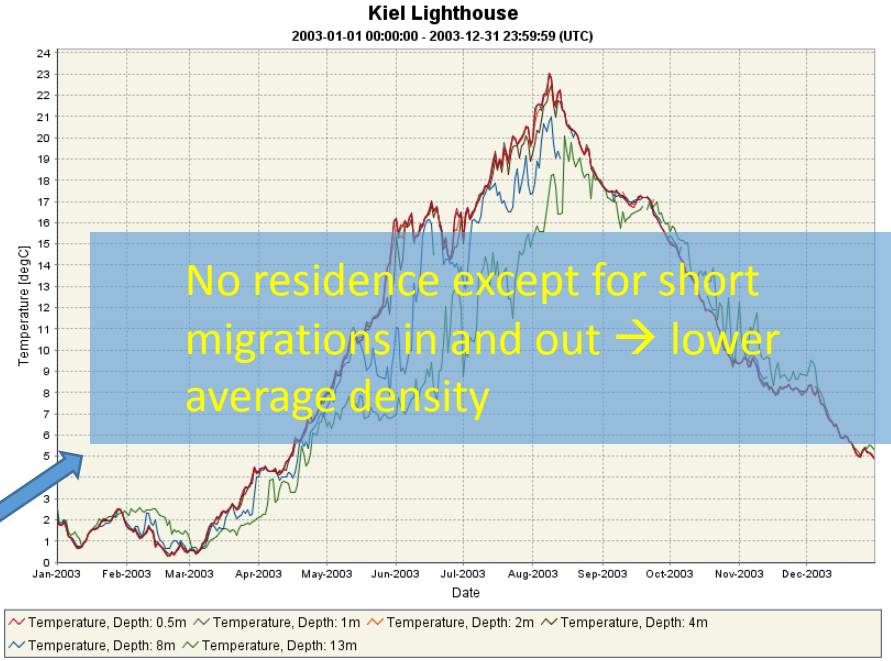
GREEN RECTANGLES:
Moving back and forth along the bottom, in and out of the warm surface layer

Results – System Formulation

Histogram and probability density function (pdf) of temperature observations in the green rectangles.

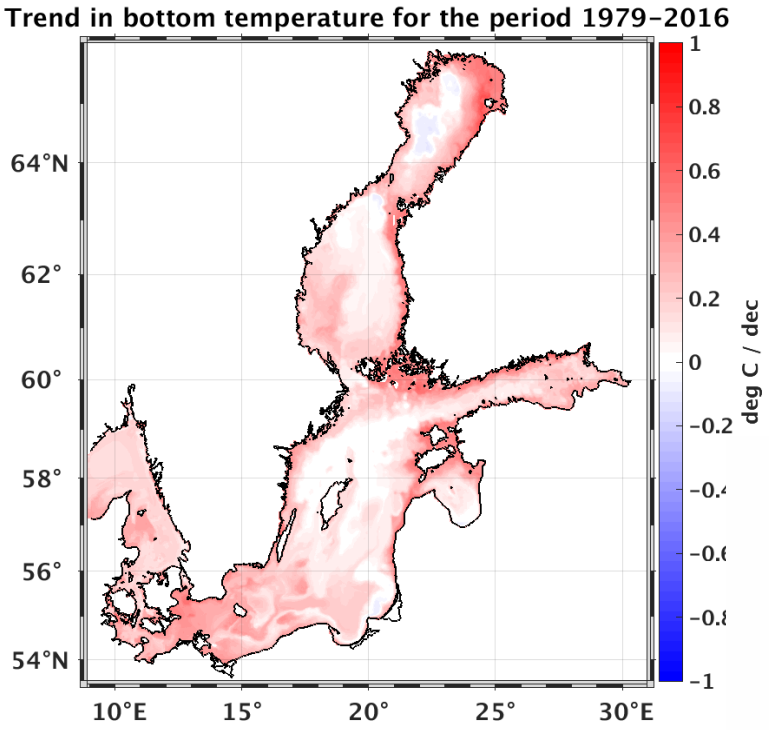


14.2°C

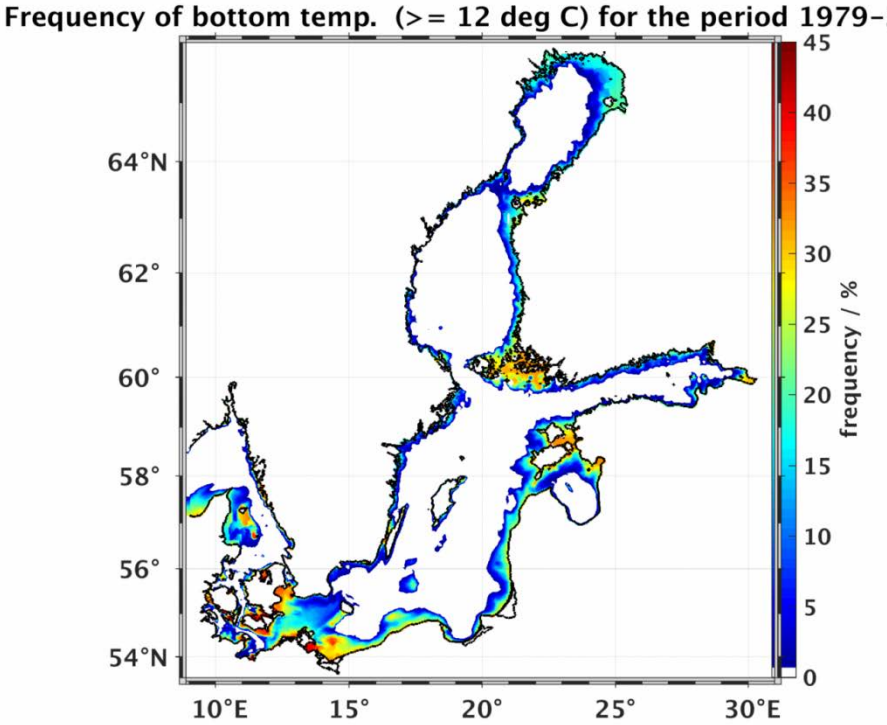


No residence except for short migrations in and out → lower average density

Results - System Formulation



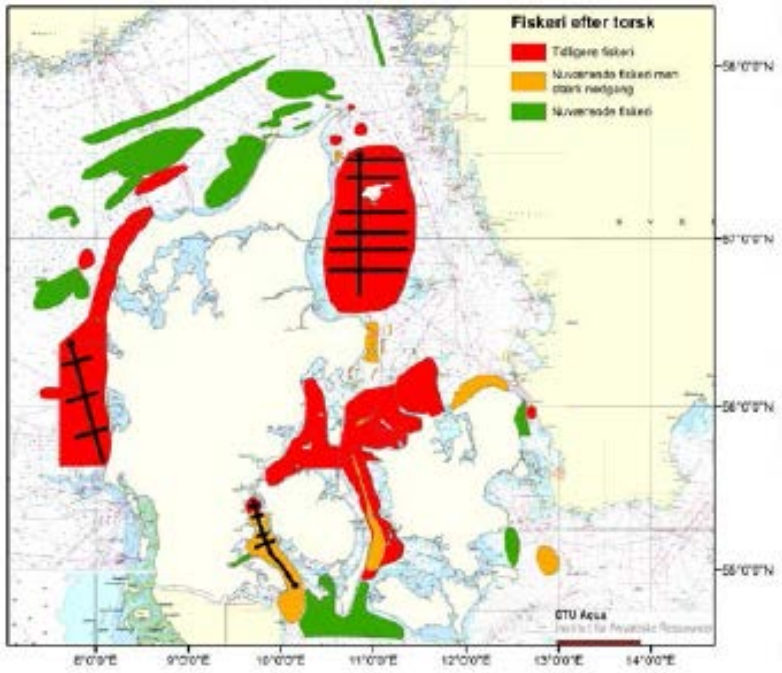
Change in temperature of bottom sea water

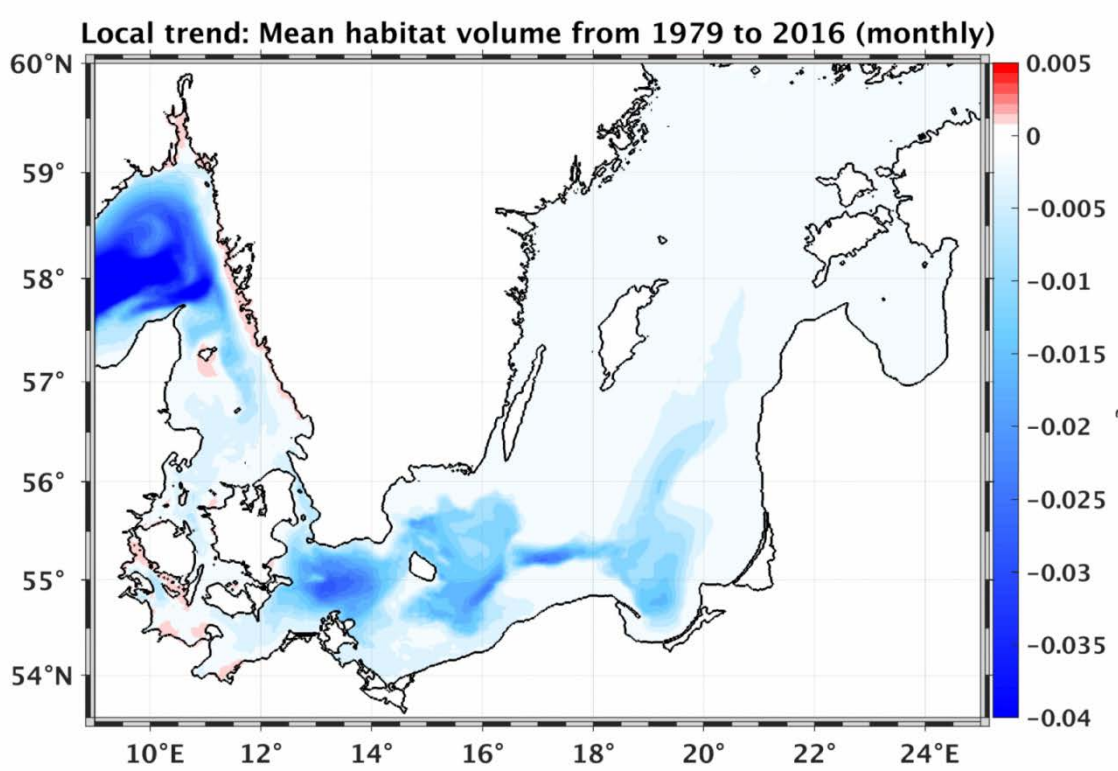


Results - System Assessment

Decline in the potential cod habitat

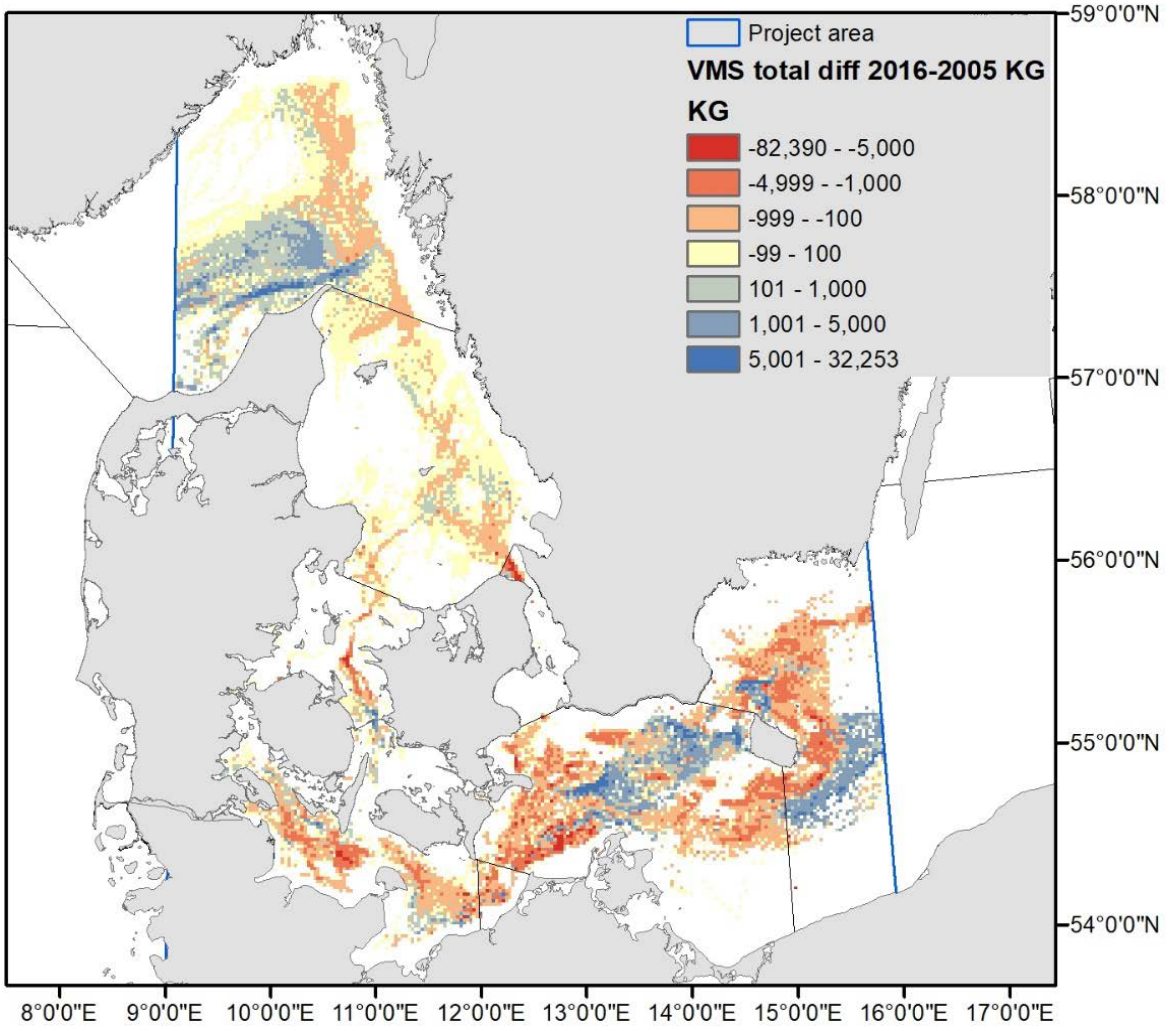
Fishermen's perception





Results - System Assessment

Change in cod landings (value evaluated in kg and €)



Discussion and conclusions

- Increase of temperature and hypoxia of bottom sea water has caused a spatial and temporal decline in potential cod habitat, especially in coastal areas of the Western Baltic Sea.
- This may explain part of the decline in the coastal cod stocks and cod fishery, and may require an adaptive management strategy.
- Potential management scenarios was discussed with stakeholders and include e.g. changes in quota allocation at a national and international level.
- Additional drivers which needs further assessment include: i) increase in predators (seals, cormorants), ii) change in fleet structure due to introduction of vessel-based individual transferable quotas (ITQs), and change in fishermen behaviour.

Acknowledgements

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