

WORKING GROUP ON INTEGRATED ASSESSMENT OF THE NORTH SEA (WGINOSE)

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i Executive summary

The Working Group on Integrated Assessment of the North Sea (WGINOSE) aims to provide a holistic analysis of the present and future status of the North Sea Ecosystem and human activities therein. Analyses are split among 14 strata since the North Sea is a diverse ecosystem spanning the shallows of the Southern North Sea banks to the deeps of the Norwegian Trench. State-of-the-art statistical methods for trend analysis were performed on time-series data spanning 35 years (1984-2019) which show a flat (constant) or downward (declining) trend in all strata for cod, herring and haddock abundance, a consistent upward (rising) trend for temperature and dissolved oxygen, while other fish species and oceanographic variables show both upward, downward or flat trends. A method to detect 'warning signals' of significant change outside statistical expectations was applied for the first time, but required further development and evaluation before practical application. A lack of consistent datasets (both spatially and temporally) from all 14 strata limited the utility of the trend and warning signal analysis, but the group aims to address this in coming years.

Mental models were developed for four subregions (strata) of the ICES North Sea Ecoregion: Southern North Sea, Kattegat, Skagerrak and the Norwegian Trench. These qualitative models were developed in partnership with subregional stakeholders to identify the most relevant ecosystem components to assess. Scenarios for future development of fisheries, shipping andmarine protection were developed based on the mental models, and these scenarios were then implemented in end-to-end ecosystem models for the Skagerrak and Kattegat using Ecopath with Ecosim. Initial comparisons between qualitative and end-to-end models show a good level of agreement in the overall system-level responses to scenario perturbations.

Developing models through stakeholder workshops is both time and resource intensive. Ideally, stakeholders should be involved in the interpretation of scenario results and work closely when further refining models to ensure they have the best chance of being operationally applied by stakeholders. Nevertheless, effort invested by members of WGINOSE to co-develop solutions and assessment tools with end-users inspired additional projects, including some collaborative activities with other ICES Integrated Ecosystem Assessment expert groups.

An interactive map of human activities and pressures for the entire Greater North Sea ecoregion was produced. This, together with the strata specific modelling and assessment work, and the trend and 'warning signal' analysis, will underpin future iterations of the ICES Greater North Sea Ecosystem Overviews and further refinement of existing conceptual models for the ecoregion.

ii Expert group information

Expert group name	Working Group on Integrated Ecosystem Assessment for the North Sea (WGINOSE)
Expert group cycle	Multi-annual fixed term
Year cycle started	2017
Reporting year in cycle	4/4
Chair(s)	Andrew Kenny, UK
	Erik Olsen, Norway
Meeting venue(s) and dates	13-17 March 2017, Bergen, Norway (11 participants)
	16-20 April 2018, Copenhagen, Denmark, (7 participants)]
	20-24 May 2019, Gothenburg, Sweden (11 participants)]
	04-08 May 2020, virtual meeting (13 participants)

1 Terms of reference

ToRs for WGINOSE 2017-2020

ToR	DESCRIPTION	BACKGROUND	SCIENCE PLAN CODES	DURATION	EXP ECTED DELIVERABLES
a	Update strata specific ecosystem trends analysis utilizing data from ICES Data Centre and other data sources, e.g. CPR, OSPAR, EEA and Member States.	a) Science Requirements b) Advisory Requirements c) Requirements from other EGs	1.3, 1.9, 6.5	Years 1, 2 & 3	Regional sea state trend analysis for inclusion in ecoregion overviews annually
b	Identify and develop additional strata and associated monitoring pro- grammes for the inshore/coastal areas of the North Sea and the Norwegian Trench.	a) Science Requirements b) Advisory Requirements c) Requirements from other EGs	6.5	Years 1, 2 & 3	Regional sea state trend analysis for inclusion in ecoregion overviews annually
c	Establish data pathways and obtain data to operationalize the integration of human activity and pressure data, distinguishing between fixed structures (e.g. pipelines, windfarms) and ongoing activities (e.g. dredging, fishing, shipping, underwater noise, litter), accidents (emergency response).	a) Science Requirements	6.5, 6.6	Years 1, 2 & 3	Recommedations and actions giving rise to the ongoing improvement to flow of data between EWG, the ICES Data Centre and WGINOSE
d	Develop strata specific decision support tools to support ecosystem management and advice (e.g. BBNs and expert systems, ecosystem models, ecosystem goods and services modelling) in collaboration with end-users (OSPAR, DG-ENV, DG-MARE)	a) Science Requirements	6.1, 6.4, 6.6	Years 1, 2 & 3	Results which explore the balance and trade-offs between ecosystem protection and sustainable marine resource development
e	Contribute to the coordination and integration of strata specific assessments with the development of integrated ecosystem monitoring in the North Sea, e.g. redesign of the Q3 IBTS surveys.	a) Science Requirements b) Advisory Requirements c) Requirements from other EGs	3.2	Years 1, 2 & 3	Regional sea state trend analysis for inclusion in ecoregion overviews annually

2 List of outcomes and achievements of the WG in this period

- New statistical methods for time-series trend analysis, including 'warning indicators', have been developed, although there is a challenge with gathering and preparing data from the new strata (Norwegian Trench, English Channel) included in the WGINOSE analysis. All 14 strata are now finalized, and a new shapefile of the final boundaries of North Sea strata has been generated.
- Pressure layers and maps of most human activities have been compiled and clipped for
 the North Sea ecoregion, including; i. shipping (cargo) routes, ii. dredging (aggregate
 extraction), iii. disposal (sediment), iv. surface abrasion (bottom trawling), v. bottom impact (bottom trawling), vi. hard structures (physical loss) and vii. Seabed substrate types.
 A HTML interactive map file has been produced to facilitate a visual assessment of the
 spatial distribution of the identified and compiled human activities in relation to the
 North Sea assessment strata and ICES statistical rectangles and discussion are ongoing
 in terms of hosting the file on the ICES WGINOSE webpage.
- Qualitative ecosystem models (Mental Models) have been developed for the Southern North Sea, Norwegian Trench, Kattegat and Skagerrak through stakeholder workshops, culminating most recently for Kattegat at the W KKEMSSP on 22nd May 2019. The mental models are used to scope main issues and interactions between ecosystem components, and to define scenarios for future use that will be subsequently quantitatively explored using ecosystem models (e.g. Ew E, EcoSpace).
- A preliminary comparative analysis of Ew E and mental model results conducted in 2020 revealed generally consistent results against a number of predefined scenarios. A full comparative analysis is planned to be published in late 2020.
- Coordination with IBTSWG on expanding IBTS survey coverage into all WGINOSE strata (e.g. Norwegian Trench) and further operational integration of survey data from the English Channel is ongoing.
- WGINOSE plan to undertake a revision of the North Sea Ecosystem Overview and include this as a standing ToR as part of its new multi-annual ToRs.

3 ToR A: Update strata specific ecosystem trends analysis

From 2017 – 2018 W GINOSE continued the trend analyses using the PCA based approaches previously applied to the North Sea and by other ICES IEA groups in their respective regions, but following the critique of the methods in Planque and Arneberg (2018) W GINOSE engaged in W KINTRA to develop and test the appropriate statistical methods for time-series analysis. Accordingly, two methods were applied in the 2020 trend analysis: i) Trend estimation and classification (TREC) (Solvang and Planque 2020), and ii) warning signal analysis. These two approaches will continue to be the method of choice for future trend analysis by W GINOSE.

3.1 Trend estimation and classification analysis (TREC)

Common trends refer to trends that are similar across ecosystem components within a given region. Identifying common trends can be useful as a diagnostic tool to reveal past changes and to explore the relationships among biological communities, as well as between these communities and environmental conditions. In the present investigation, trend estimation and classification analyses (TREC) are applied to WGINOSE time-series data including.

- DATRAS CPUE data for the central North Sea (excluding the Norwegian Trench and English Channel) from 1984–2019
- ICES Oceanographic data from all 14 WGINOSE subregions from 1984 2019
- IMR trawl data from the Norwegian Trench from 1984 2019
- Modelled oceanographic data for all 14 WGINOSE regions from 2006 2100
- Plankton data (including zoo- and phytoplankton species) for the North Sea as a whole from 1984 – 2019, and
- Zooplankton data in the Norwegian Trench WGINOSE area from the Torungen Hirtshals transect (2009 2019)

The analysis by TREC requires the same data length for all for all variables. These data are prepared as consistent annual time-series. The analysing procedure in TREC is summarized in Figure 1. The simple classification categorizes the trends in the time-series as either upward (rising), flat (constant), or downward (declining) in nature. The detailed results per area are shown in Annex 3. The dendrogram (Figure 1) is described based on the distance measurement given by the discriminant function and the trees for upward, flat and downward are coloured by red, blue and green. The variables corresponding to these groups are summarized with the dendrogram.

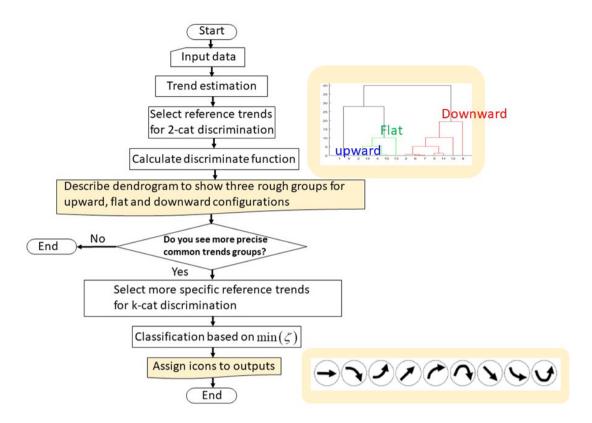


Figure 1 The analysing procedure by TREC.

Next, further classification by multiple category discriminates is performed. The represented trend patterns in each classified group is assigned by the icons that we defined. Summary results following the application of this methodological approach are presented in the sections below:

3.1.1 Outputs for two-categorical discriminates for ICES CPUE data from the central North Sea from the IBTS surveys 1984-2019.

Overall, all species and strata of the North Sea exhibit a mix of different trends, but some dominant patterns are noticeable. For example, herring, cod and haddock all show either flat or downward trends in all 11 strata, while the trends for whiting, plaice, saithe, mackerel, sprat and Norway pout were more variable showing both downward, upward, flat and u-shaped trends during the 35 year time-series analysed (Table 1).

Table 1 The details for multi category classification of DATRAS CPUE data from the IBTS survey for the central North Sea (excluding the Norwegian Trench and English Channel) from 1984–2019.

species	1: Orkney- Shetland	2: Skagerrak	3: Kattegat	4: Fladen	5: Utsira	6: Long Forties	7: Dogger Bank	8: Norfolk Banks	9: German Bight	10: Oyster Ground	11: South Bight
1: Clupea harengus	(((((\rightarrow		•	((•
2: Gadus morhua			(igored	(•	(•	(((
3:Melanogrammus aeglefinus	(((•	(((((((
4: Merlangius merlangus	((9	•	Ø	(Ø	3	\odot	((
5: Pleuronectes platessa		Ø		Ø				9	\odot	((
6: Pollachius virens	\odot	Ø	(lack	\rightarrow	\rightarrow	O	\rightarrow	Ø	(
7: Scomber scombrus	(\rightarrow	(lack	9	\rightarrow	3	\rightarrow	O	9	
8: Sprattus sprattus	\odot	\rightarrow	2	\bigcirc	(\rightarrow	Ø	2	→	\rightarrow	U
9: Trisopterus esmarkii		Ø	(((2)	Ø	(Ø		((

Trends in the northernmost strata, Orkney-Shetland were downwards or flat for all species, while the other strata had both upwards and downwards trends in addition to flat and/or ushaped trends (Table 1 and Figure 2).

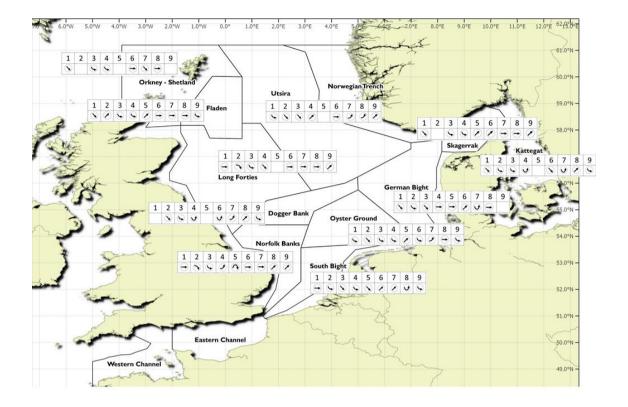


Figure 2 Trends in DATRAS CPUE time-series for the North Sea strata 1-11. Numbers in each regional sub-table correspond to the species in Table 1. Note, trends for the Norwegian Trench, Eastern Channel and Western Channel are not included.

3.1.2 Outputs for two-categorical discriminates for CPUE from Norwegian trawl data from the Norwegian Trench from 1984-2019

The trend analysis of the Norwegian trench strata based on CPUE data from the Norwegian (IMR) trawl catches from 1984–2019 (Table 2) showed upward trends for nine species (greater argentine, chimera, cod, long-rough dab, monkfish, whiting, greater forkbeard, saithe, Norway pout, mackerel, halibut and pearlside), downward trends for five (cusk, spiny scorpionfish, thorny ray, roundnose grenadier and sailray, while seven species showed flat trends (lump-sucker, velvet belly, silvery pout, blue whiting, ling and haddock).

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Table 2 The details for multi category classification of time-series (1984 – 2019) of CPUE data from the IMR trawl survey data from the Norwegian trench (area 12).

ICES

species	icon	species	icon	species	icon	species	icon
1: Arge	3	8: Glyp	•	15: Phyc	9	22: Ambl	•
2: Bros	(A)	9: Hipp	9	16: Poll		23: Hipph	3
3: Chim	>	10: Loph		17: Seba	(24: Cory	(
4: Cycl	•	11: Merl		18: Squa		25: Maur	
5: Etmo	•	12: Micr	\rightarrow	19: Tris		26: Raje	(
6: Gadi	\rightarrow	13: Molv	→	20: Mela	\rightarrow		
7: Gadu		14: Pand		21: Scom	3		

Trends for whiting, mackerel and Norway pout were the same in the Norwegian trench (Table 2) as for the Utsira area (Table 1), while for cod the trend was opposite (decrease in the Norwegian trench, increase in Utsira) and for haddock flat in the Norwegian trench instead of decreasing as in Utsira.

3.1.3 Outputs for two-categorical discriminates for Zooplankton data in the Norwegian Trench WGINOSE area (2009-2019).

For the Norwegian trench WGINOSE had access to a 10 year (2009 - 2019) time-series of zoo-plankton data collected on Norwegian (IMR) research surveys and oceanographic sections crossing the Norwegian trench. These were also analysed using the TREC method. The zooplankton data were analysed in relation to the categories of how the samples were sorted (Table 3).

Table 3 Abbreviations used in figures and tables of Norwegian trench plankton data.

Abbreviation	Full variable name
1: lc180_1000	Mean of 180-1000 mu size-fractions
2: lc1000_2000	Mean of 1000 – 2000 mu size-fractions
3: lc2000	Mean of > 2000 mu size-fractions
4: Krill	Krill
5: Paraucheta	Pareucheta
6: Calanus Hyp	Calanus hyperboreus
7: Jellyfish	Jellyfish
8: DryWeight_Tot	Total dry weight of all fractions

Declining trends were observed for the 180-1000 *mu* size fraction, Paraeucheta and krill, while the 1000–2000 *mu* size fraction, >2000 *mu* size fraction, total dry weight and *Calanus hyperboreus* showed increasing trends, and jellyfish showed a flat trend.

Table 4 The details for multi category classification of Norwegian trench plankton data.

variable	icon	variable	icon
1:lc180_1000	(3)	5:Paraeucheta	(3)
2:lc1000_2000		6:Calanus_Hyp	>
3:lc2000	3	7:Jellyfish	\rightarrow
4:Krill	•	8:DryWeight_Tot	

3.1.4 Outputs for two-categorical discriminates for mean ICES Oceanographic data from all 14 WGINOSE subregions from 1984-2019.

ICES oceanographic data were available for all 14 strata allowing for a full trend analysis of oceanographic conditions from the full ICES North Sea ecoregion. All variables were however not available for all strata and especially for the two strata in the English Channel (strata 13 and 14) only a few oceanographic time-series were included in the analysis (2 and 5 respectively).

Surface and bottom temperature and dissolved oxygen show consistent increasing of flat trends for all areas (Table 5), except the Western English channel which had a downward U trend for surface temperature, and bottom dissolved oxygen in Skagerrak which had an upward U trend. The other variables showed more varied trends by strata.

Table 5 The details for multi category classification of ICES Oceanographic data from all 14 WGINOSE subregions from 1984 – 2019.

	1: Orkney- Shetland	2:Skage- rrak	3: Kattegat	4: Fladen	5: Utsira	6: Long Forties	7: Dogger Bank	8: Norfolk Banks	9: German Bight	10: Oyster Ground	11: South Bight	12:Norw- egian Trench	13: Easte- rn Channel	14:Weste- rn Channel
1sTEMP		Ø	Ø	Ø		Ø	Ø		8	Ø	Ø	•		(A)
2sPSAL		(©		(Ø	(4)	Ø			•	4	•
3sDOXY	•		•	•	•	<u>Q</u>	4		4	•	•	(3)		
4sPHOS			\rightarrow	Ø	Ø		•	\rightarrow	((•	(Q)		(A)
5sSLCA	Q	Ø			©			(•			Ø	((x)
6sNTRA	5/5/8/5				O	(x)		<u>Q</u>	©		(7)	•		(x)
7sNTRI			\rightarrow				•	Q	((x)		(
8sAMON						•	(•	((x)	(
9bTEMP	((\rightarrow		Ø	(2)	Ø	(3)	(7)	A	8		
10bPSAL								•			Ø	•		
11bDOXY	(O	((x)	(x)	(3)	•		•		(A)	•		
12bPHOS	•	(v)	Ū	$\overline{\bullet}$	$\overline{\bullet}$	- Company	(X)	(x)		(A)	(Q)	Ø		
13bSLCA	(x)	(<u>(</u>		$\overline{\bullet}$					(A)		Ø		
14bNTRA	Ø	(1)	(1)		(A)		(A)			(4)		<u>(</u>		

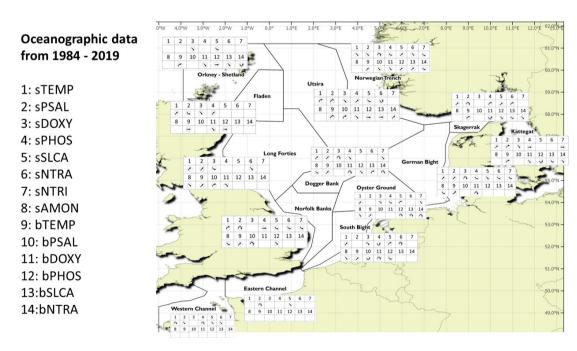


Figure 3 Multi category classification of ICES Oceanographic data (1984 – 2019) mapped to each of the 14 WGINOSE subregions.

3.2 Warning signal analysis

To investigate whether the most recent observation follow or deviate from the recent tendency of the data, a time-series analysis for forecasting the recent abiotic and biotic status is considered. The statistical procedure first applies a stochastic trend model to the data to estimate the long-term trend. The stochastic trend model is represented by a class of auto-regressive models. The model adopts a state space representation, and the trend component and the residual components are estimated by a Kalman filter algorithm. The algorithm is also able to obtain one- or more-years-ahead prediction values using all past information from the data (Harvey, 1990; Kato

et al., 1996; Kitagawa and Gersch, 1996). Thus, as a secondary procedure, we set the number of recent specific years and make a specific years-ahead prediction using the data observed before the specific years through the Kalman filter algorithm. Using the standard deviation of the residual components, the forecast bands are also calculated. The prediction (forecast values) and the related forecast bands are used to make a comparison with the data observed in the specific years. The existence of recent data falling outside the forecast bands of the predicted data represents potential warning signals that warrants closer examination and that may give hints in planning human intervention via fishing efforts or other interactions with the oceans as well as be used to communicate with stakeholders.

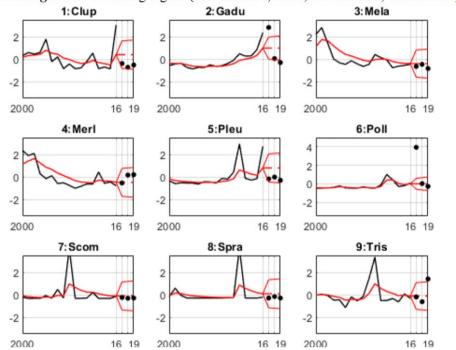
The resulting trend estimates are more fluctuating than estimates from the polynomial trend model, because the stochastic trend follows the data variation precisely for each time point. We run the algorithm using the data recorded until 2016 and make the predictions for the years within the period 2017-2019. In this analysis, it is not necessary for all the data to cover the exact same number of years as was the case when applying the TREC procedure. In the figures, the estimated trend and the prediction with the forecast band in each area are plotted with a red line. Real observations within the period 2017-2019 are plotted with black dots. Black/blue dots located inside/outside the upper/lower limit of forecast bands ($\pm 2 \times 1000$ x standard deviation) provide a statistical criteria to measure a difference between observation and predicted value. This method can be useful in determining a deviation in ecosystem indicator status beyond statistical expectation and therefore may be useful as an early warning signal.

3.2.1 Warning signal analysis of CPUE time-series from the IBTS survey of the central North Sea (1984-2019)

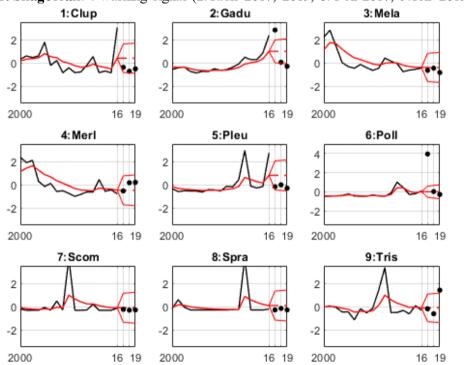
Below are presented plots of the warning signal analysis for strata 1-11 with a 3-year-forward-prediction with forecast bands (red line) for the trend obtained using observations for 2000 – 2016 (black line). Black dots indicate observations for 2017 – 2019, respectively. If a black dot falls either below or above the forward prediction (red line) then this would suggest a deviation outside statistical expectations.

Strata 1: Orkney-Shetland: 1 warning signal (9:Tris 2017)

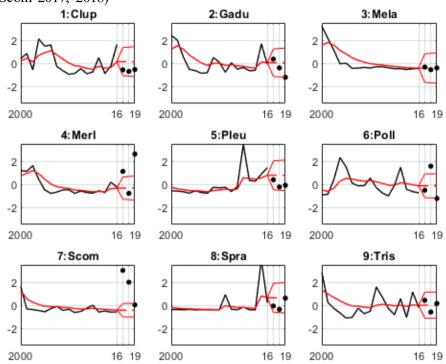
Strata 2: Skagerrak: 4 warning signal (2:Gadn 2017, 2019, 6: Poll 2017, 9:Tris 2019)



Strata 2: Skagerrak: 4 warning signal (2:Gadn 2017, 2019, 6: Poll 2017, 9:Tris 2019)

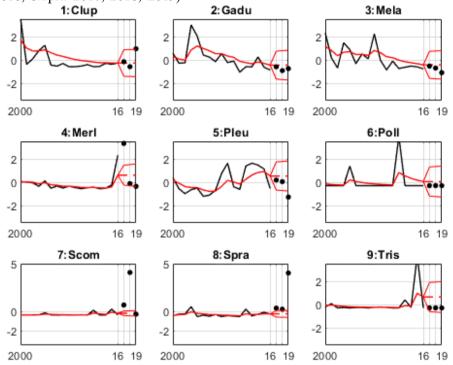


Strata 3: Kattegat: 7 warning signal (2:Gadn 2019, 4:Merl 2017, 2019, 6: Poll 2018, 2019, 7:Scom 2017, 2018)

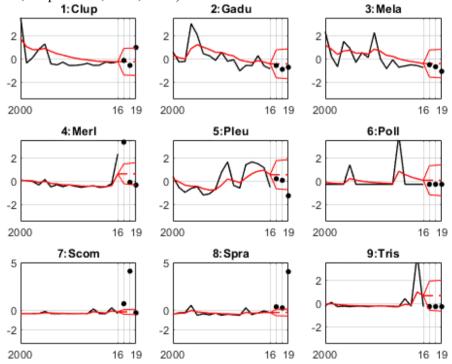


Strata 4: Fladen: 3 warning signal (2:Gadn 2017, 6: Poll 2017, 2019) 3: Mela 1:Clup 2: Gadu 2 2 2 0 0 0 -2 -2 -2 16 19 16 19 16 19 2000 2000 2000 4: Merl 5:Pleu 6:Poll 2 2 2 0 0 0 -2 -2 -2 2000 16 19 2000 16 19 2000 16 19 7:Scom 8: Spra 9:Tris 2 2 2 0 0 0 -2 -2 -2 2000 2000 16 19 2000 16 19 16 19

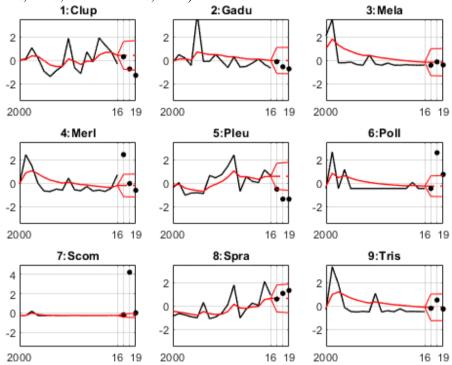
Strata 5: Utsira: 8 warning signal (1:Clup 2019, 4:Merl 2017, 5:Pleu 2019, 7: Scom 2017, 2018, 8:Spra 2017, 2018, 2019)



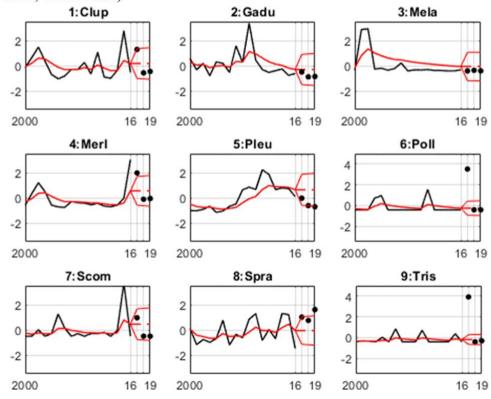
Strata 5: Utsira: 8 warning signal (1:Clup 2019, 4:Merl 2017, 5:Pleu 2019, 7: Scom 2017, 2018, 8:Spra 2017, 2018, 2019)



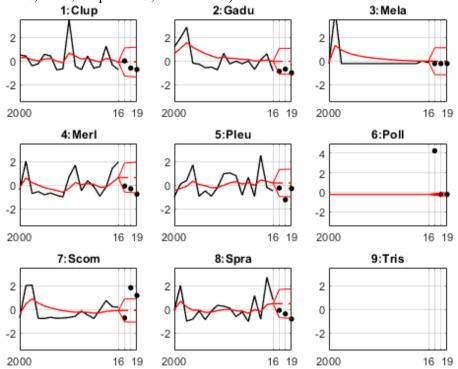
Strata 7: Dogger Bank: 8 warning signal (1:Clup 2019, 4:Merl 2017, 5:Pleu 2018, 2019, 6:Poll 2018, 2019, 7: Scom 2018, 2019)



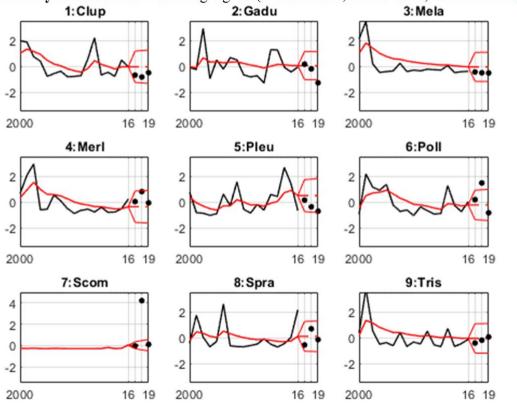
Strata 8: Norfolk Banks: 5 warning signal (4:Merl 2017, 5:Pleu 2019, 6:Poll 2017, 8:Spra 2019, 9:Tris 2017)

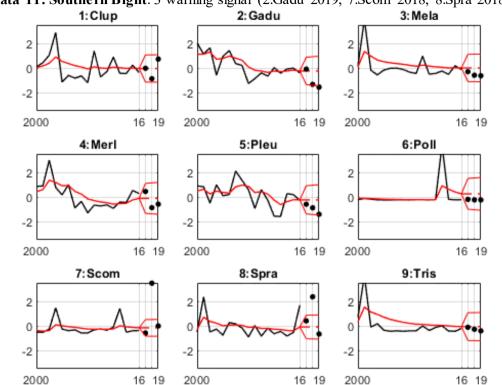


Strata 9: German Bight: 6 warning signal (4:Merl 2019, 5:Pleu 2018, 6:Poll 2017, 7:Scom 2018, 2019, 8:Spra 2019, 9:Tris 2017)



Strata 10: Oyster Ground: 3 warning signal (2:Gadu 2019, 6:Poll 2018, 7:Scom 2018)





Strata 11: Southern Bight: 3 warning signal (2:Gadu 2019, 7:Scom 2018, 8:Spra 2018)

The total number of warning signals in each strata is presented in Figure 3. The central areas, Utsira and Dogger bank both have the highest number of warning signals (8 in each), while in the Orkney-Shetland area only one warning signal was detected. Some time-series data indicated non-linear fluctuations and extremely high rates of change, as seen for saithe (*Pollachius virens*) in strata 2, 7, 8, and 9, mackerel (*Scomber scombrus*) in strata 3, 5, 6, 7, 10, and 11, sprat (*Sprattus sprattus*) in strata 5, and Norway pout (*Trisopterus esmarkii*) in strata 9. While these data points were identified as warning signals, further analysis is necessary to determine whether or not this represents an indication of a significant change in the ecosystem status associated with these strata or if it is simply an artefact of analytical method including potential biases in sample data (e.g. sample number and location).

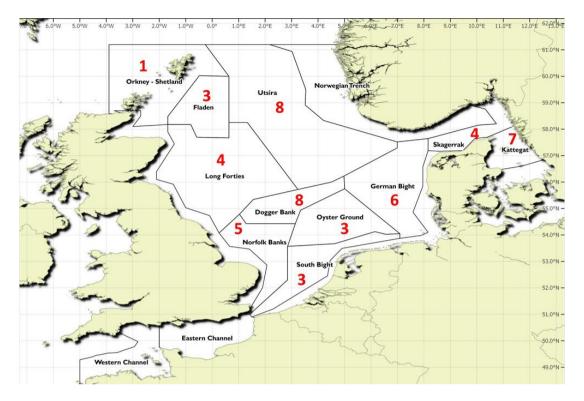
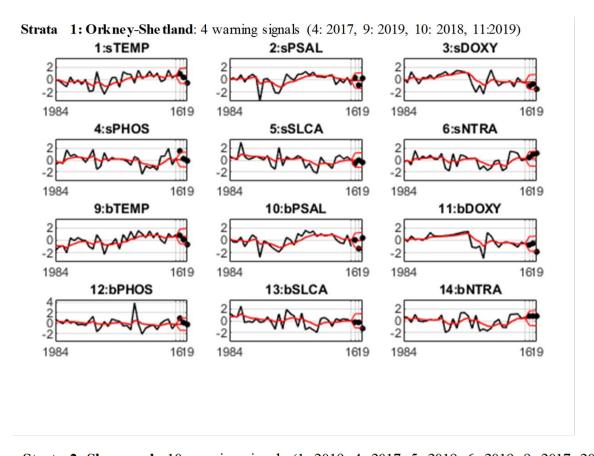


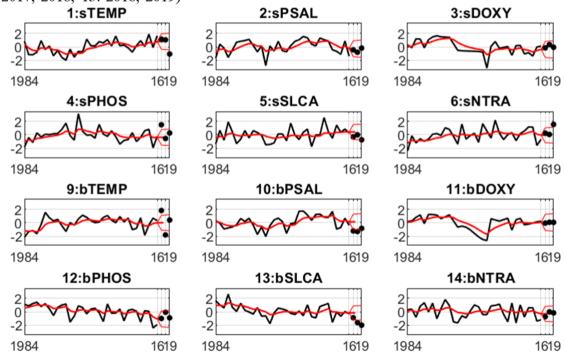
Figure 4 Total number of warning signals seen in recent three years from 2017 – 2019 for the CPUE catch data from the IBTS survey 1984 – 2019.

3.2.2 Warning signal analysis for oceanographic time-series

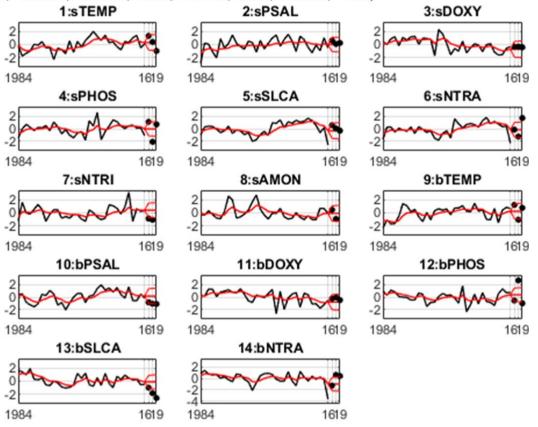
In the following, the estimated trend and prediction with the forecast band in each strata for mean values of ICES oceanographic data from 1984 – 2019 are plotted with a red line for each strata. Real observations within the period 2017 – 2019 are plotted with black dots. Black/blue dots located inside/outside the forecast bands provide the statistical criteria to know the residuals between observation and predicted value by the trend model. The total number of warning signals in each area is presented in Figure 5.



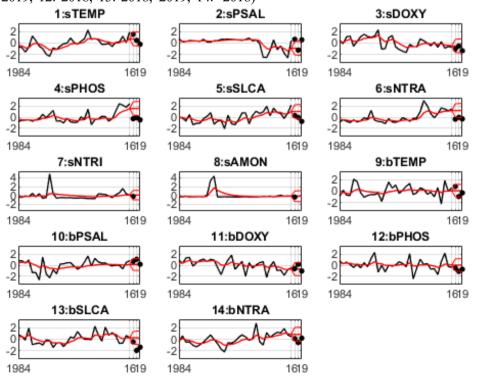
Strata 2: Skagerrak: 10 warning signals (1: 2019, 4: 2017, 5: 2019, 6: 2019, 9: 2017, 2018, 10: 2017, 2018, 13: 2018, 2019)



Strata 3: Kattegat: 14 warning signals (1: 2019, 4: 2017, 2018, 6: 2019, 7: 2017,2018, 9:2018, 10:2018, 12:2018, 2019, 13:2018, 2019, 14:2018, 2019)



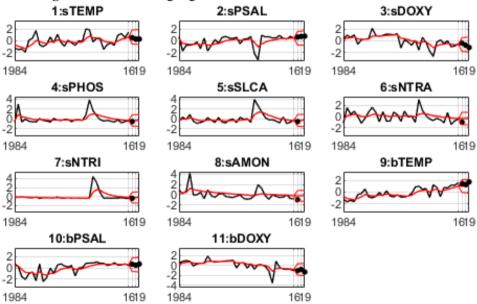
Strata 4: Fladen: 12 warning signals (2: 2017, 2019, 4: 2017, 2018, 2019, 5: 2019, 6: 2017, 2019, 12: 2018, 13: 2018, 2019, 14: 2018)



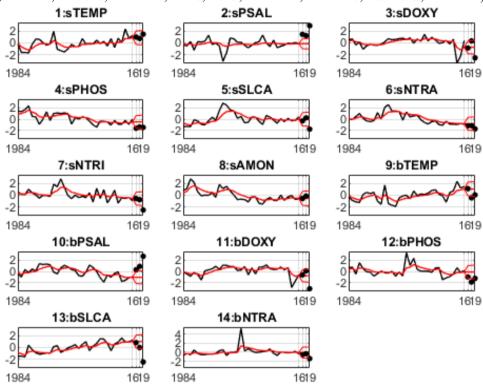
3:sDOXY 1:sTEMP 2:sPSAL -2V -2 4:sPHOS 5:sSLCA 6:sNTRA 2 0 -2 7:sNTRI 8:sAMON 9:bTEMP 0 -2 -2 10:bPSAL 12:bPHOS 11:bDOXY 0 -2 0 -2 13:bSLCA 14:bNTRA 0 -2

Strata 5: Utsira: 2 warning signals (3: 2019, 11: 2019)

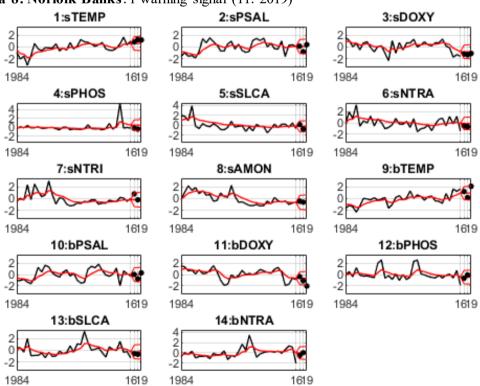
Strata 6: Long Forties: 0 warning signal

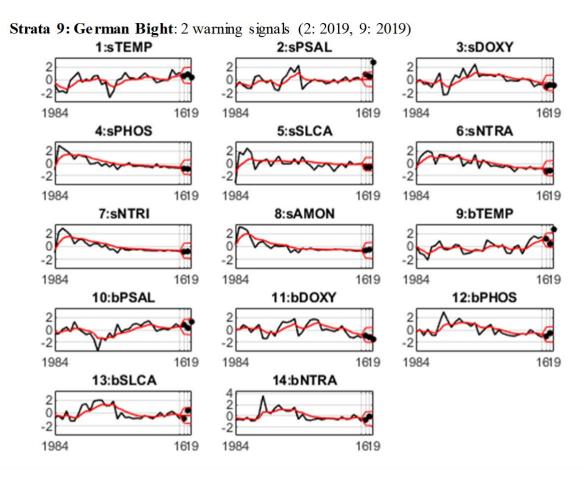


Strata 7: Dogger Bank: 15 warning signals (2: 2017, 2018, 2019, 3: 2019, 4: 2017, 5: 2019, 7: 2019, 9: 2018, 10: 2017, 2018, 2019, 11: 2019, 12: 2018, 13: 2019, 14: 2019)

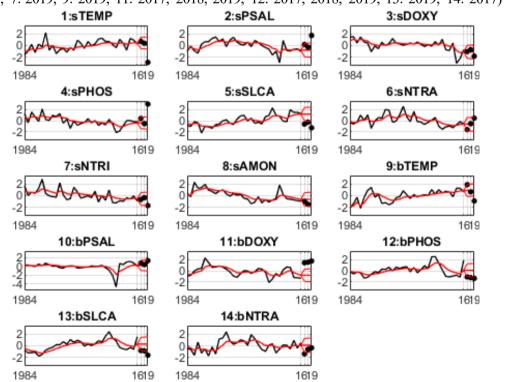


Strata 8: Norfolk Banks: 1 warning signal (11: 2019)

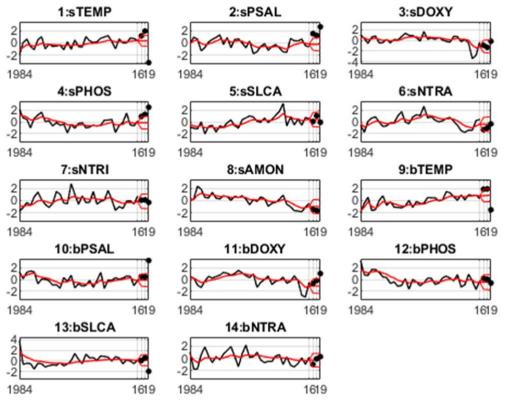




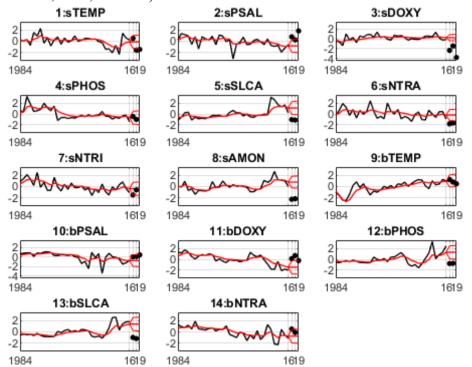
Strata 10: Oyster Ground: 15 warning signals (1: 2019, 2: 2019, 4: 2019, 5: 2017, 2018, 2019, 7: 2019, 9: 2019, 11: 2017, 2018, 2019, 12: 2017, 2018, 2019, 13: 2019, 14: 2017)

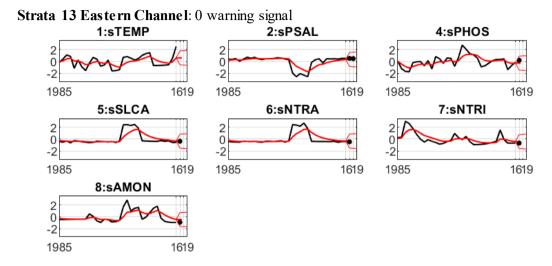


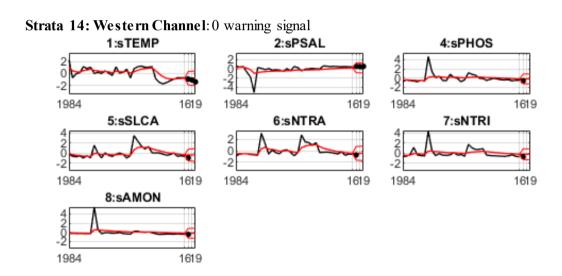
Strata 11: Southern Bight: 14 warning signals (1: 2018, 2019, 2: 2017, 2018, 2019, 4: 2017, 2018, 2019, 9: 2017, 2018, 2019, 10: 2019, 11: 2019, 13:2019)



Strata 12 Norwegian Trench: 20 warning signals (1: 2018, 2019, 2: 2017, 2019, 3: 2017, 2018, 2019, 5: 2017, 2018, 6: 2017, 2018, 8: 2017, 2018, 11: 2017, 2018, 12: 2017, 2018, 13: 2017, 2018, 14: 2017)







The number of warning signals was much higher for the oceanographic data (Figure 4) than for the CPUE data (Figure 3), most likely because more oceanographic variables (14) were evaluated compared to the CPUE (9 variables). The highest number of warning signals observed was in the Norw egian trench (20 warning signals), while both areas in the English channel and the Long Forties had no warning signals. The Utsira strata only had two warning signals, compared to the CPUE data where it had eight.

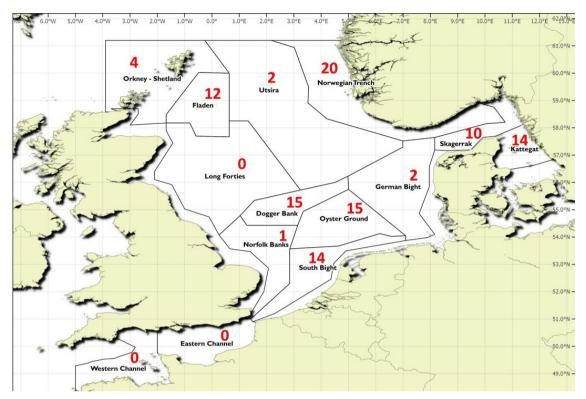


Figure 8b.

Figure 5 Total number of warning signals seen in recent three years from 2017 –2019 based on analysis of the ICES oceanographic data.

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4 ToR B: Identify and develop additional strata

The analysis of North Sea ecosystem monitoring data undertaken by ICES (2006) and subsequently by other Working Groups (e.g. European Commission JMP NS/CS group) highlights the importance of spatial gradients in system attributes (such as bathymetry, and sediment grain size) that define significant differences in the status of North Sea subregions at any one time. An important task that was addressed by the group between 2015 and 2019 was to agree a definitive set of subregional strata for subsequent trend analysis and ecosystem model development (see ToR D). In 2016 W GINOSE essentially used 4 strata which covered the ICES greater North Sea ecoregion, i. northern North Sea, ii. southern North Sea, iii. Skagerrak and Kattegat, and iv. the English Channel (Figure 4 A). These strata were identified on the basis of significant differences in water mass resident times and differences in bathymetry, but further analysis using ATLAN-TIS model outputs derived from the EU V ECTORS project (EU, 2015), revealed a number of additional strata of significance for North Sea fisheries ecology - based upon pelagic-benthic habitat biogeochemical properties (Figure 4 B).

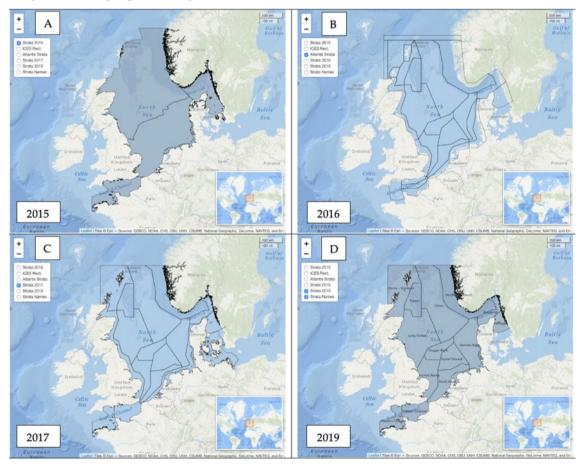


Figure 6. Evolution of ICES Greater North Sea Ecoregion subregional assessment strata as used by WGINOSE.

The ATLANTIS model boundaries were subsequently refined in 2017 (ICES, 2017) to produce 14 strata covering the whole of the greater North Sea ecoregion, with the inclusion of the Norwegian Trench and English Channel (Figure 4 C). The English Channel was further subdivided into the i. western Channel, and ii. eastern Channel (see Figure 4 C) on account of differences in seabed substrate type (see ToR C). Finally, in 2019 the strata representing the coastal margins of the North Sea (eastern UK, and the coast of Belgium, Netherlands, Germany and Denmark) were

removed to produce a final map as shown in Figure 4 D. The strata names were taken from existing maps of the North Sea, recognizing that certain historical place names defined areas very similar in location and extent to the WGINOSE defined strata based upon their unique habitat and physical characteristics, e.g. the Oyster Ground, Dogger Bank and Fladen Ground (Figure 5).

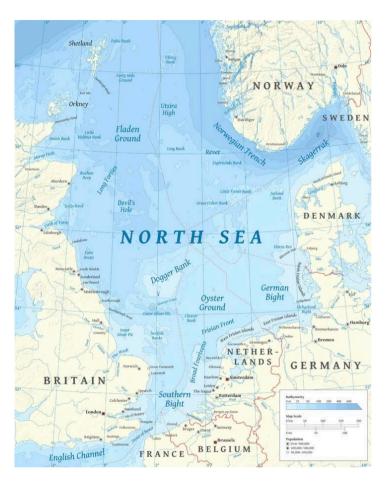


Figure 7. North Sea historical place names used to name WGINOSE assessment subregional strata.

https://commons.wikimedia.org/wiki/File:North Sea map-en.png

4.1 References

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5 ToR C: Data to operationalize the integration of human activity and pressure data

In order to perform holistic integrated ecosystem assessments, it is necessary to not only consider attributes of the natural environment, but also to take into account any relevant human activities and the socio-economic benefits derived from the 'natural' system include the human activities themselves. Accordingly, WGINOSE began in 2017 exploring other sources of data, in addition to fisheries and environmental data, describing a full range of human activities operating at the scale of the North Sea (ICES, 2017).

This work concluded in the production of a scientific paper "assessing cumulative human activities, pressures and impacts on North Sea benthic habitats using a biological traits approach" (Kenny at al., 2017) and the results subsequently contributed to the work of two ICES workshops on seabed disturbance (ICES; 2018, 2019). A summary of the study findings is presented below:

5.1 Bottom fishing sediment abrasion and seabed habitat impact

Seabed surface sediment abrasion caused by bottom fishing activities in the Northeast Atlantic was assessed by ICES (ICES, 2016). The fishing pressure dataset generated used fishing vessel positional monitoring system (VMS) data processed according to methods given by Lee *et al.* (2010), and combined with information on gear types generated by a European Union funded research project (Eigaard *et al.*, 2016). The data used covered a period between 2009 and 2015 to determine average swept-area ratios for 0.05 x 0.05-degree grid cells using the approach of C-square reference (Rees, 2003). Four bottom-contact gear types were assessed (beam trawlers, dredges, otter board trawlers, demersal seines) and aggregated to create a single surface abrasion data layer (Figure 6). These data were then combined with an assessment of seabed habitat sensitivity to sediment abrasion, derived from a combination of seabed habitat data (EUSeaMap¹) and biological traits analysis (Bolam, *et al.*, 2017), to generate a map of bottom trawling seabed habitat impact (Figure 7 A and B).

5.2 Sediment removal (Aggregate extraction)

Sediment removal was estimated by the extent of licensed marine aggregate (sand and gravel) extraction sites. Data were obtained from EMODnet² for non-UK licensed areas in the form of points indicating the central position of aggregate dredging sites. For the UK, actual licensed polygon areas were obtained from the Crown Estate³ and their overall average area calculated (12 km²). This value was then applied to point data for other (non-UK) aggregate extraction sites resulting in a 2 km radius polygon positioned around each point location (Figure 7 C).

¹ https://www.emodnet-seabedhabitats.eu accessed April 2020.

² https://www.emodnet.eu/emodnet-human-activities-portal accessed April 2020.

³ https://www.thecrownestate.co.uk/en-gb/resources/downloads/accessed April 2020.

5.3 Smothering (dredge material sediment disposal)

For sediment smothering, data on licensed sea disposal sites were obtained from EMODnet. These were a mix of point data and polygon areas. To estimate the footprint of those sites represented only by point data, the average area of the polygon data were calculated (e.g. $2.24 \, \mathrm{km^2}$). This was then used to calculate a radius ($0.84 \, \mathrm{km^2}$) to buffer the point data to achieve the same average polygon area of $2.24 \, \mathrm{km^2}$ (Figure 7 D).

5.4 Hard structures

Activity data related to offshore wind farms, wave and tidal energy, oil and gas activities were again obtained from a combination of the Crown Estate UK and EMODnet. Only operational sites were considered and given the point source nature of these activities their associated pressure 'footprints' were assigned a value of 1. To determine the pressure footprint of each turbine the polygons were divided into a lattice based on the number of turbines within each wind farm licensed block. The nodes of the lattice were then used as the approximate position of each individual turbine. The number of turbines was obtained from the 4C Offshore database (4C Offshore, 2020) and each estimated turbine location was then given a buffer of 15 m radius based on the methodology of Foden et al. (2011). No published estimates of wave or tidal energy devices pressure footprints were found, largely due to the contemporary nature of the technologies, but also because there are wide differences in the design of the technologies employed. To account for this, the present study applied a conservative buffer of 50 m radius around each development data point. In addition, both oil and gas well-heads, and production platforms were considered. Abandoned wells were not included, as were platforms that have ceased operation and have been or are soon to be decommissioned. For these structures, a conservative 100 m buffer was placed around each point following the approach adopted by Goodsir and Koch (2015) (Figure 7 E).

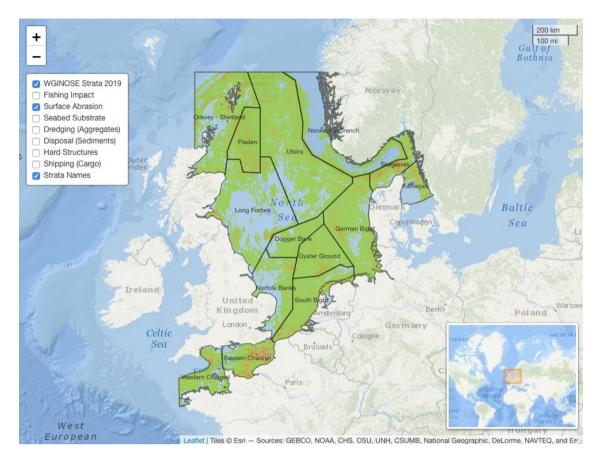


Figure 8. OSPAR seabed surface abrasion layer derived from bottom trawl gear types and SAR analysis of fishing effort (VMS) data in 2017.

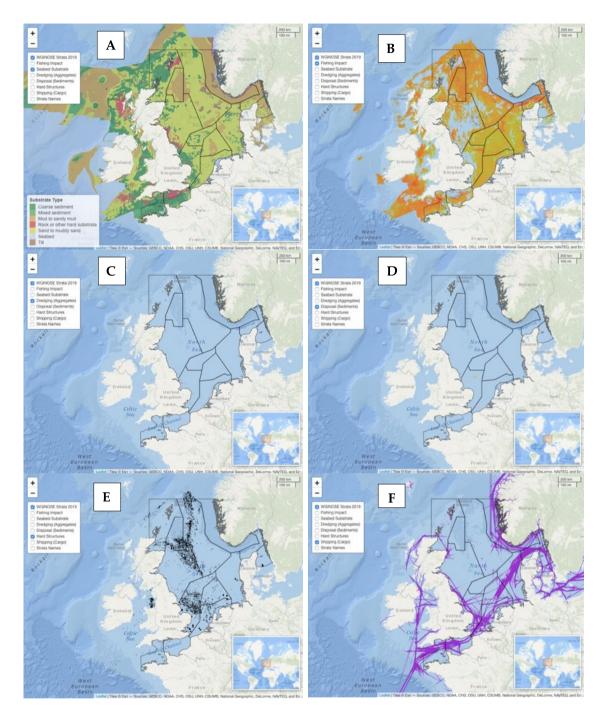


Figure 9 ICES Greater North Sea Ecoregion seabed substrate types (A), bottom fishing impact (B), and maps of human activity pressure footprints; aggregate extraction (C), dredge material disposal (D), placement of hard structures (E) and cargo-shipping routes (F).

5.5 Shipping (Cargo)

Shipping vessel density data were obtained EMODNet human activities data portal⁴. Data are collected from Automatic Identification System (AIS) receivers that track and transmit the location of the ships' on-board transponders. Traffic density records 13 different vessel types on a monthly basis from 2017. In the present study only cargo vessel density was downloaded so as

⁴ https://www.emodnet-humanactivities.eu/view-data.php accessed April 2020.

to identify the main cargo shipping routes and areas. Density is expressed as the average number of hours spent by ships in a square kilometre over a year, in this case 2019. Figure 7 F, shows areas which have in excess of 100 hrs of cargo shipping traffic per Km² per year in 2019.

5.6 Assessing the seabed area and frequency of impact by each activity

For each of the North Sea strata an estimate of the proportion of the area occupied by each activity and pressure was determined (Table 6.). This information was used to assist with the prioritization of strata to be further investigated through the development of conceptual models (see ToR D). The analysis of overlap between activities and strata revealed that the southern Bight of the North Sea is subject to the greatest level of human activity with an estimated 127% of the strata area occupied by a range of activities, suggesting that activities overlap or operate in very close proximity to each other. By contrast it can be seen that shipping is almost exclusively the single most important pressure associated with the Norwegian Trench, followed by fishing. Overall the southern North Sea strata are subject to the greatest pressure with the top five strata, in terms of percentage activity (>100%), all being southern North Sea strata. The southern Bight was subject to a stakeholder engagement workshop to develop a conceptual model in 2018, followed by Skagerrak with a stakeholder workshop convened in 2019 (see ToR D).

An analysis of the overall pressure footprint area, for each activity, reveals unsurprisingly, that bottom fishing (dominated by trawling activities associated with otter and beam trawls) occupies the greatest surface area of the North Sea (Table 7). However, as the swept-area ratio (SAR) is based on the theoretical maximum area of abrasion using vessel speed and gear width, and a swept-area ratio of < 1 effectively results in a very low probability of the same area of seabed being impacted more than once per year, it essentially represents the full areal extent of fishing activity. It is therefore assumed, in the current assessment, that a swept-area ratio >10 is sufficiently intense to ensure that a given area of seabed will be subject to a disturbance of at least once per year, and mostly likely many times more. Estimating the area of seabed disturbance at different levels of SAR results in very different areal extents of seabed fishing disturbance. For example, it can be from Table 6 that using a SAR value > 0 results in about two thirds of the Greater North Sea seabed being subject to fished pressure (but most areas will not be fished more than once and indeed may not be fished at all), whereas using a SAR of > 10 results in a about 1 percent of the North Sea area being subject to repeated fishing disturbance in a single year. Therefore, understanding the frequency of disturbance is especially important when determining the relative impacts on the seabed fauna, since even at fairly high levels of fishing effort (e.g. SAR = 1) the frequency of repeated impact at any one location is likely to be a lot less than the longevity of the longest living organisms present in the habitat subject to fishing disturbance. The same rational also applies to other human activities and pressures which have a dominant temporal trend..

5.7 Operational updates and links with other ICES WGs

Data on human activities accessed via the EMODNet data portal (dredging, disposal, hard structures) can be reviewed annually and where significant changes are noted in the number, distribution and extent of spatially static activities occurs, then new maps can be generated and any subsequent specific human activity metrics updated and incorporated into the relevant strata specific assessments. However, there are two human activity pressures layers which are likely to change significantly over time, e.g. fishing and shipping. For these activities it will be important to further explore the operational pathways for updating and integrating strata specific

pressure metrics. With respect to fishing activities the ICES WG on Spatial Fisheries Data (WGSFD) generates fishing pressure outputs that could become operational inputs to WGINOSE. To facilitate this pathway discussion with the Chairs of WGSFD was initiated at the WGCHAIRS meeting in 2020 with the expectation that a Recommendation would be prepared by WGINOSE in 2020 to develop operational links with WGSFD from 2021. Shipping is now being addressed by the newly established ICES WGSHIP and links with the cumulative effects assessment working group WGCEA should also be established as the analysis presented here is relevant.

Table 6 Spatial extent for different levels of SAR in the Greater North Sea Ecoregion.

Activity Pressure	% of Greater North Sea Ecoregion
Low Sediment Abrasion (fishing – SAR, >0)	66
Moderate Sediment Abrasion (fishing – SAR, >1)	27
High Sediment Abrasion (fishing – SAR, >10)	1

Table 7. Area occupied by different human activities in the Greater North Sea Ecoregion Strata.

WGINOSE Strata 2019	Shipping Cargo Km² (> 100 hrs/Km²/year) ⁵	Fishing Im- pact ⁶ Km ²	Disposal (dredge material) Km ²	Dredging (aggregate extraction) km²	Construction (hard structures) Km ²	Total Activity Km²	Strata Km²	% All Activi- ties/Strata Over- lap
Southern Bight	19,623 (14)	39872 (6)	33	916	9	60,453	47,696	127
Oyster Ground	9,919 (7)	35574 (5)	-	-	5	45,497	36,448	125
Skagerrak	8,848 (6)	12807 (2)	1	-	< 1	21,656	17,431	124
German Bight	21,864 (15)	54961 (8)	10	79	< 1	76,914	64,849	119
Norfolk Banks	16,601 (12)	31106 (5)	695	-	28	48,430	45,104	107
Eastern Channel	14,440 (10)	17863 (3)	65	410	< 1	32,778	33,320	98
Dogger Bank	411 (<1)	21700 (3)	-	-	3	22,113	22,837	97
Western Channel	8,230 (6)	25575 (4)	14	149	< 1	33,968	35,642	95
Fladen	60 (<1)	24095 (4)	-	-	15	24,170	25,770	94
Utsira	3,481 (2)	93102 (14)	-	-	45	96,627	111,870	86
Kattegat	5,861 (4)	6356 (1)	44	12	< 1	12,273	15,210	81
Orkney - Shetland	2,796 (2)	37643 (6)	11	-	5	40,456	64,106	63
Long Forties	6,499 (5)	48024 (7)	61	505	35	55,123	101,524	54
Norwegian Trench	23,255 (16)	230 (<1)	5	-	< 1	23,490	57,260	41
% Activity/North Sea Ecoregion Overlap	21	66	<1	<1	<1	-	-	-

 $^{^5}$ Values in parenthesis are hrs shipping per Km 2 per year as a percentage of total shipping hours in the Greater North Sea ecoregion

⁶ Values in parenthesis are Km² as a percentage of the total area of the Greater North Sea ecoregion

5.8 References

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6 ToR D: Strata specific decision support tools to support ecosystem management and advice

6.1 Strata specific decision support system: Mental models and Ecopath with Ecosim

In 2017 the group expanded its portfolio of tools to carry out IEAs and support scenario-based EBM through the development of qualitative ecosystem models at a regional level and linking those to existing quantitative ecosystem models for the same regions, where available. The qualitative ecosystem models were developed at four different regional meetings and workshops with a strong stakeholder participation, and in collaboration with WGMARS. Qualitative models are simple, intuitive, and quick to develop and have shown utility as scoping tools to create a common understanding of the system links and interactions. They allow for identifying the most important human pressure and interaction pathways that can be used to formulate scenarios for future ecosystem states and management that can be explored qualitatively, or fed into quantitative ecosystem models.

WGINOSE was guided and inspired in the development of a qualitative modelling approach by WGNARS who had spearheaded the adoption of qualitative models in IEA of the Western North Atlantic (DePiper *et al.*, 2017). In 2017 WGINOSE started exploring the use of the qualitative modelling tool 'mentalmodeler' (www.mentalmodeler.org, (Gray *et al.*, 2013)) to develop models for WGINOSE subregions. This modelling tool allows for the construction of simplified networks encompassing different components affecting each other in either a positive or negative way with a scaling going from – 1 (strong negative effect) to 1 (strong positive effect). Scenarios for future conditions where one or more model components are perturbated in a positive or negative direction can be evaluated in the modelling tool itself, or the interaction matrix of the model can be exported for analysis in R using the 'QPRESS' package for qualitative press perturbation scenarios of network models (Melbourne-Thomas *et al.*, 2012). Such scenarios could also be translated into quantitative scenarios that could be evaluated using quantitative ecosystem models such as Ecopath with Ecosim or Atlantis.

Our aim was to start developing qualitative models of the ecosystem and human activities, management actions and management objectives, using the 'mentalmodeler' tool for each of the 14 WGINOSE regions. Models and relevant future scenarios should be developed with stakeholder participation.

In the period 2017 – 2020 WGINOSE facilitated three stakeholder workshops to develop regional mental models:

- Southern North Sea (Dutch region): at joint WGMARS WGINOSE on management objectives and analysis for Integrated Ecosystem Assessments (Den Haag, 2018) see Figure 8;
- Norw egian Trench: a workshop hosted by the Institute of Marine Research with Norwegian fisheries managers and fishers (Bergen, 2018), see Figure 9;
- Kattegat: Workshop on Kattegat Ecosystem Modelling Scenarios with Stakeholder Participation (WKKEMSSP, Gothenburg, 2019), see Figure 10;
- In addition, the WGINOSE group itself developed a mental model for the Skagerrak region at the 2018 annual meeting, see Figure 11.

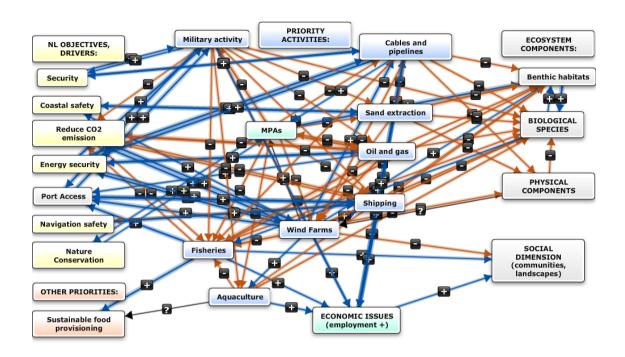


Figure 10 Qualitative model for the Southern North Sea (Dutch sector) developed using the 'mentalmodeler' tool at a workshop with Dutch stakeholders in 2018. Arrows between components show the positive (blue) or negative (red) interaction from one component to the other. Strengths of interactions are shown by the width of the arrows.

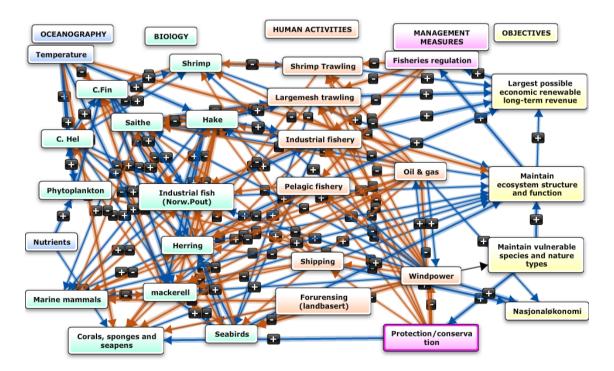


Figure 11 Qualitative model for the Norwegian Trench developed using the 'mentalmodeler' tool at a workshop with Norwegian stakeholders in 2019. Arrows between components show the positive (blue) or negative (red) interaction from one component to the other. Strengths of interactions are shown by the width of the arrows.

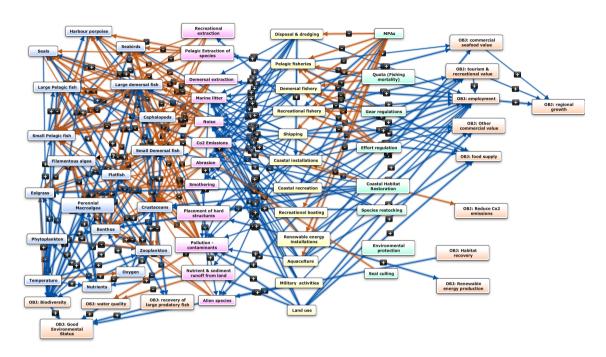


Figure 12 Qualitative model for the Kattegat developed using the 'mentalmodeler' tool at WKKEMSSP in 2019. Arrows between components show the positive (blue) or negative (red) interaction from one component to the other. Strengths of interactions are shown by the width of the arrows.

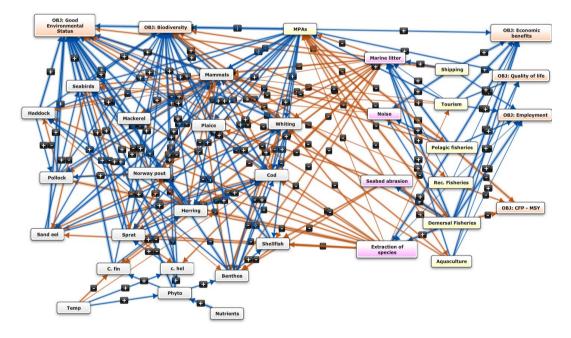


Figure 13 Qualitative model for the Skagerrak developed using the 'mentalmodeler' tool at WGINOSE 2018. Arrows between components show the positive (blue) or negative (red) interaction from one component to the other. Strengths of interactions are shown by the width of the arrows.

For each model a set of scenarios were developed and explored with the stakeholders using the 'mentalmodeler' tool. Further information on each of the four models and the scenarios can be found in the reports from WGINOSE 2018, WGINOSE 2019 and WKKEMSSSP 2019.

6.1.1 Experiences gained from developing mental models

Based on developing qualitative models with different stakeholder groups we can observe the following:

Models structure (i.e. w hich components are included and the linkages) is very dependent on w hat group of stakeholders are developing the model; e.g. the Southern North Sea model is very focused on activities and objectives, and very little on the biological system, w hile the Skagerrak model (developed by natural scientists) has a very detailed biological system with less details on the human activities;

- Ideally several groups of stakeholders should develop models for the same region independently, and then these models should be combined;
- The ease and simplicity of the tool is very positive for engaging stakeholders and building ownership to a description of the socio-economic system;
- It easily leads to building very complex models (e.g. the Kattegat model) where the linkages are difficult to see and follow;
- Running and interpreting scenarios becomes very difficult on very complex models;
- For running scenarios more refined (smaller models) should be developed based on the full (large) models, where components and links not affecting the scenario issue should be removed;
- Such a two-staged process keeps the initial full model in place for description and reference, while developing a more focused model better adapted to exploring the scenario topic;
- For WGINOSE it is of interest that there is enough commonality in the components and structure of the regional models to allow for inter-region comparisons. A minimum common structure should be developed to be used by facilitators at future model development workshops to ensure comparability.

6.1.2 Model scenarios for quantitative analysis comparing mental models with Ecopath with Ecosim

A set of common scenarios were developed for the four models, but due to different structures of the four models and different components these were limited to:

- Fishing (all);
- Shipping;
- Marine Protection.

We wanted to explore how the ecosystems responded to changing (increasing) these components, both in the mental models developed, and using available quantitative ecosystem models for the Kattegat (Niiranen *et al.*, 2012) and North Sea (ICES 2016). These Ew E models only have fishing included as a human activity, so the scenarios explored using both mental models and the two Ew E models were:

- Decreasing fishing (no fishing and -50% fishing);
- Increasing fishing (+25% and +75%).

For the Kattegat we also explored increasing the seal population biomass (by 2X and 10X).

These comparisons of common scenarios will form the basis of a paper under development by WGINOSE with the working title: "Future scenarios for the North Sea explored using qualitative and quantitative models".

6.1.3 Scenario analysis using QPRESS on mental models

Mental model interaction matrices were imported to QPRESS and 10 simulations were run for each model. With each simulation the components fisheries and marine mammals were perturbed and results explored using the plots showing the response of each model component to the perturbation (See Figure 12, Figure 13 and Figure 14).

In the fishery scenario we increased and decreased demersal fisheries (in the southern North Sea 'fishery' as this model did not have fishing split pelagic and demersal).

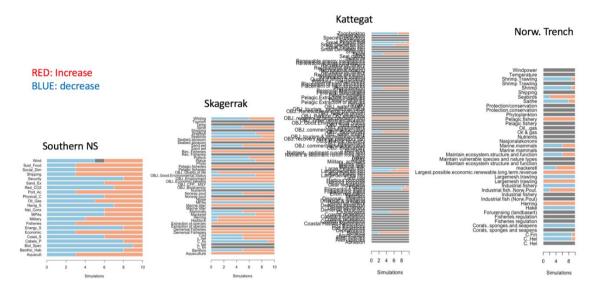


Figure 14 Increased fishing scenario explored on four mental models using the QPRESS analysis tool.

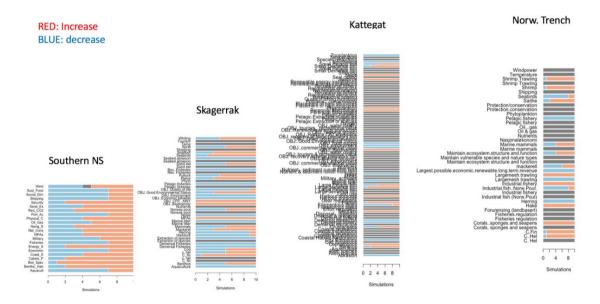


Figure 15 Decreased fishing scenario explored on four mental models using the QPRESS analysis tool.

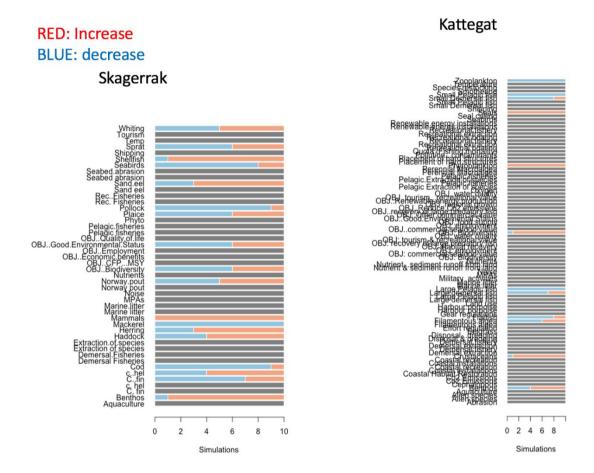


Figure 16 Increased marine mammal (seals) scenario explored on mental models for the Skagerrak and Kattegat using the QPRESS analysis tool.

The fisheries and marine mammal scenarios were then run on the Kattegat Ew E model with a constant forcing function (Figure 15 and Figure 16).

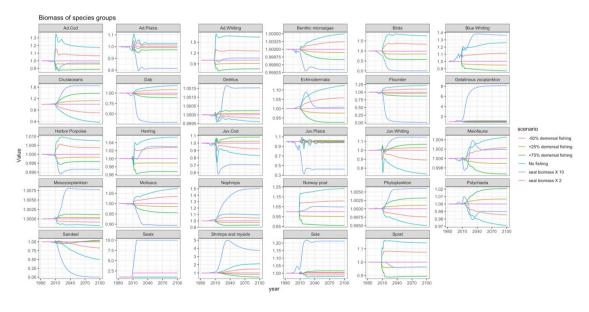


Figure 17 Changes in biomass over time normalized to the baseline run for all species groups in the Kattegat EwE model for scenarios for increased and decreased fishing, and increasing seal populations.

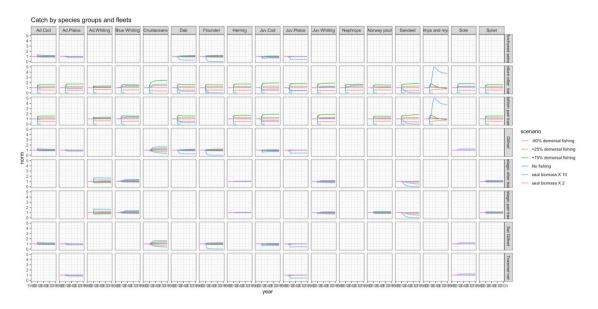


Figure 18 Changes in fisheries catches by fleet and species group in catch over time normalized to the baseline in the Kattegat EwE model for scenarios for increased and decreased fishing, and increasing seal populations.

Overall, the responses of the biological ecosystem components to the scenarios were similar for both the mental model (Figure 12-13) and the Ew E model (Figure 15). There were, however, differences in the responses of zooplankton to the increased seal population scenario where the mental model showed a decline while the Ew E model showed an increase. Such differences are possibly a result of differences in the trophic structure (links) of the biological system of the model. As the Ew E model structure is based on best available biological knowledge the mental model biological subsystem should be updated to reflect the trophic structure of the published Ew E (and other relevant ecosystem models).

It was also discussed whether a 10X increase in seal population was a realistic scenario, and this would be evaluated before including in the manuscript.

The mental model did not show any responses of the fishery components, something we attribute to the overly complex model structure, illustrating the need to refine such mental models prior to running scenarios to make them fit to answer the management question asked.

6.1.4 Further development of modelling approaches for IEA in the North Sea

The developments of regional qualitative models of the socio-economic system and linking them to quantitative ecosystem models such as EwEshows great promise. WGINOSE aims to continue this development in the coming period focusing on the following:

- Develop regional mental models for all 14 subregions, learning from the experiences from developing the first four;
- Update the existing four models with trophic networks matching published ecosystem models / trophic networks for the regions;
- Analyse the mental model using network analysis techniques (such as 'igraph' package in r see example of the Southern North Sea network plotted in Figure 17 below);
- Define scenarios and management questions and use these together with the network analysis to refine to full mental models to ones fit to explore the scenarios;
- Explore scenarios for all models using available ecosystem models (such as EwE or Atlantis).

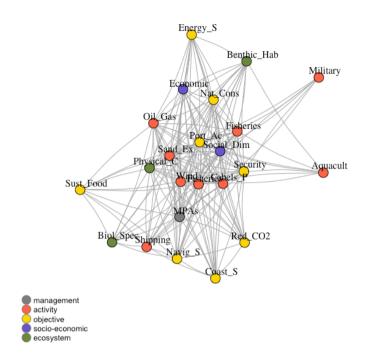


Figure 19 Mental model of the Southern North Sea plotted using the 'igraph' package in R.

6.1.5 References

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6.2 Risk-based cumulative effects assessment in OSPAR using BOW-Tie Analysis

When conducting cumulative effects type assessments, it is important to consider how the data and evidence are filtered and applied. The approach being applied in OSPAR follows a risk-based stepwise approach (Judd *et al.*, 2015), that clearly defines the purpose and scope of the assessment (problem formulation); the sources, pressures and environmental responses; the interactions between different pressures and environmental responses; the scale, risk and certainty; the significance and the management response (see also Stelzenmüller *et al.*, 2018). The risk assessment and management approach is implemented through the use of Bow Tie Analysis (an ISO supporting risk assessment standard (IEC/ISO 2009)) see also ICES 2014 for discussion on the potential use of bow tie analysis in cumulative effects assessment.

Achieving a full understanding of all ecosystem components and potential effects is a complex (if not impossible) undertaking. As such 'environmental indicators' are commonly used as a

proxy to describe discrete elements that are representative and indicative of the wider ecosystem and any changes arising from human induced pressures. Indicators consider change over time in certain features of the ecosystem. Achieving a desired environmental state requires understanding and management of the 'hazards' that might compromise that desired state. Environmental indicators are essential tools for tracking environmental progress, supporting policy evaluation and informing the public. To fulfil the requirements of the MSFDOSPAR has developed a suite of 'common indicators' which cover the Criteria and Indicators of the European Commission Decision (2010/477/EU), the Characteristics, Pressures and Impacts of Annex III of the MSFD (as amended) and the targets and associated indicators of Art. 10 of the MSFD. The cumulative effects assessment in OSPAR for the Quality Status Report 2023 is based on Bow Tie Analysis of this suite of OSPAR indicators (see https://oap.ospar-assessments/intermediate-assessment-2017/chapter-6-ecosystem-assessment-outlook-developing-approach-cumul/).

A Bow Tie contains several components as illustrated in Figure 18. The definitions for these components are crucial for its proper use as a risk management method (ICES, 2014). The components are:

- i. Hazard: Source of potential harm (Stelzenmüller *et al.*, 2018) e.g. driving a car, or carrying out a seismic survey. In this methodology the "hazard" is the relevant indicator which contains multiple threats and consequences;
- ii. Top Event: The undesired event that describes the loss of control over the hazard or the risk source (ICES, 2014);
- iii. Threats (or causes): Each threat represents a scenario that can lead to the top event. There may be multiple threats/causes that can independently bring about the top event. The threat or cause may occur at different temporal and spatial scales (Stelzenmüller et al., 2018);
- iv. Consequences: Potential harmful effects that may occur as a result of the top event. A top event can lead to multiple consequences (ICES, 2014);
- v. Barriers: There are two types of barriers in a Bow Tie: preventative (on the left of the Bow Tie) and mitigation and recovery controls (on the right of the Bow Tie). The preventative controls reduce the likelihood of the top event occurring. The mitigative and recovery controls reduce the repercussions or severity of the consequences (ICES, 2014). Barriers can be inserted to act on all possible links between the threats, top event and potential consequences. The position of the barriers can be considered as follows:
 - The first set of barriers are placed between the threat and the top event (the knot of the bow tie). These barriers are aimed at preventing the threat from causing the top event by eliminating, avoiding or controlling the causes (e.g. reduce the likelihood of a hazard such as a change in state of the ecosystem). These 'barriers' are often referred to as preventive controls;
 - The second set of controls are placed between the top event and the consequences. These are aimed at providing mitigation or recovery from the consequences resulting from the top event (e.g. reduce the magnitude or severity of the impacts on ecosystem structure or function or to ecosystem services). These 'barriers' are often referred to as mitigation or recovery controls.

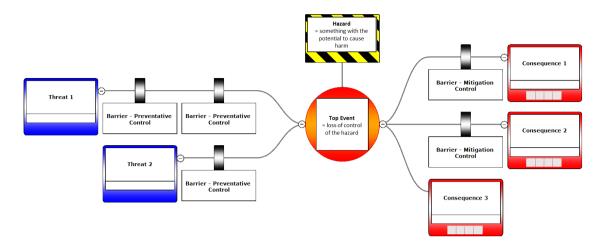


Figure 20 Bow Tie Approach showing the undesired top event, threats and consequences. Barriers that aim to prevent the threats or mitigate the consequence have been added.

6.2.1 Application of Bow-Tie (BTA) approach in the context of strata specific IEAs in the southern North Sea

To explore the potential application and comparability of the two conceptual modelling approaches (BTA and MentalModler) a joint WGMARS-WGINOSE workshop on "management objectives and analysis for Integrated Ecosystem Assessments" was convened on 22 February 2018 at Wageningen Economic Research in The Hague, The Netherlands. Members of ICES WGMARS, WGINOSE and stakeholders attended the workshop, including the chairs of both WGMARS and WGINOSE. At this still relatively early stage of interdisciplinary IEAs for the North Sea, the workshop targeted interested North Sea stakeholders from management bodies only, rather than to take a broader, cross-sectoral audience of marine/maritime practitioners. Accordingly, stakeholders came primarily from Rijkswaterstaat, which is the Dutch national body responsible for roads, waterways, and water systems and part of the Ministry of Infrastructure and Water Management. A list of attendees is provided in Annex 1.

There were three, interrelated goals for the workshop: 1) To further the understanding of the important management questions for Dutch government stakeholders (representatives of management authorities); 2) to explore the use of two conceptual modelling approaches (tools) that may be used to facilitate a truly interdisciplinary approach to integrated ecosystem assessments; and 3) to discuss the models usefulness with both stakeholders and working group members. Because the workshop conveners sought to capture the knowledge and frank assessments of the stakeholders, the workshop was conducted under "Chatham House rules", e.g. stakeholders were advised that comments would not be attributed to any particular speaker.

6.2.2 Bow Tie Analysis

Bow Tie Analysis is intended to "untangle cumulative effects". It starts by identifying a top event, and then, identifying "threats" to (displayed on the left) and consequences (displayed on the right) of the top event (Figure 19). "Escalators" can be added with respect to threats, and "barriers" that affect consequences can also be added. In this way, the factors affecting and affected by top events and associated activities can be followed in detail. The mapping of individual "top events" can be subsequently connected via variables/factors that different "top events" have in common.

The Bow Tie workshop session began with two "top events" as the starting point for the discussion: (1) meeting the offshore wind energy target for Energy security, and (2) meeting the MPA target for nature conservation. Since top events in Bow Tie Analysis are described as hazards that one wants to prevent, the phrasing in the Bow Tie is negative, i.e. NOT meeting the target. Stakeholders actively worked to identify threats and consequences relating to these two top events. The discussion about energy security covered wide variety of issues around offshore wind farms, such as the length of the licensing process, noise levels from construction and whether wind farms can work to protect the sea floor. It was quickly noted that limits set, for example, for underwater noise were social constructs. The discussion on the creation of MPAs revealed the complexity of the task: the success of MPAs depends on who creates them for what reason. One of the complexities being that species are often distributed in different areas at different life stages.

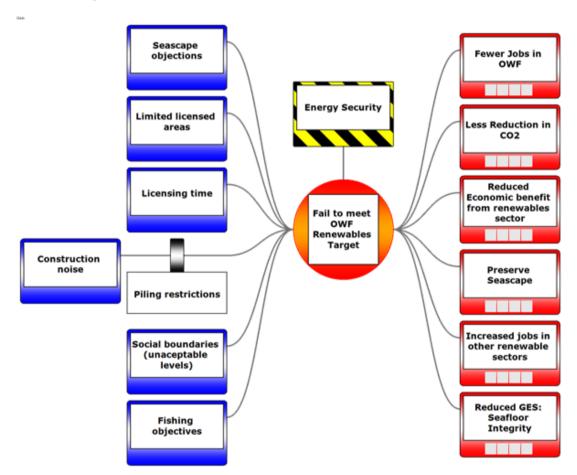


Figure 21 Bow Tie» created in workshop with Dutch government stakeholders. "OWF" refers to "Offshore Wind Farm""Threats" are found to the left of the model, consequences to the right.

6.2.3 Conclusions

Stakeholders engaged actively throughout the workshop, suggesting and jointly discussing potential components and interactions between them for building the conceptual models. They gained an appreciation for how the two models worked, how WGINOSE proposed to use these and how they might use them themselves.

Both tools (Mental Modeler and Bow Tie Analysis) were considered very useful in particular for the visual representation aspect of conceptual models, as they help to organize and create an

overview of the more - and less important components /drivers in the system from the stakeholder perspective. Both tools are considered attractive for communication with stakeholders, in particular using them in a "screening exercise" or for assessing consequences of scenarios. Conceptual models are useful to provide insights into connections (between model nodes/ecosystem components) that may not have been identified before and help the different stakeholders to understand how to proceed in further analysis. If carried out systematically, a participatory process of building a conceptual model is a useful scientific method/tool from the social sciences to systematically gather perceptions, information, knowledge, etc. If the links/interactions between the model nodes/components that are created can be 'backed up' by scientifically established facts (i.e. triangulation of information/data), conceptual models become even useful as assessment products/. The stakeholders pointed out that the final "picture" of a participatory conceptual model building process should rather not be used as a communication tool on its own, since the communication value lies in the participatory process of building the model together, and not in presenting the final outcome.

The scientific depth of a conceptual model certainly depends on the time limit for developing it, as well as on the expertise present in the group developing the model. Outcomes of conceptual models are useful in identifying areas for further analysis, e.g. more in-depth (quantitative) modelling and the process of building conceptual models was considered useful in facilitating the discussion between, and integration across, multiple disciplinary and sectoral (or departmental – within government) viewpoints. They can also help to identify available management options, thus helping in scenario development and for assessing consequences of scenarios. Identifying model components, interactions between the "nodes," and their directions and strengths for different management options (scenarios) can help both scientists and stakeholders to visualize the potential consequences of the different scenario choices, i.e. trade-offs.

Stakeholders appreciated the fact that the Mental Modeler software does allow for characterizing the degree of certainty about the relationships it captures. However, this can lead to too much focus on the existence of quantifiable data at the expense of relative relationships and possibly the downgrading of qualitative data.

It was noted that in the Dutch context, a small country with many stakeholders who meet each other regularly, application of conceptual modelling tools (as applied in this context) was not seen as necessary in most cases. However, at the regional level or in meetings with new stakeholders (for instance relative new departments due to restructuring of government) it was seen as a useful approach.

Finally, it was concluded that the actual process of identifying the "top-event" related to a policy objective and the process of building the network of causal links in the mental model with stakeholders is very important. The process itself is especially important in facilitating a better understanding of the potential trade-offs between different policy objectives and management advice to sustain ecosystem goods and services.

6.2.4 References

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6.3 Regional workshop of Kattegat ecosystem modelling scenarios with stakeholder participation (WKKEMSSP)

In 2019 WGINOSE or ganized a workshop, WKKEMSSP⁷ to scope out for key ecosystem interactions and future modelling scenarios for human use that are most relevant to stakeholders and managers in the Kattegat. Specifically, WKKEMSSP addressed the following aspect:

a) Contribute to developing strata specific decision support tools (WGINOSE ToR d) by developing and exploring scenarios for future conditions and human use of the Kattegat sea area using the Mentalmodeller tool, a scoping tool that allows transparent stakeholder participation in identifying key links between the natural ecosystem, pressures, human activities and management objectives.

The Kattegat mental model was developed through the following stepwise process:

- 1. Identify key management objectives for the region
- 2. Identify key human activities and linking these to the objectives
- 3. Identify pressures stemming from the human activities and linking these to the activities
- 4. Identify management actions relevant to the objectives and human activities and linking these to the activities
- 5. Identify the ecosystem components (biological and physical) and linking these to the pressures and objectives

Five future scenarios were developed at the very end of the meeting and briefly discussed:

- 1. Increase MPAs
- 2. Increase demersal fishery
- 3. Decrease pelagic fishery
- 4. Increase recreational fishery
- 5. Increase habitat restoration

The outcome of WKKEMSSP have been considered for WGINOSE 2020 Tord,

Were the Kattegat mental model was used to scope main issues and interactions between ecosystem components, and to define scenarios for future use that were quantitatively explored using the Ecopath with Ecosim (Ew E) model for Kattegat. A comparative analysis of model results is presented in this report.

https://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/IEASG/2019/WKKEMSSP%20report%202019.pdf

7 ToR E: Coordination and integration of strata specific assessments with IBTSWG

One of the main data sources for WGINOSE trend analysis are the catch data from the two yearly IBTS surveys. These surveys only cover parts of the shallower parts of the wester, southern North sea and Skagerrak / Kattegat, but excluding the Norwegian Trench area as this is deeper than the 250 m depth limit set for the IBTS surveys. WGINOSE therefore formulated a request to IBTSWG in 2018 to:

"WGINOSE recommends to IBTSWG to evaluate how an expansion of the IBTS Q3 survey into the Norwegian Trench could be designed, and what this requires in extra survey time. Evaluation of experimental trawl in hauls in the trench area in 2018 should form a basis for this."

IBTS responded to this request in their 2019 report, highlighting that Norway had undertaken experimental tows in deeper waters along the slope of the Norwegian Trench during the Q32018 and Q1 2019 surveys (four tows during each survey). Sweden had also had an intention to carry out similar deep hauls during the IBTS survey, but were limited due to shortage of survey time. Sweden had however carried out 20 deep hauls (250-485 m) in October as part of a national groundfish survey (see Figure 1 for the position of the deep hauls in 2018 and 2019.

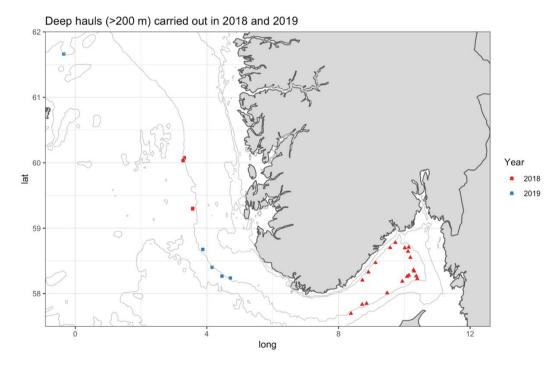


Figure 22 Position of deep hauls carried out by Norway during the IBTS Q3 survey in 2018 and Q1 survey in 2019, and by Sweden during their national groundfish survey in October 2018.

Norway continued to take some experimental deeper stations along the slope trench during the Q3 survey in 2019. No deeper stations were taken during the Q1 survey in 2020 due to bad weather limiting the survey for all participating nations leading to no time for additional experimental stations.

WGINOSE should continue requesting deeper stations in the Norwegian Trench from the IBTS WG.

Furthermore, WGINOSE should consider requesting that all benthos in the demersal trawlhauls during the IBTS is identified and measured / weighted. This would provide valuable data on the benthos community in the North Sea than can form the basis of a time-series to be used in the integrated trend analysis as well as linking to assessment of human impacts on seabed habitats. Before formulating a request to IBTSWG development of a benthos time-series for the North Sea should be discussed with key members of BEWG for guidance.

Annex 1: List of participants

List of participants 2020

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Virtual WGINOSE group photo from Thursday 7th May. (© Julie Krogh Hallin)

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Annex 2: Resolutions

WGINOSE - Working Group on Integrated Assessments of the North Sea

2016/MA2/SSGIEA04 A Working Group on North Sea Integrated Assessments (WGINOSE), chaired by Andrew Kenny, UK, and Erik Olsen, Norway, will work on ToRs and generate deliverables as listed in the Table below.

	MEETING DATES	VENUE	REPORTING DETAILS	COMMENTS (CHANGE IN CHAIR, ETC.)
Year 2017	March 13 - 17	Bergen, Norway	Interim report by 1 May to SSGIEA	
Year 2018	16-20 April	ICES HQ, Denmark	Interim report by 1 May IEASG	
Year 2019	20–24 May	Gothenburg, Sweden	No reporting	
Year 2020	4-8 May	by correspondence	Final report by 5 June to IEASG	

ToR descriptors

ToR	DESCRIPTION	BACKGROUND	SCIENCE PLAN CODES	Duration	EXPECTED DELIVERABLES
a	Update strata specific ecosystem trends analysis utilizing data from ICES Data Centre and other data sources, e.g. CPR, OSPAR, EEA and Member States.	a) Science Requirements b) Advisory Requirements c) Requirements from other EGs	1.3, 1.9, 6.5	Years 1, 2 & 3	Regional sea state trend analysis for inclusion in ecoregion overviews annually
b	Identify and develop additional strata and associated monitoring programmes for the inshore/coastal areas of the North Sea and the Norwegian Trench.	a) Science Requirements b) Advisory Requirements c) Requirements from other EGs	6.5	Years 1, 2 & 3	Regional sea state trend analysis for inclusion in ecoregion overviews annually
c	Establish data pathways and obtain data to operationalize the integration of human activity and pressure data, distinguishing between fixed structures (e.g. pipelines, windfarms) and ongoing activities (e.g. dredging, fishing, shipping, underwater noise, litter), accidents (emergency response).	a) Science Requirements	6.5, 6.6	Years 1, 2 & 3	Recommedations and actions giving rise to the ongoing improvement to flow of data between EWG, the ICES Data Centre and WGINOSE

d	Develop strata specific decision support tools to support ecosystem management and advice (e.g. BBNs and expert systems, ecosystem models, ecosystem goods and services modelling) in collaboration with end-users (OSPAR, DG-ENV, DG-MARE)	a) Science Requirements	6.1, 6.4, 6.6	Years 1, 2 & 3	Results which explore the balance and trade-offs between ecosystem protection and sustainable marine resource development
e	Contribute to the coordination and integration of strata specific assessments with the development of integrated ecosystem monitoring in the North Sea, e.g. redesign of the Q3 IBTS surveys.	a) Science Requirements b) Advisory Requirements c) Requirements from other EGs	3.2	Years 1, 2 & 3	Regional sea state trend analysis for inclusion in ecoregion overviews annually

Summary of the Work Plan

Year 1	THE FIRST YEAR WILL FOCUS ON COMPLETING THE ASSESSMENT OF NORTH SEASTRATA STRUCTURE AND FUNCTIONS ANALYSIS AS WELL AS PREPARING A DRAFT PAPER TO BE SUBMITTED IN A PEER REVIEW JOURNAL "APPROPRIATE SPATIAL SCALES FOR NORTH SEA INTEGRATED ECOSYSTEM ASSESSMENTS"
Year 2	Mapping of human activity pressures data at scales appropriate to asssessment strata in the North Sea, and to operationalize processes for updating the inclusion of such data on an annual basis
Year 3	Finalization of modelling approaches to support the provision of ecosystem based management advice.

Supporting information

Priority	The current activities of this Group will lead ICES into issues related to the development of Integrated Ecosystem Assessments for the North Sea (a data rich ecosystem) as a step to wards implementing the ICES Science Plan and the ecosystem approach, these activities are considered to have a very high priority.
Resource requirements	Assistance of the Secretariat in maintaining and exchanging information and data to potential partcipants, especially the services of the ICES Data Centre to generate data tables for analysis from selected variables held in the database.
Participants	The Group is normally attended by some 10–20 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	Relevant to the work of ACOM and SCICOM
Linkages to other committees or groups	There is a very close working relationship with all the groups of IEASG. It is also very relevant to the EWG identified in WGHAME 2013 report.
Linkages to other organizations	OSPAR, EU, NAFO, NEAFC

8 Annex 3: Trend analysis using TREC method

8.1.1 Outputs for two-categorical discriminates for DATRAS CPUE data for the central North Sea (excluding the Norwegian Trench and English Channel) from 1984 – 2019

Figure 2a. Outputs for two-categorical discriminates for DATRAS CPUE data for the central North Sea (excluding the Norwegian Trench and English Channel) from 1984 – 2019.

Abbreviations used in figures and tables are:

Strata 1: Orkney-Shetland

1: Clup	Clupea harengus,	Herring
2: Gadu	Gadus morhua	Cod
3: Mela	Melanogrammus aeglefinus	Haddock
4: Merl	Melangius merlangus	Whiting
5: Pleu	Pleuronectes platessa	Plaice
6: Poll	Pollachius virens	Saithe
7: Scom	Scomber scombrus	Mackerel
8: Spra	Sprattus sprattus	Sprat
9: Tris	Trisopterus esmarkii	Norw ay pout

The plots of trend estimate in upper left-hand side panel (black: standardized data; red: estimated trend by polynomial trend model) and dendrograms in upper right-hand side panel (red: upward; blue: flat; green: downward). The lower table summarizes variables classified into three groups in each are.

1:Clup 2:Gadu 3:Mela 9 8 0 0 0 7 6 4:Merl 5:Pleu 6:Poll 5 0 4 3 2 7:Scom 9:Tris 8:Spra 1

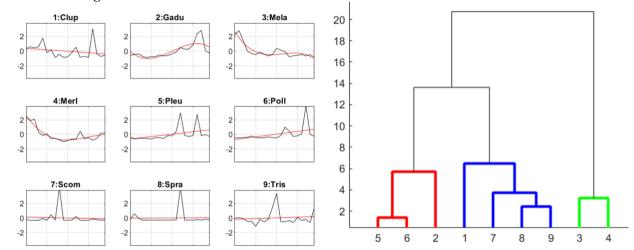
0

Common trend	Species
Upward	Cod, plaice and Norway pout (2,5,9)
Flat	Herring, saithe, mackerel, sprat (1, 6, 7, 8)

Downward

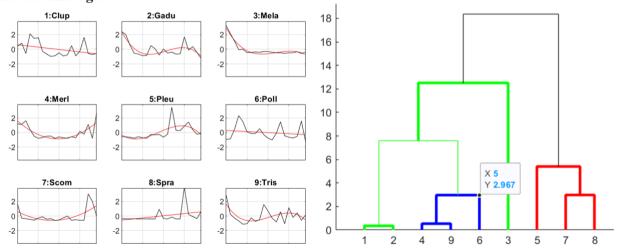
Haddock and whiting (3,4)

Strata 2: Skagerrak



Common trend	Species
Upward	Cod, plaice and saithe (2, 5, 6)
Flat	Herring, mackerel, sprat, Norway pout (1, 7, 8, 9)
Downward	Haddock and whiting (3,4)

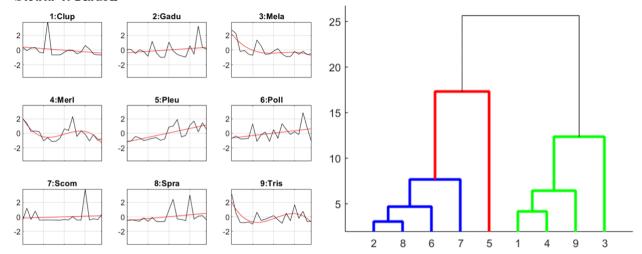
Strata 3: Kattegat



Common trend	Species
Upward	Plaice, mackerel and sprat (5, 7, 8)
Flat	Whiting, saithe and Norway pout (4, 6, 9)

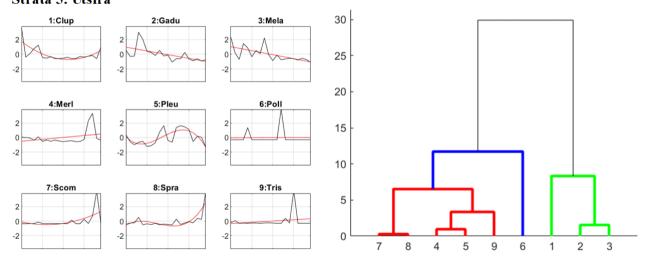
ICES

Strata 4: Fladen



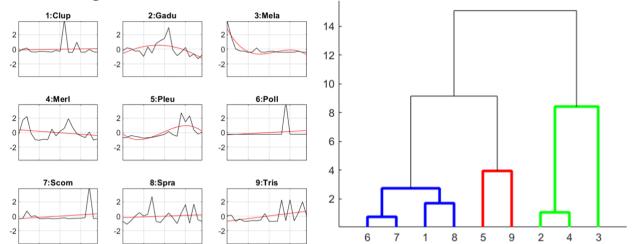
Common trend	Species
Upward	Plaice (5)
Flat	Cod, saithe, mackerel and sprat (2, 6, 7, 8)
Downward	Herring, haddock, whiting and Norway pout (1, 3, 4, 9)

Strata 5: Utsira



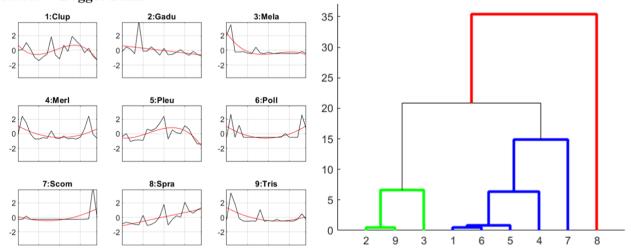
Common trend	Species
Upward	Whiting, plaice, mackerel, sprat and Norway pout (4, 5, 7, 8, 9)
Flat	Saithe (6)
Downward	Herring, cod and haddock (1, 2, 3)

Strata 6: Long Forties



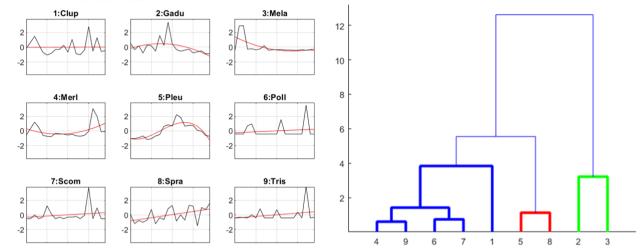
Common trend	Species
Upward	Plaice and Norway pout (5,9)
Flat	Herring, saithe, mackerel and sprat (1, 6, 7, 8)
Downward	Cod, haddock and whiting (2, 3, 4)

Strata 7: Dogger Bank



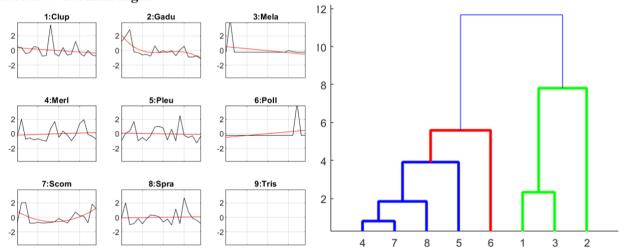
Common trend	Species
Upward	Sprat(8)
Flat	Herring, whiting, plaice, saithe. and mackerel $(1,4,5,6,7)$
Downward	Cod, haddock and Norway pout (2, 3, 9)

Strata 8: Norfolk Banks



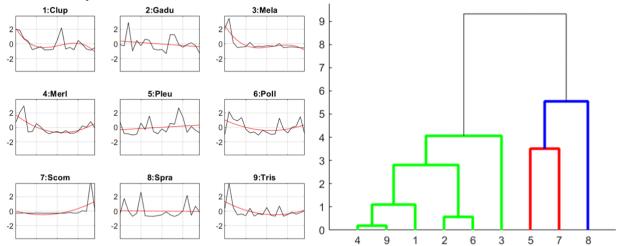
Common trend	Species
Upward	Plaice and sprat (5, 8)
Flat	Herring, whiting, saithe, mackerel and Norway pout $(1,4,6,7,9)$
Downward	Cod and haddock (2,3)

Strata 9: German Bight



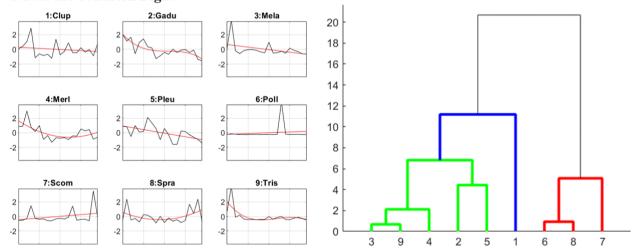
Common trend	Species
Upward	Saithe (6)
Flat	Whiting, plaice, mackerel and sprat (4, 5, 7, 8)
Downward	Herring, cod and haddock (1, 2, 3)

Strata 10: Oyster Ground



Common trend	Species
Upward	Plaice and mackerel (5,7)
Flat	Sprat(8)
Downward	Herring, cod, haddock, plaice, saithe and Norway pout (1, 2, 3, 5, 6, 9)

Strata 11: Southern Bight



Common trend	Variables
Upward	Saithe, mackerel and sprat (6, 7, 8)
Flat	Herring(1)
Downward	Cod, haddock whiting, plaice and Norway pout (2, 3, 4, 5, 9)

8.1.2 Outputs for two-categorical discriminates for IMR trawl data from the Norwegian Trench from 1984-2019

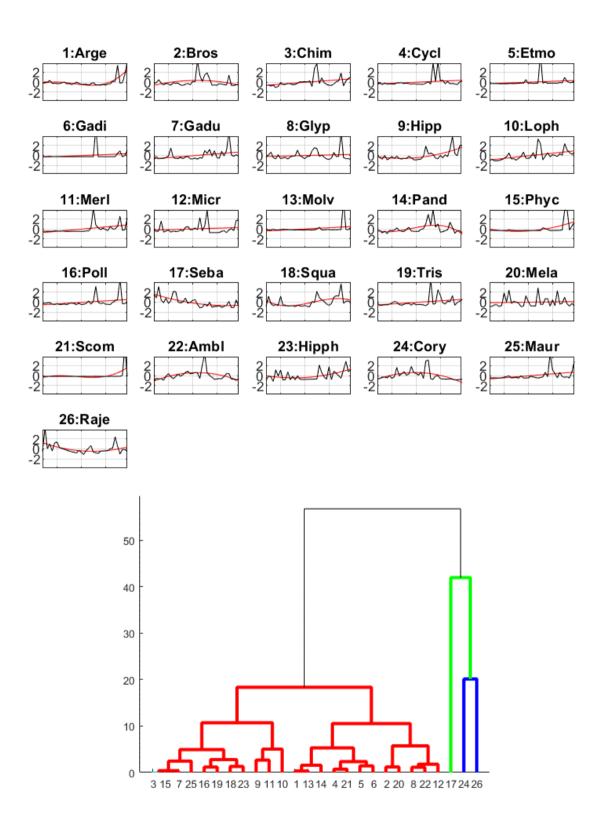
Abbreviations used in figures and tables are listed in

Table 8 Abbreviations of species names used in TREC analysis of Norwegian Trench data.

Abbreviation	Latin name	English name
1: Arge	Argentina silus	Greaterargentine
2: Bros	Brosme brosme	Cusk
3: Chim	Chimaera monstrosa	Chimera
4: Cycl	Cyclopterus lumpus	Lumpsucker
5: Etmo	Etmopterus spinax	Velvet belly lantemshark
6: Gadi	Gadiculus argenteus	Silvery pout
7: Gadu	Gadus morhua	Cod
8: Glyp	Glyptocephalus cynoglossus	Witch flounder
9: Hipp	Hippoglossoides platessoides	Long rough dab
10: Loph	Lophius piscatoriu	Monkfish
11: Merl	Merluccius merluccius	Whiting
12: Micr	Micromesistius poutassou	Blue whiting
13: Molv	Molva molva	Ling
14: Pand	Pandalus borealis	Deep watershrimp
15: Phyc	Phycis blennoides	Greaterforkbeard
16: Poll	Pollachius virens	Saithe
17: Seba	Sebastes viviparus	Spinyscorpionfish
18: Squa	Squalus acanthias	Spurdog
19: Tris	Trisopterus esmarkii	Norway pout
20: Mela	Melanogrammus aeglefinus	Haddock
21: Scom	Scomber scombrus	Mackerel
22: Ambl	Amblyraja radiata	Thorny ray
23: Hipph	Hippoglossus hippoglossus	Halibut
24: Cory	Coryphaenoides rupestris	Roundnose grenadier
25: Maur	Maurolicus muelleri	Pearlside

26: Raje Rajella lintea Sailray

The plots of trend estimate in upper left-hand side panel (black: standardized data; red: estimated trend by polynomial trend model) and dendrograms (red: upward; blue: flat; green: downward) in upper right-hand side panel. The lower table summarizes variables classified into three groups in each are.



Common trend Species

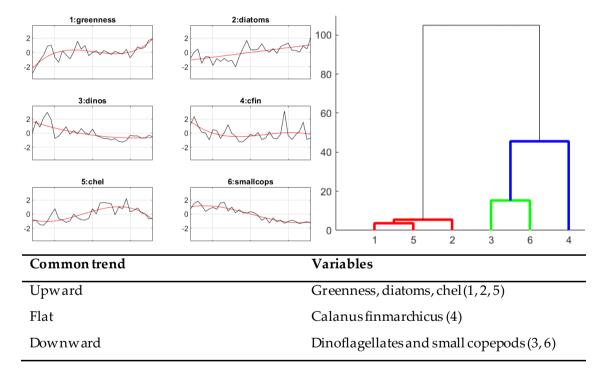
Upward

Greater argentine, cusk, chimera, lumpsucker, velvet belly, silvery pout, cod, witch, long rough dab, monkfish, whiting, blue whiting, ling, deepwater shrimp, greater forkbeard, saithe, spurdog, Norway pout, haddock, mackerel, thorny ray, halibut and pearlside (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20, 21, 22, 25)

Flat	Roundnose grenadier and sailray (24, 26)
Downward	Spiny Scorpionfish (17)

8.1.3 Outputs for two-categorical discriminates for plankton data for the North Sea from 1984-2019

The plots of trend estimate in upper left-hand side panel (black: standardized data; red: estimated trend by polynomial trend model) and dendrograms (red: upward; blue: flat; green: downward) in upper right-hand side panel. The lower table summarizes variables classified into three groups.



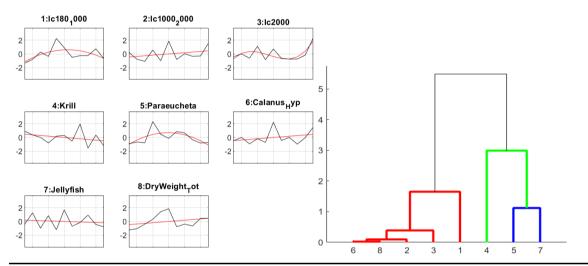
8.1.4 Outputs for two-categorical discriminates for Zooplankton data in the Norwegian Trench WGINOSE area (2009-2019). Numbering for the variable is that:

Table 9 Abbreviations used in figures and tables of Norwegian trench plankton data.

Abbreviation	Full variable name
1: lc180_1000	Mean of 180-1000 musize-fractions
2: lc1000_2000	Mean of 1000 – 2000 musize-fractions
3: lc2000	Mean of > 2000 mu size-fractions

4: Krill	Krill
5: Paraucheta	Pareucheta
6: Calanus Hyp	Calanus hyperboreus
7: Jellyfish	Jellyfish
8: DryWeight_Tot	Total dry weight of all fractions

The plots of trend estimate in upper left-hand side panel (black: standardized data; red: estimated trend by polynomial trend model) and dendrograms (red: upward; blue: flat; green: downward) in upper right-hand side panel. The lower table summarizes variables classified into three groups.



Common trend	Variables
Upward	180-100um fraction, 1000-2000um fraction, >2000um fraction, Calnus hyperboreus, and total dry weight (1, 2, 3, 6, 8)
Flat	Paraeucheta and jellyfish (5,7)
Downward	Krill (4)

8.1.5 Outputs for two-categorical discriminates for mean ICES Oceanographic data from all 14 WGINOSE subregions from 1984-2019

Table 10 Abbreviations used in figures and tables of the mean value oceanographic data.

Abbreviation	Oceanographic variable
1: sTEMP	surf.TEMP.mn
2: sPSAL	surf.PSAL.mn
3: sDOXY	surf.DOXY.umol.lmn
4: sPHOS	surf.PHOS.umol.lmn

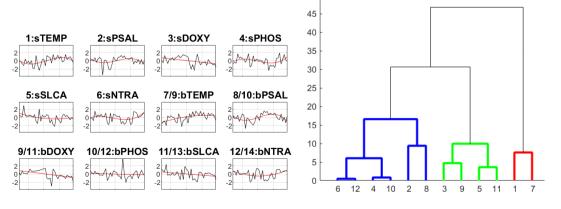
5: sSLCA	surf.SLCA.umol.lmn
6: sNTRA	surf.NTRA.umol.lmn
7: sNTRI	surf.NTRI.umol.lmn
8: sAMON	surf.AMON.umol.lmn
9: bTEMP	bot.TEMP.mn
10: bPSAL	bot.PSAL.mn
11: bDOXY	bot.DOXY.umol.lmn
12: bPHOS	bot.PHOS.umol.lmn
13: bSLCA	bot.SLCA.umol.lmn
14: bNTRA	bot.NTRA.umol.lmn

The data consisting of mean included several missing values. After interpolation and excluding over 30 % missing to all years, the data with the following conditions were analysed:

- Areas 1, 2, and 4: excluding sNTRI and sAMON
- Areas 3, 5, 7, 8, 9, 10, 11, and 12: using the period 1984 2018
- Area 6: excluding bDOXY, bPHOS, bSLCA, and bNTRA and using the period 1984 2018
- Area 13: including sTEMP, sPSAL, sPHOS, sSLCA and sNTRA, and using the period 1984 – 2018
- Area 14: including sTEMP, sPSAL, sPHOS, sSLCA and sNTRA, and using the period 1985 – 2017

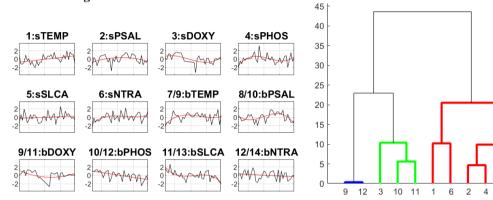
The plots of trend estimate in upper left-side panel (black: standardized data; red: estimated trend by polynomial trend model) and dendrograms in upper right-side panel. The lower table summarizes variables classified into three groups in each area.



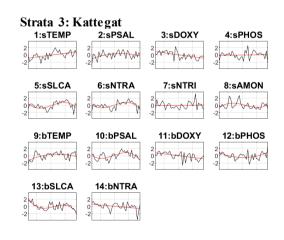


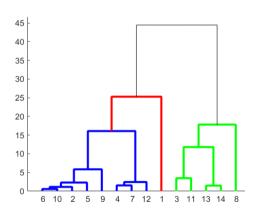
Common trend	Variables
Upward	1,7(9)
Flat	2, 4, 6, 8(10), 10(12), 12(14),
Downward	3, 5, 9(11), 11(13)

Strata 2: Skagerrak



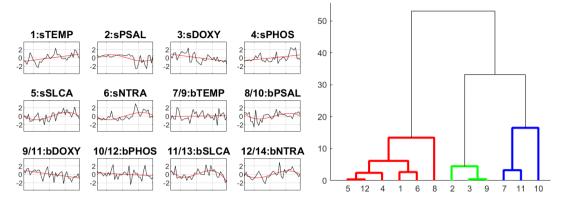
Common trend	Variables
Upward	1, 2, 4, 5, 6, 7(9), 8(10)
Flat	9(11), 12(14)
Downward	3, 10(12), 11(13)



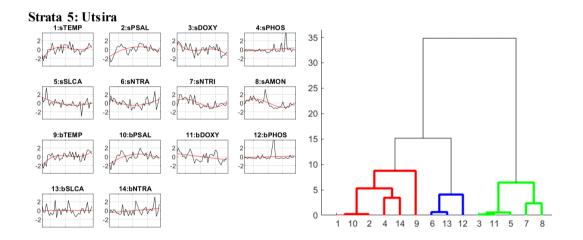


Common trend	Variables
Upward	1
Flat	2, 4, 5, 6, 7, 9, 10, 12
Downward	3, 8, 11, 13, 14

Strata 4: Fladen

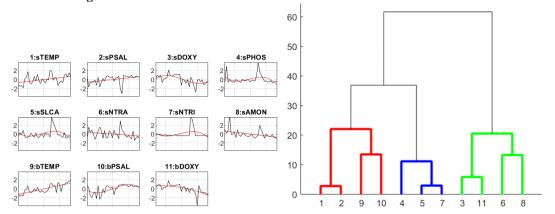


Common trend	Variables	
Upward	1, 4, 5, 6, 8(10), 12(14)	
Flat	7(9), 10(12), 11(13)	
Downward	2, 3, 9(11)	

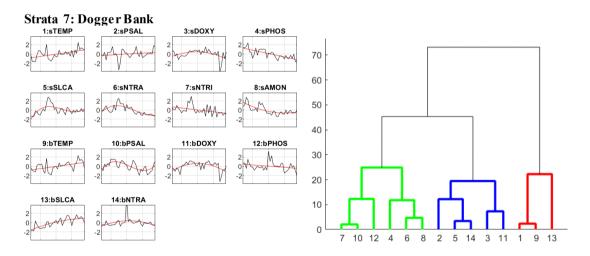


Common trend	Variables
Upward	1, 2, 4, 9, 10, 14
Flat	6, 12, 13
Downward	3, 5, 7, 8, 11

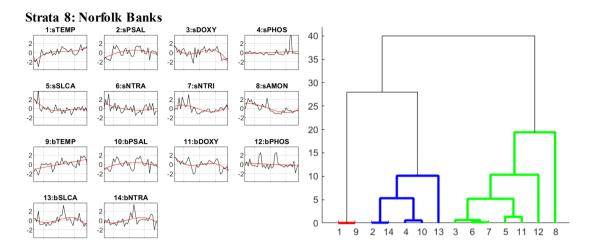
Strata 6: Long Forties:



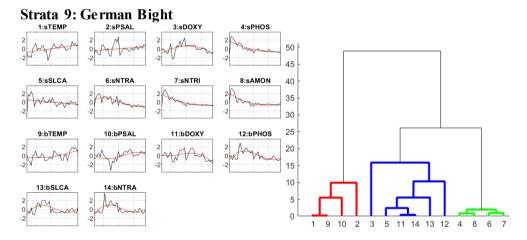
Common trend	Variables
Upward	1, 2, 9, 10
Flat	4,5,7
Downward	3, 6, 8, 11



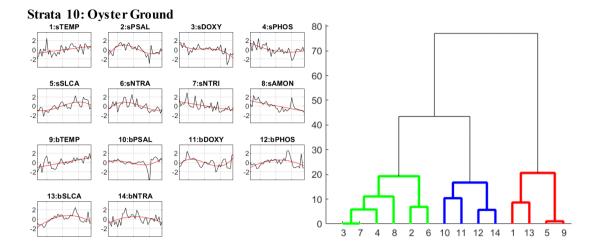
Common trend	Variables
Upward	1, 9, 13
Flat	2, 3, 5, 11, 14
Downward	4, 6, 7, 8, 10, 12



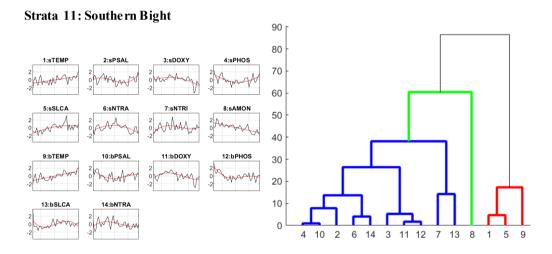
Common trend	Variables
Upward	1,9
Flat	2, 4, 10, 13, 14
Downward	3, 5, 6, 7, 8, 11, 12



Common trend	Variables
Upward	1, 2, 9, 10
Flat	3, 5, 11, 12, 13, 14
Downward	4, 8, 6, 7

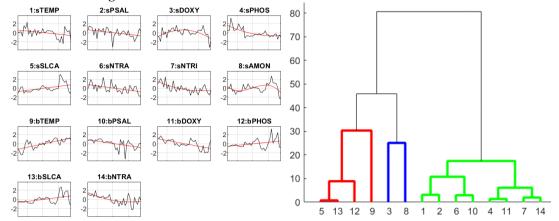


Common trend	Variables	
Upward	1, 5, 9, 13	
Flat	10,11,12,14	
Downward	2, 3, 4, 6, 7, 8	



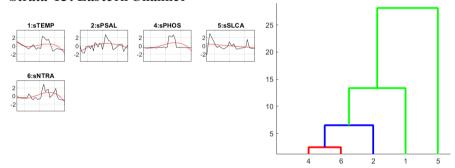
Common trend	Variables
Upward	1, 5, 9
Flat	2, 3, 4, 6, 7, 10, 11, 12, 14
Downward	8

Strata 12: Norwegian Trench



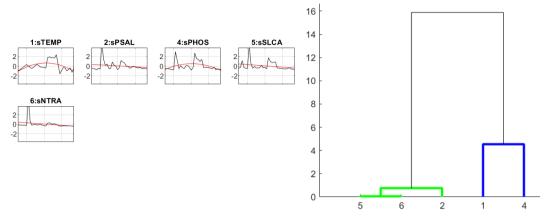
Common trend	Variables
Upward	5, 9, 12, 13
Flat	3,8
Downward	1, 2, 4, 6, 7, 10, 11, 14

Strata 13: Eastern Channel



Common trend	Variables	
Upward	4, 6	_
Flat	2	
Downward	1,5	

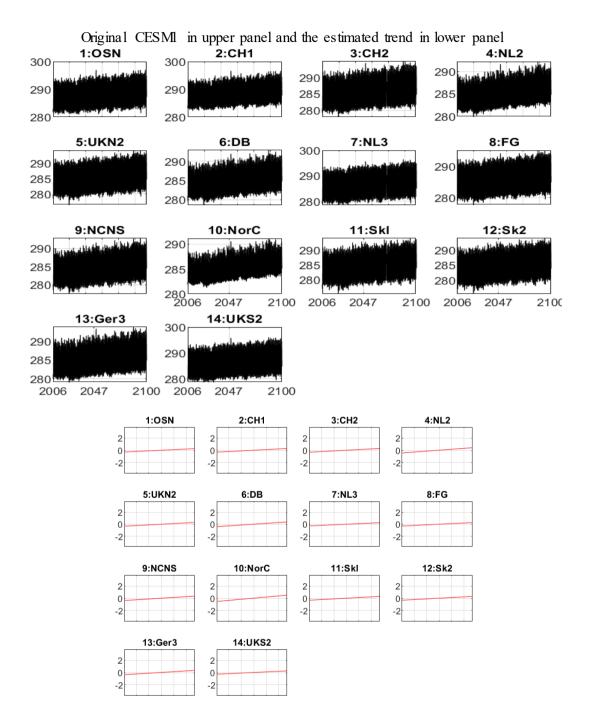


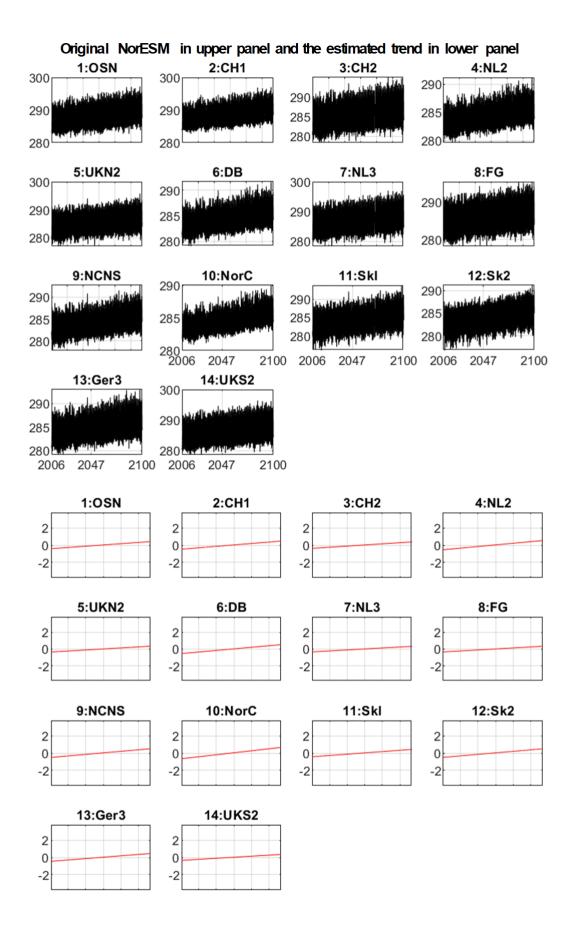


Common trend	Variables
Upward	
Flat	1,4
Downward	2, 5, 6

8.1.6 Outputs from modelled oceanographic data for all 14 WGINOSE regions from 2006-2100

The data includes simple 12 months cyclic patterns and total 1140 time points. All estimated trends indicate upward configuration. This is because of not showing dendrogram and applying any discriminates analysis.





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CESM1/MPI/NorESM

area	icon	area	icon
1 OSN	2	8 FG	
2 CH1	2	9NCNS	
3 CH2	2	10NorC	Ø
4 NL2		11Sk1	
5 UKN2		12Sk2	
6 DB		13 Ger3	
7 NL3		14 UKS2	8

Modelled oceanographic data for all 14 WGINOSE regions from 2006 – 2100

CESM1 MPI NorESM

