PANEL-BASED ASSESSMENT OF ECOSYSTEM CONDITION OF THE NORTH SEA SHELF ECOSYSTEM - APPENDICES

Per Arneberg, Berengere Husson, Anna Siwertsson, Jon Albretsen, Knut Yngve Børsheim, Côme Denechaud (IMR), Joël Durant (UiO), Tone Falkenhaug (IMR), Per Fauchald (NINA), Anders Martin Frugård Opdal (UiB), Sissel Jentoft (UiO), Tore Johannessen, Espen Johnsen, Elizabeth Jones, Cecilie Kvamme (IMR), Gabriella Ljungström (UiB), Pål Buhl-Mortensen, Yves Reecht, Hiroko Kato Solvang, Morten D Skogen, Aril Slotte, Espen Strand, Guldborg Søvik and Gro van der Meeren (IMR)

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Author(s):

Per Arneberg, Berengere Husson, Anna Siwertsson, Jon Albretsen, Knut Yngve Børsheim, Côme Denechaud (IMR), Joël Durant (UiO), Tone Falkenhaug (IMR), Per Fauchald (NINA), Anders Martin Frugård Opdal (UiB), Sissel Jentoft (UiO), Tore Johannessen, Espen Johnsen, Elizabeth Jones, Cecilie Kvamme (IMR), Gabriella Ljungström (UiB), Pål Buhl-Mortensen, Yves Reecht, Hiroko Kato Solvang, Morten D Skogen, Aril Slotte, Espen Strand, Guldborg Søvik and Gro van der Meeren (IMR)

Reasearch group leader(s): Erik-Jan Lock (Fôr og ernæring) Approved by: Research Director(s): Geir Huse Program leader(s): Henning Wehde

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UNIVERSITY OF BERGEN

UiO : Universitetet i Oslo

NINA Norsk institutt for naturforskning

Content

Appendix 8.1: Scientific basis for indicators

1. Indicator: Annual primary productivity [NI01]

Ecosystem characteristic: Primary productivity

Phenomenon: Increasing annual primary productivity [NP01]

Main driver: Climate

1.1 Supplementary metadata

None

1.2 Supplementary methods

None

1.3 Plots of indicator values

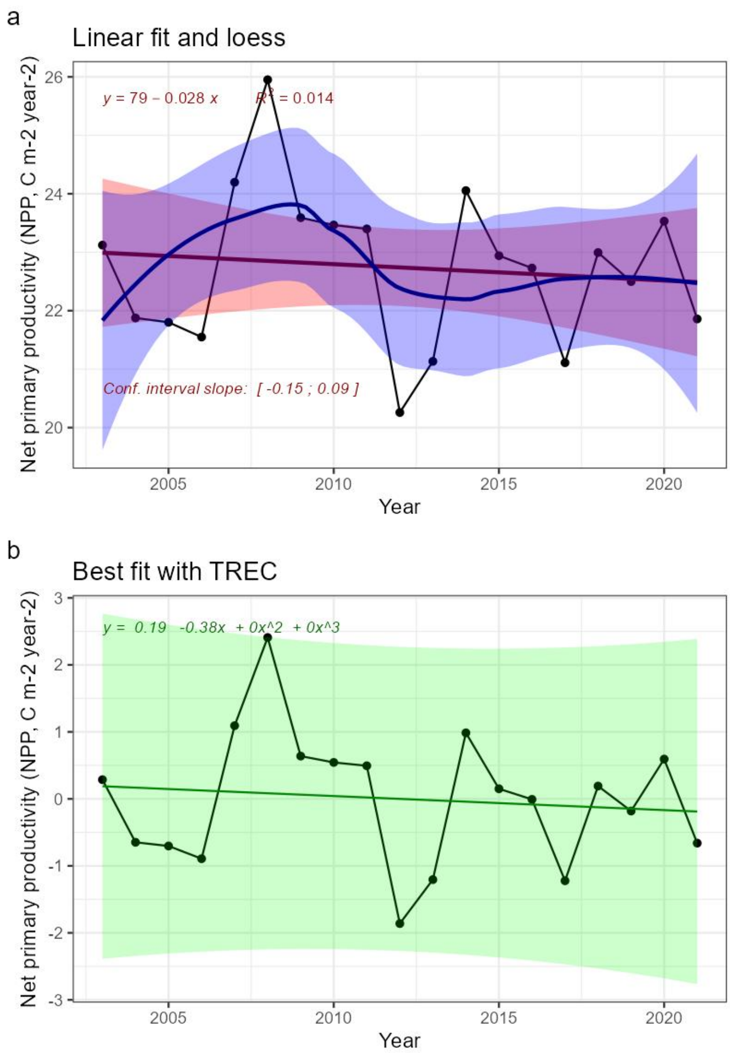


Figure 1.1: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on scaled time series

Assessment of the evidence for the phenomenon

There is **no evidence** of a net change over the entire length of the time series.

1.4 Background data and supplementary analysis

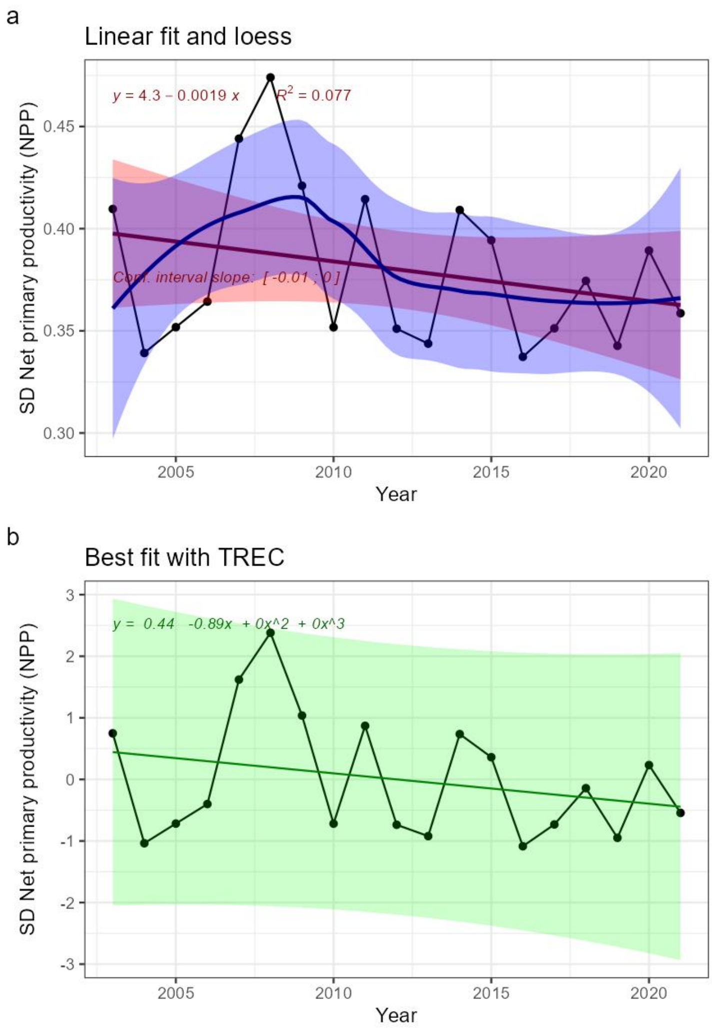


Figure 1.2: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on scaled time series

1.5 Recommendations for future development of the indicator

2. Indicator: Timing of the spring bloom [NI02]

Ecosystem characteristic: Primary productivity

Phenomenon: Change in the spring bloom timing [NP02]

Main driver: Climate

2.1 Supplementary metadata

None

2.2 Supplementary methods

None.

2.3 Plots of indicator values

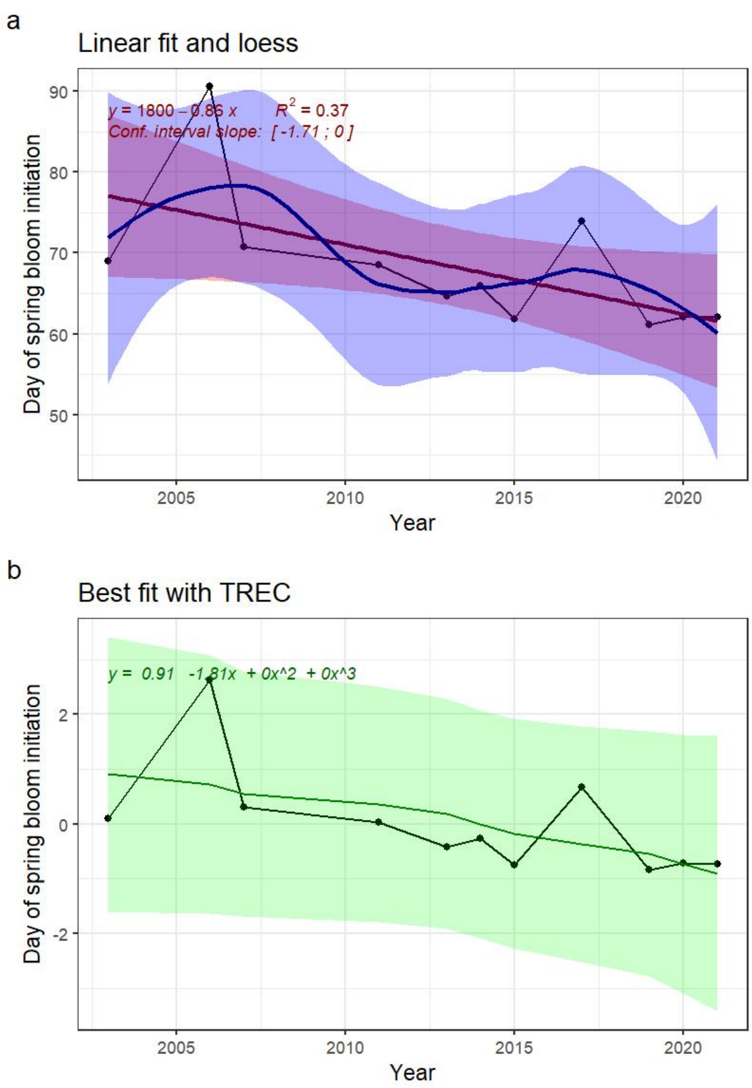


Figure. 2: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on scaled time series

Assessment of the evidence for the phenomenon

There is a tendency towards an earlier start of the spring bloom over the entire length of the time series. However, this trend seems to be driven by the high value in 2006, and the time series is otherwise short and has missing values. It is thus hard to evaluate the interannual variability and whether this value of 2006 is exceptional or not. In addition, the confidence intervals are large independently of the statistical method employed and include the slope 0. There is thus **no evidence** of a change in the spring bloom timing.

2.4 Background data and supplementary analysis

2.5 Recommendations for future development of the indicator

3. Indicator: Herbivorous copepods [NI03]

Ecosystem characteristic: Biomass distribution among trophic levels

Phenomenon: Decreasing abundance of herbivorous copepods [NP03]

Main driver: Climate change

3.1 Supplementary metadata

None

3.2 Supplementary methods

The indicator is represented by a time series based on CPR abundance values (annual means in March-September from selected grids with high sampling effort within or in the vicinity of the Norwegian sector) of copepods assigned as omnivore (UK Pelagic Habitats Expert Group, 2021)

3.3 Plots of indicator values

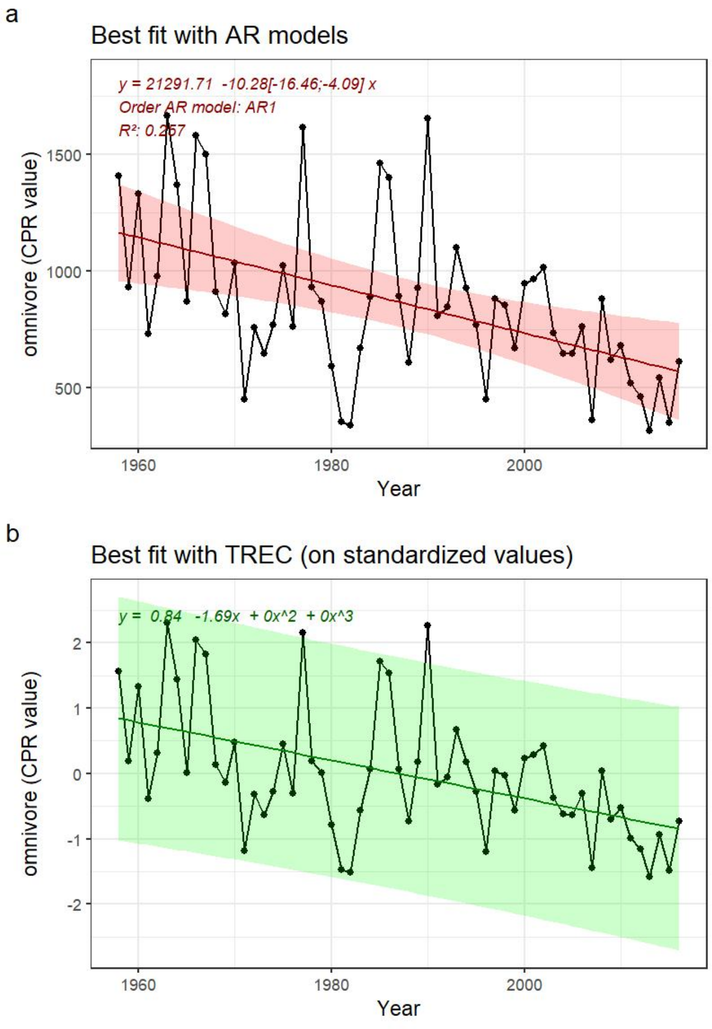


Figure 3.1: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC

Assessment of the evidence for the phenomenon

There is a clear decline in the time series, which is seen also when the data are split into small (which contribute most to the overall pattern) and large species. The pattern for the large group is driven by Calanus I-IV and by Acartia and Para/Pseudocalanus for the small group. For both Calanus and Para/Pseudocalanus, the declines can be linked to climate change (for the former through a direct effect of temperature and possibly advection and for the latter through reduced primary production in the summer and autumn. As the change is also expected to have considerable consequences for other parts of the ecosystem, the evidence for the phenomenon is rated as **high**.

3.4 Background data and supplementary analysis

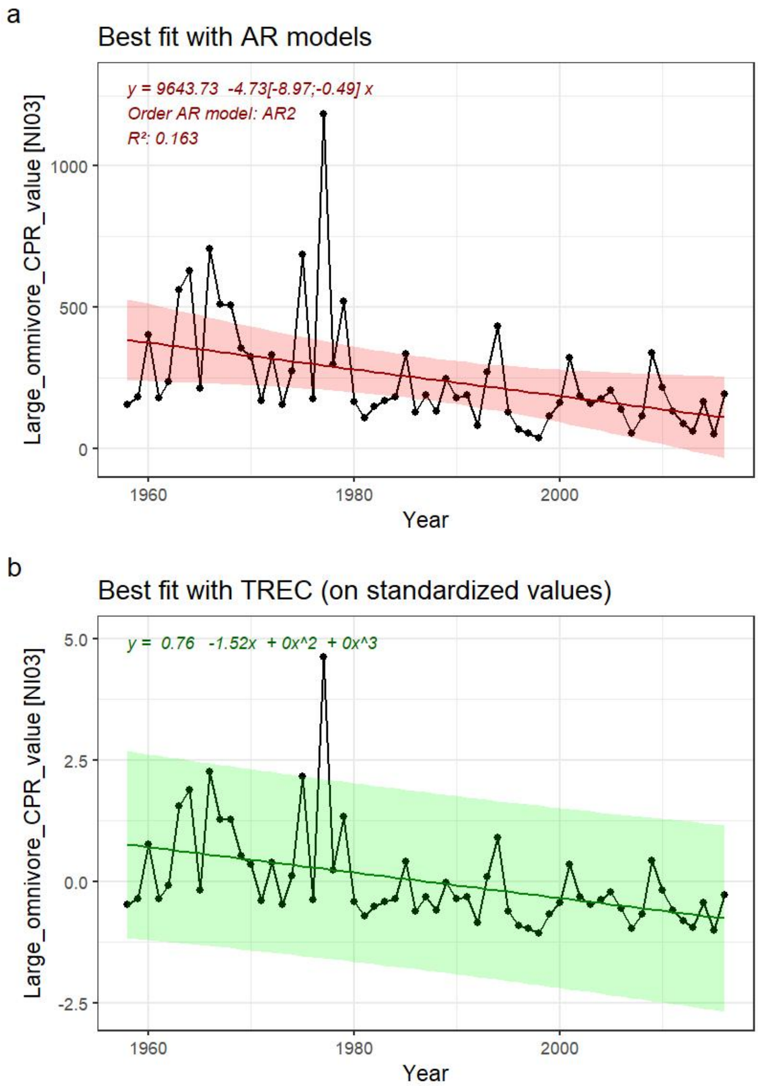


Figure. 3.2: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

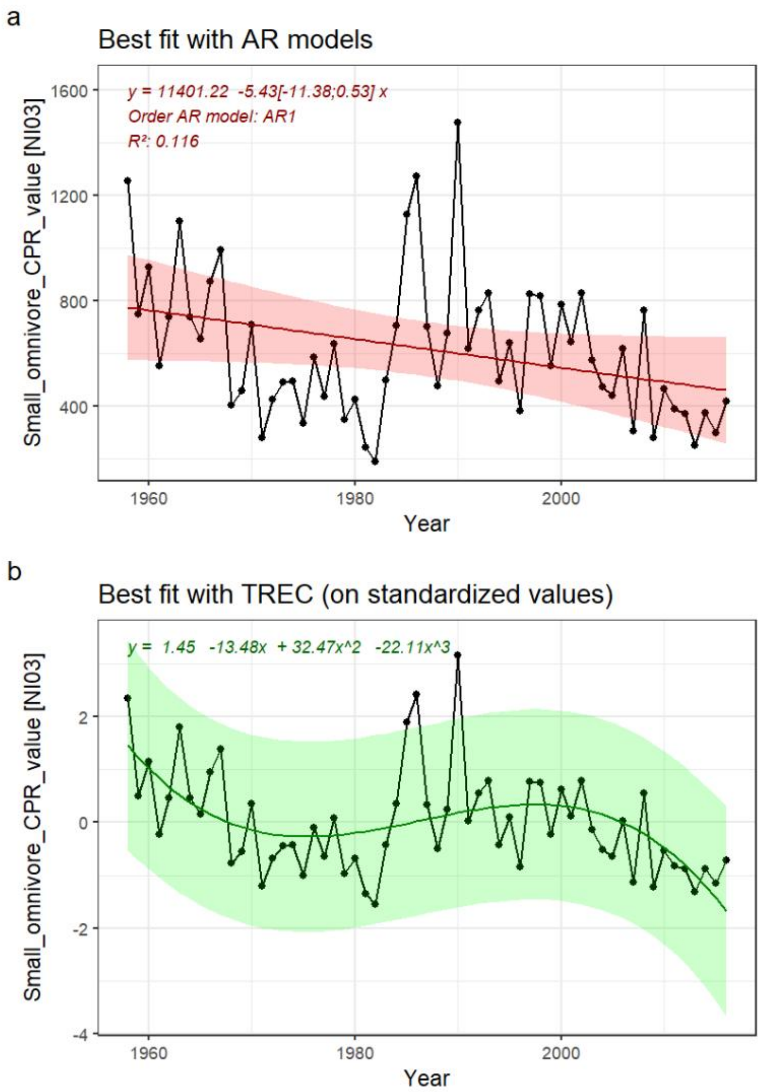


Figure. 3.3: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

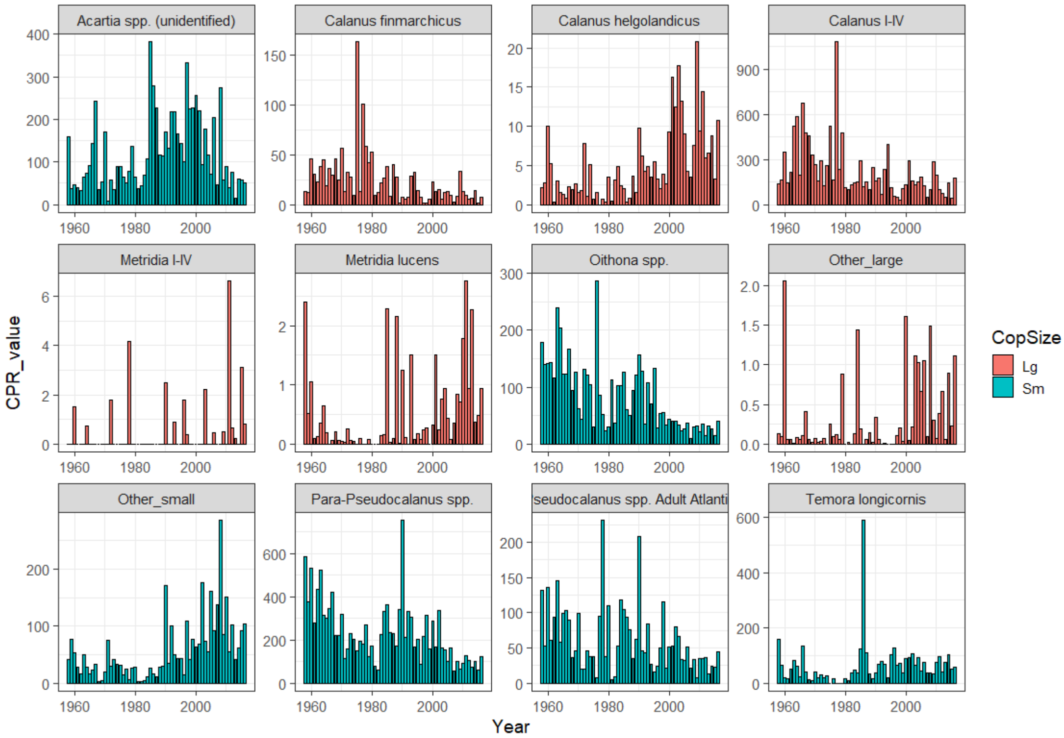


Figure 3.4: CPR abundance development of the 5 most common Small (green) and Large (red) copepod groups. All other species pooled into Other_small and Other_large.

3.5 Recommendations for future development of the indicator

4. Indicator: Carnivorous zooplankton [NI04]

Ecosystem characteristic: Biomass distribution among trophic levels

Phenomenon: Increasing abundance of carnivorous zooplankton [NP04]

Main driver: Climate change

4.1 Supplementary metadata

None

4.2 Supplementary methods

None

4.3 Plots of indicator values

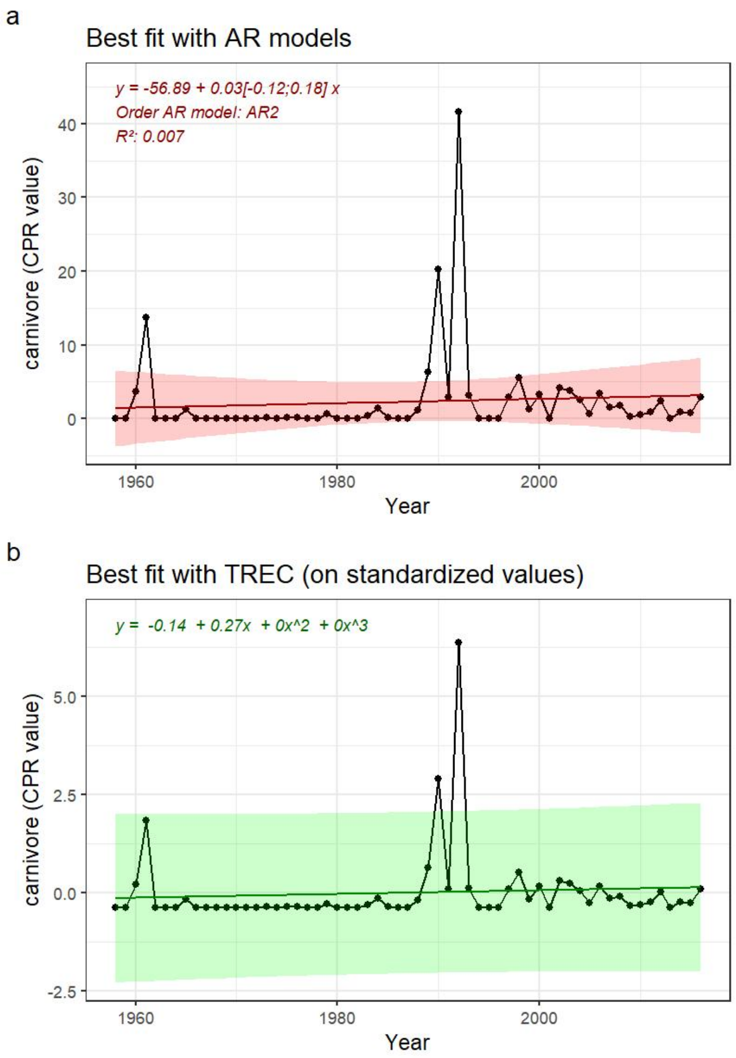


Figure 4: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

CPR is not sampling carnivorous zooplankton well as they may avoid be sampled due to generally larger body size than herbivorous and omnivorous species and generally reside deeper in the water column than the CPR sampling depth.

4.4 Background data and supplementary analysis

4.5 Recommendations for future development of the indicator

5 Indicator: Low trophic level fish [NI05]

Ecosystem characteristic: Biomass distribution among trophic levels

Phenomenon: Change in biomass of LTL fish [NP05]

Main driver: Climate change and fisheries

Table 5: list of species included in the indicator "Low trophic level fish"

Taxon
Ammodytes spp.
Ammodytes marinus
Ammodytes tobianus
Aphia minuta
Atherina presbyter
Awaous commersoni
Benthosema glaciale
Ciliata septentrionalis
Clupea harengus
Crystallogobius linearis
Cyclopterus lumpus
Engraulis encrasicolus
Gadiculus argenteus
Gymnannodytes semisquamatus
Maurolicus muelleri
Myctophidae spp.
Notoscopelus elongatus kroyeri
Notoscopelus kroyeri
Osmerus eperlanus
Sardina pilchardus
Sarpa salpa
Schedophilus medusophagus
Scomber japonicus
Sprattus sprattus
Syngnathus rostellatus
Syngnatha typhle
Trisopterus esmarkii

5.1 Supplementary metadata

None.

5.2 Supplementary methods

Species identified in the IBTS survey and tagged as planktivorous or herbivorous constitute the pool of data used for this indicator. The complete list is indicated in the table below

5.3 Plots of indicator values

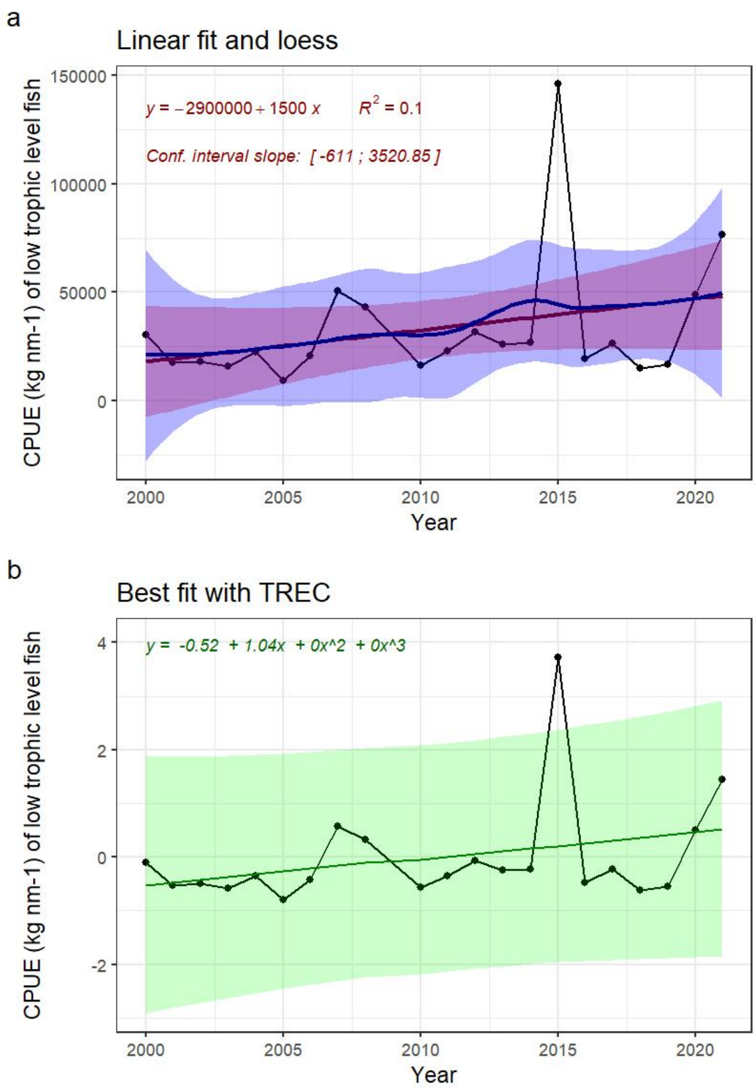


Figure 5: Indicator time series and fitted trends. a) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. b) Best fitted trend using the first steps of a TREC analysis on scaled time

Assessment of the evidence for the phenomenon

There is a slight increase in biomass of low trophic level species according to the indicator time series, but the slope confidence interval includes 0, so we cannot say that there is a trend over this time period. There is thus **no evidence** of change in this indicator.

5.4 Background data and supplementary analysis

5.5 Recommendations for future development of the indicator

6 Indicator: High trophic level fish [NI06]

Ecosystem characteristic: Biomass distribution among trophic levels

Phenomenon: Decreasing biomass of HTL fish [NP06]

Main driver: Climate change and fisheries

6.1 Supplementary metadata

None

6.2 Supplementary methods

Species identified in the IBTS survey and tagged as planktivorous or herbivorous constitute the pool of data used for this indicator. The complete list is indicated in the table below.

Table 6: list of species included in the indicator "Low trophic level fish"

Taxon
Belone belone
Centrophorus granulosus
Conger conger
Galeorhinus galeus
Hippoglossus hippoglossus
Hyperoplus immaculatus
Lamna nasus
Lampetra fluviatilis
Lophius budegassa
Lophius piscatorius
Petromyzon marinus
Raja microocellata
Sarda sarda
Trachipterus arcticus
Zeus faber

6.3 Plots of indicator values

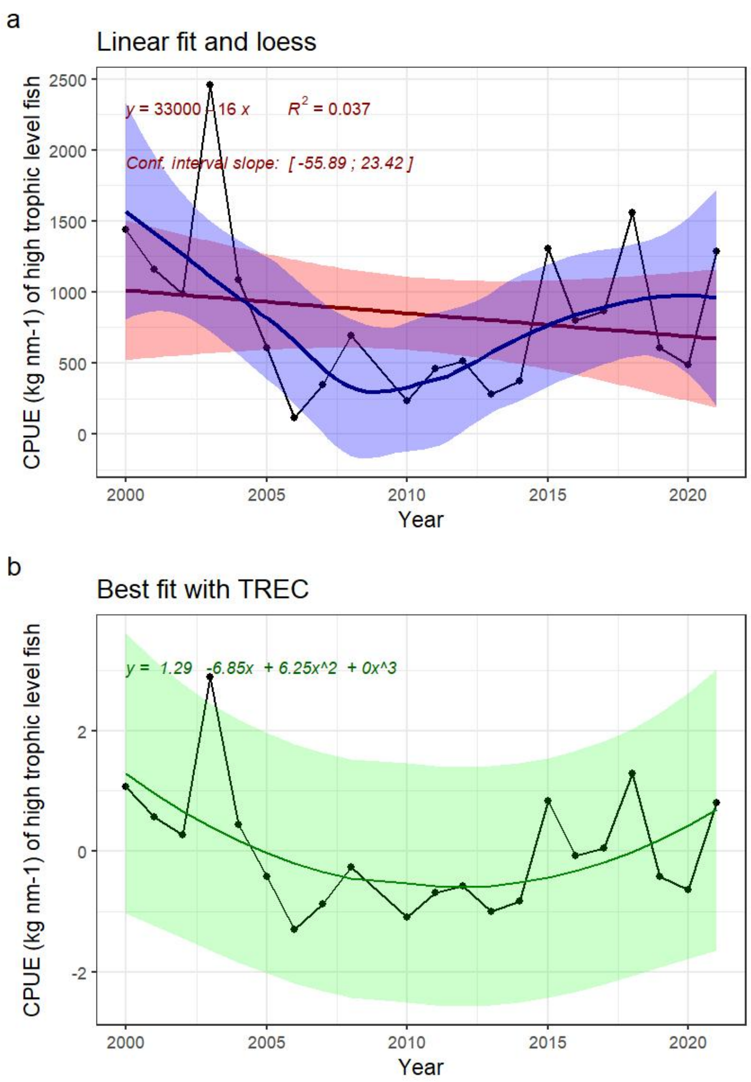


Figure 6: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on scaled time series

Assessment of the evidence for the phenomenon

The linear trend shows a slight decrease, but the slope confidence interval includes 0, so we cannot say that there is a trend over this time period. There is thus **no evidence** of change in this indicator.

6.4 Background data and supplementary analysis

6.5 Recommendations for future development of the indicator

7 Indicator: High trophic level seabirds [NI07]

Ecosystem characteristic: Biomass distribution among trophic levels

Phenomenon: Decline in populations of piscivorous surface feeding seabirds [NP07]

Main driver: Fisheries, eutrophication, and climate change

7.1 Supplementary metadata

7.2 Supplementary methods

Data are from population monitoring of breeding colonies of herring gull (*Larus argentatus*), common gull (*Larus canus*), lesser black-backed gull (*Larus fuscus*), great black-backed gull (*Larus marinus*), common tern (*Sterna hirundo*) and Arctic tern (*Sterna paradisaea)* in the seabird reserves in the counties of Viken, Vestfold og Telemark, Agder, Rogaland and Vestland. In some colonies in the North Sea the two tern species are not separated and are referred to as “terns”. The dataset spans a time period from the 1970’s or 1980’s (from around the establishment of the reserves) to present and covers the entire Norwegian coast of Skagerrak and North Sea with a total of 469 sites (seabird colonies). Counting were done by counting the number birds, pairs or active nests. In total, the dataset includes 20,613 observations.

The dataset was divided into two ocean areas: Colonies west of Lindesnes (North Sea) and colonies east of Lindesnes (Skagerrak). Analyses were done separately for each species and ocean area. Generalized Additive Models (GAMs) from the “mgcv” library (Wood 2006) in R v.3.6.3 (R Development Core Team 2020) were used to model the temporal trends of counts. To account for nonlinear trends, the response to year was modeled with a thin plate regression spline. To account for the average population size in each colony, colony was included as a factor. The counts followed a heavy-tailed distribution with an excess of zeroes, and counts were therefore modeled with a negative binomial distribution. From the fitted models, the “predict” function in the “mgcv” library was used to predict the count for an average colony including a 95% confidence interval. Values are shown as the percentage of the average count in the predicted time series.

Table 7.1: Data sources

Dataset name	**Dataset DOI/URL/storage**	**Owner institution**	**Contact person for data**	**Content and methods**	**Temporal coverage**
Population monitoring in seabird reserves in Agder, Vestfold and Telemark and Viken	www.seapop.no	NINA		Counts of active nests or adults in breeding colonies	Varies between colonies.
Population monitoring in seabird reserves in Rogaland	https://www.temakart-rogaland.no/sjofugl	Statsforvalteren i Rogaland	Bjørn Mo	Counts of active nests or adults in breeding colonies	Varies between colonies
Population monitoring in seabird reserves in Hordaland (Vestland)	Stored at Statsforvalteren i Vestland	Statsforvalteren i Vestland	Stein Byrkjeland	Counts of active nests or adults in breeding colonies	Varies between colonies
Population monitoring in seabird reserves in Sogn og Fjordane (Vestland)	Stored at Statsforvalteren i Vestland	Statsforvalteren i Vestland	Tore Larsen	Counts of active nests or adults in breeding colonies	Varies between colonies

7.3 Plots of indicator values

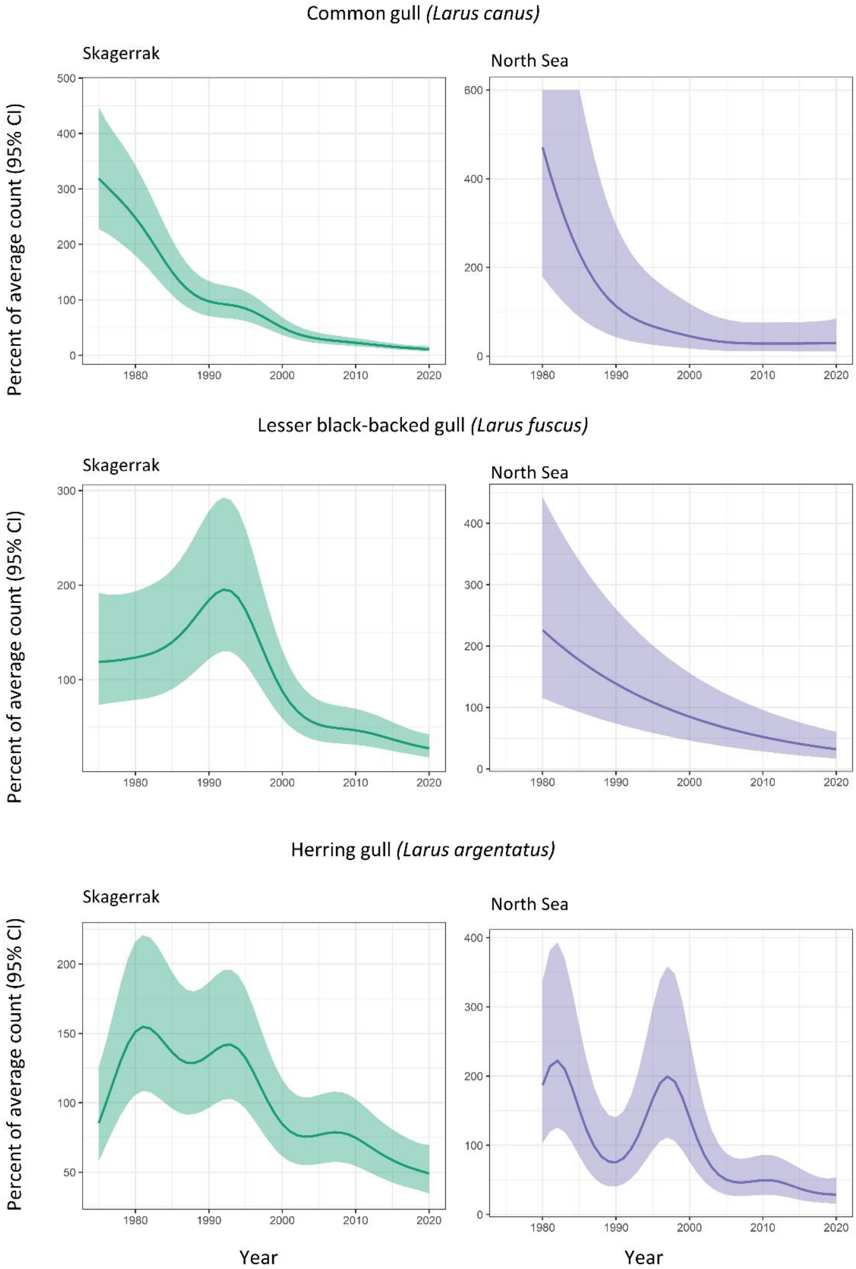


Figure 7.1 : Estimated population trends of common gull, lesser black-backed gull, herring gull in the North Sea area and Skagerrak respectively. Estimates are given as percent of the average count in the time series of an average colony.

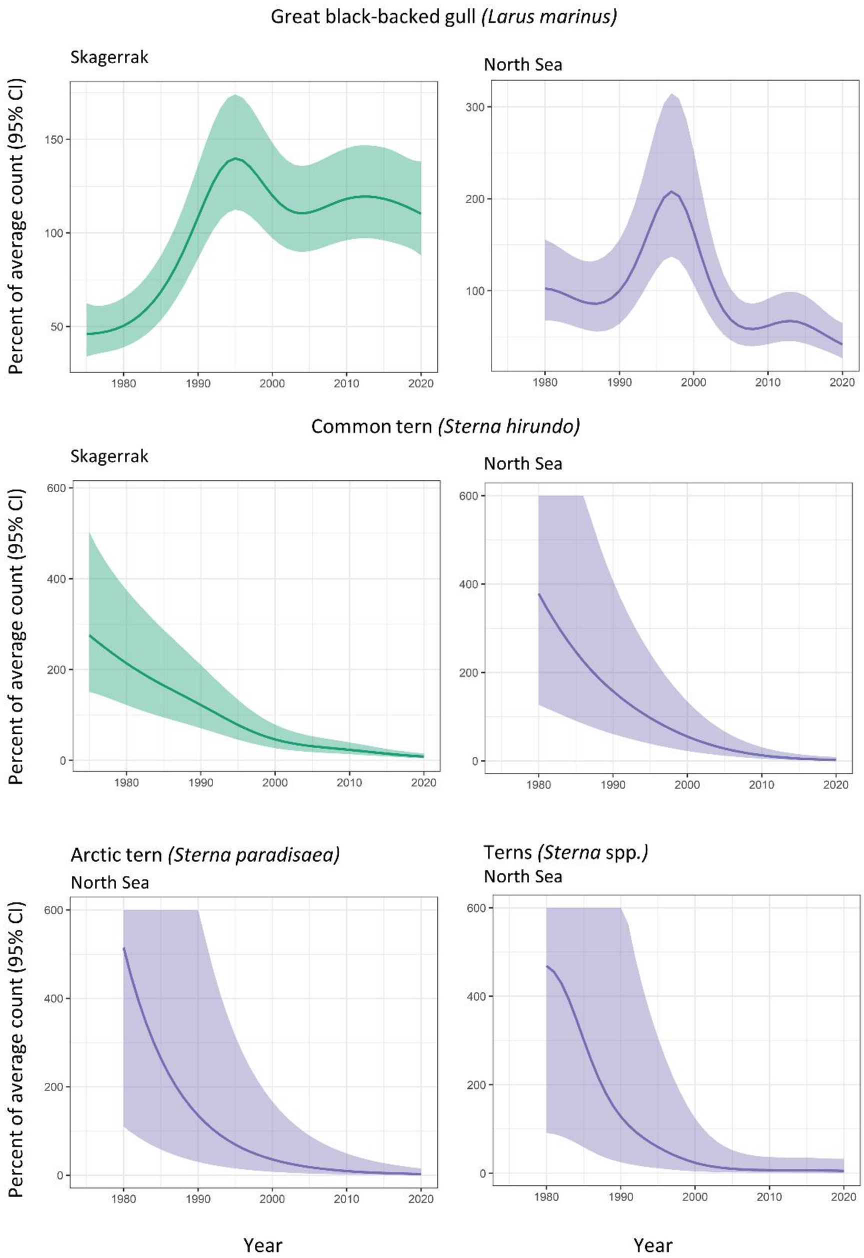


Figure 7.2: Estimated population trends of great black-backed gull, common tern, Arctic tern and both tern species combined in the North Sea area and Skagerrak respectively. Estimates are given as percent of the average count in the time series of an average colony. Note that Arctic tern is only monitored in North Sea colonies.

Table 7.2: Summary of GAM models relating population counts to year.

GAM model: CountPair ~ s(Year) + s(Site, bs = "re")							
Family: Negative binomial, Link function: Log							
Skagerrak				s(Year)		s(Site)	
Species	n Total	n Site	Deviance explained (%)	Estimated degree of freedom	P-value	Estimated degree of freedom	P-value
Common gull	1658	54	74.9	6.803	<0.0001	51.887	<0.0001
Lesser black-backed gull	1702	85	58.8	6.787	<0.0001	80.12	<0.0001
Herring gull	1561	60	64.9	7.294	<0.0001	57.353	<0.0001
Great black-backed gull	1085	39	69.4	6.477	<0.0001	36.906	<0.0001
Common tern	1713	62	41.7	4.105	<0.0001	55.84	<0.0001
North Sea				s(Year)		s(Site)	
Species	n Total	n Site	Deviance explained (%)	Estimated degree of freedom	P-value	Estimated degree of freedom	P-value
Common gull	1227	102	46.7	4.206	<0.0001	87.3	<0.0001
Lesser black-backed gull	858	74	57.9	1	<0.0001	63.79	<0.0001
Herring gull	1214	99	51.8	8.029	<0.0001	89.786	<0.0001
Great black-backed gull	1094	92	55.6	7.606	<0.0001	84.289	<0.0001
Common tern	332	33	28.2	2.047	<0.0001	18.082	<0.0001
Arctic tern	395	41	25.1	1.001	<0.0001	17.47	<0.0001
Terns (Sterna spp.)	1790	118	35.4	4.935	<0.0001	86.482	<0.0001

Table 7.3: Estimated population size in 2020 as percent of the population size in 1980.

Species	**Area**	**2020 populations in percent of the 1980 populations (±95% CI)**	
Common gull	Skagerrak	4.4	(3.0, 6.6)
	North Sea	6.3	(2.2, 17.9)
Lesser black-backed gull	Skagerrak	22.4	(14.5, 34.5)
	North Sea	14.1	(7.5, 26.7)
Herring gull	Skagerrak	32.4	(22.8, 46.1)
	North Sea	15.4	(8.2, 28.7)
Great black-backed gull	Skagerrak	218.7	(174.6, 273.9)
	North Sea	40.5	(25.9, 63.3)
Common tern	Skagerrak	3.9	(2.1, 7.3)
	North Sea	0.6	(0.1, 2.4)
Arctic tern	North Sea	0.5	(0.1, 3.0)
Terns	North Sea	1.2	(0.2, 7.0)

All species except great black-backed gull in Skagerrak showed marked population declines during the period of monitoring (Figure 7.2, Table 7.3). Most dire is the situation for terns and common gull. In 2020 the populations of these two species were less than 10% of the populations in 1980 (Table 7.3).

Assessment of the evidence for the phenomenon

The data show a strong long-term (40 years) decline in all populations of piscivorous surface-feeding seabirds except great black-backed gull. The declines can be attributed to anthropogenic drivers and are assessed to have significant effects on other parts of the ecosystem. The evidence for the phenomenon is thus assessed as **high**.

7.4 Background data and supplementary analysis

7.5 Recommendations for future development of the indicator

8. Indicator: Holoplankton vs meroplankton [NI08]

Ecosystem characteristic: Functional groups within trophic levels

Phenomenon: Changes in Meroplankton vs. Holoplankton composition [NP08]

Main driver: Climate change

8.1 Supplementary metadata

None

8.2 Supplementary methods

None

8.3 Plots of indicator values

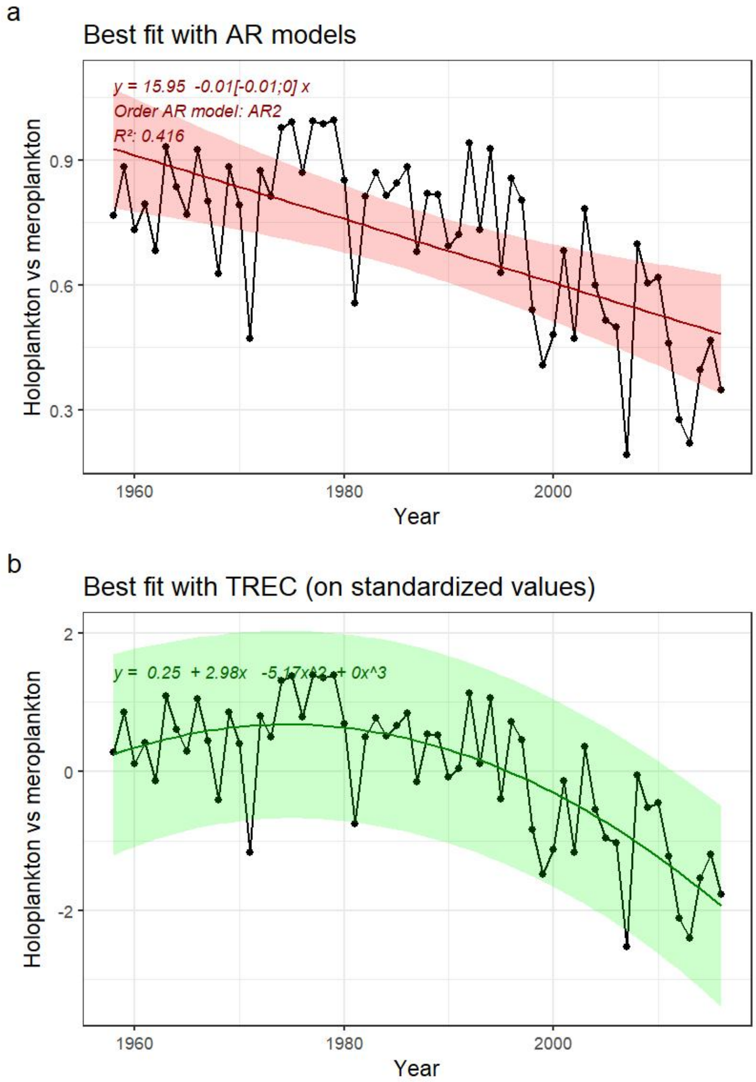


Figure.8.1: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

There is a clear decline in the time series that can be attributed to a positive effect of increasing temperature on larval abundance of the echinoderm *Echinocardium cordatum*. There are considerable uncertainties about consequences of the changes for other parts of the ecosystem, and the evidence for the phenomenon is therefore rated as **intermediate**.

8.4 Background data and supplementary analysis

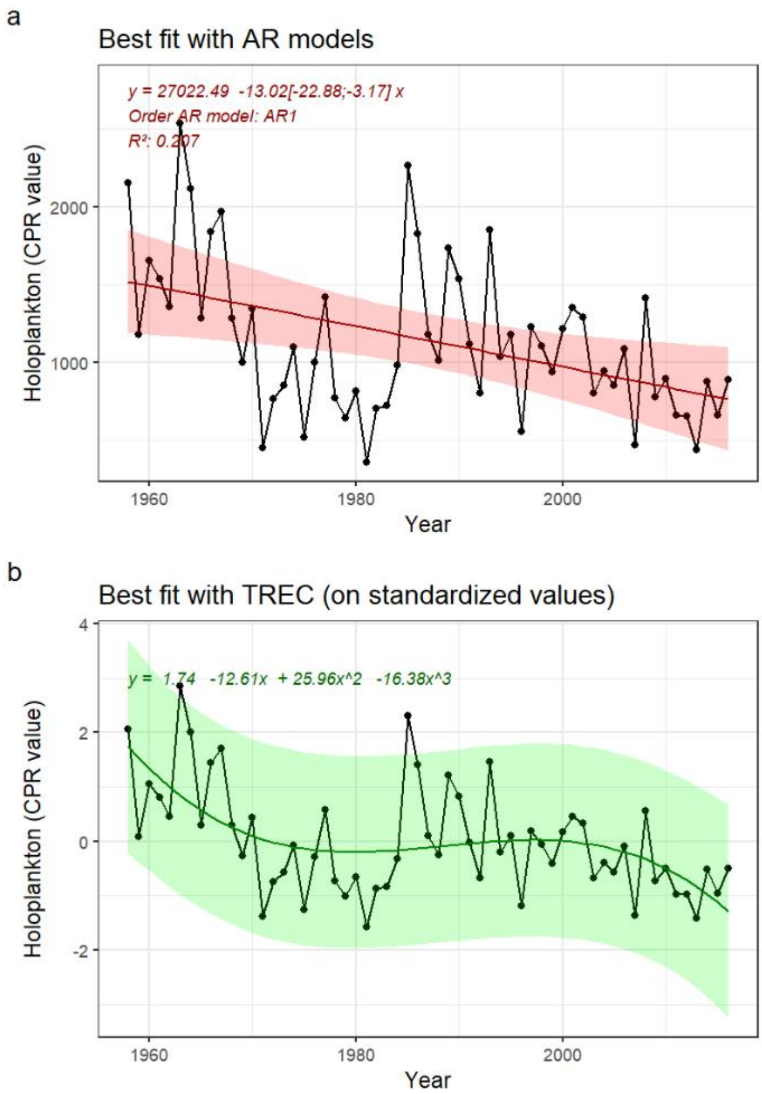


Figure 8.2: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

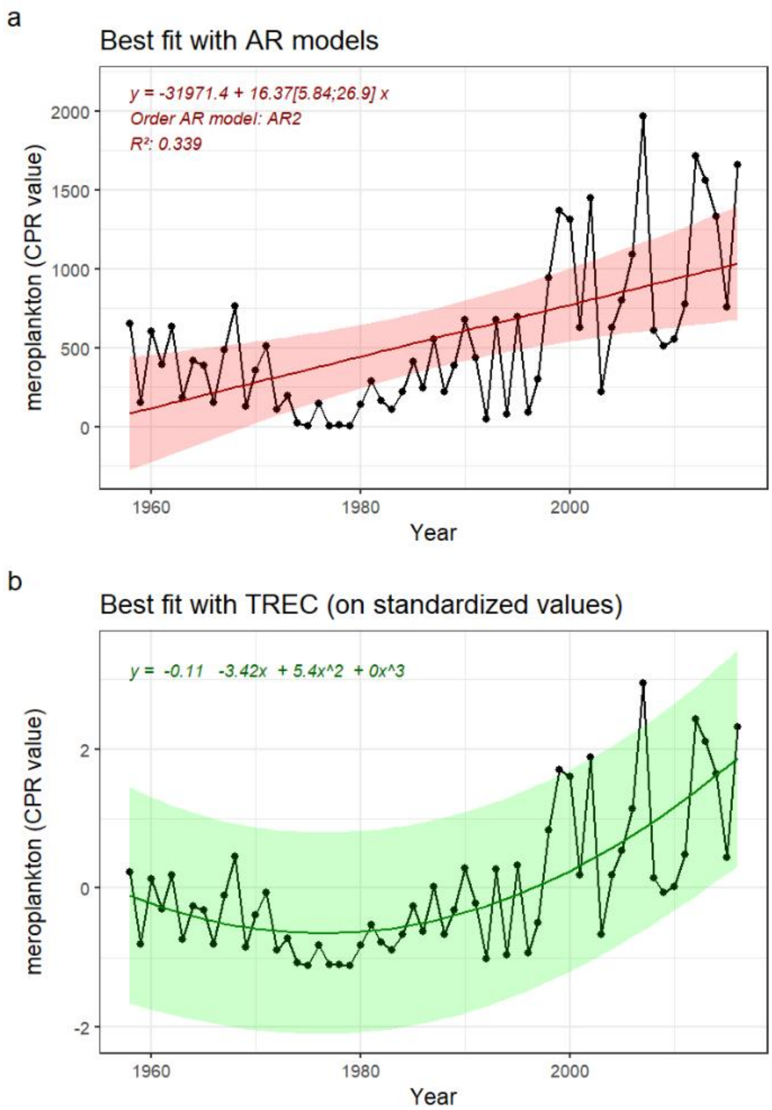


Figure 8.3: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

8.5 Recommendations for future development of the indicator

9 Indicator: Copepod body size [NI09]

Ecosystem characteristic: Functional groups within trophic levels

Phenomenon: Reduced average copepod community body size [NP09]

Main driver: Climate change

9.1 Supplementary metadata

None

9.2 Supplementary methods

None

9.3 Plots of indicator values

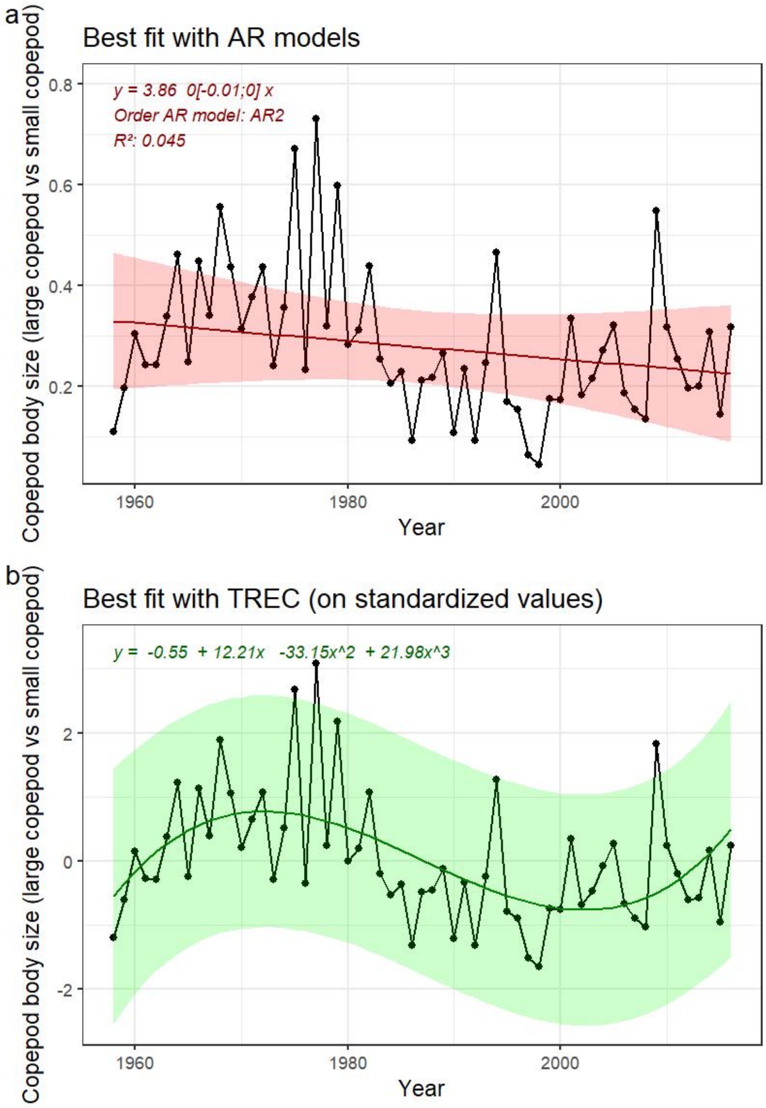


Figure 9.1 : A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

There is a decline among both small and large copepods, with the large declining more rapidly than the small, resulting in an overall tendency for a decline for the ratio of abundance of large to small. The decline in the large group is driven by Calanus I-IV and in the small group by Acartia and Para/Pseudocalanus. The declines of both of these groups can be linked to climate change (see evaluation of phenomenon for NI03). A development towards smaller copepods is expected to have consequences in the ecosystem, for example for fish larvae. It should be noted that the data only measures change in size as a result of changes in relative species composition and that any changes within species are not measured. Given these points, the evidence for the phenomenon is rated as **intermediate**.

9.4 Background data and supplementary analysis

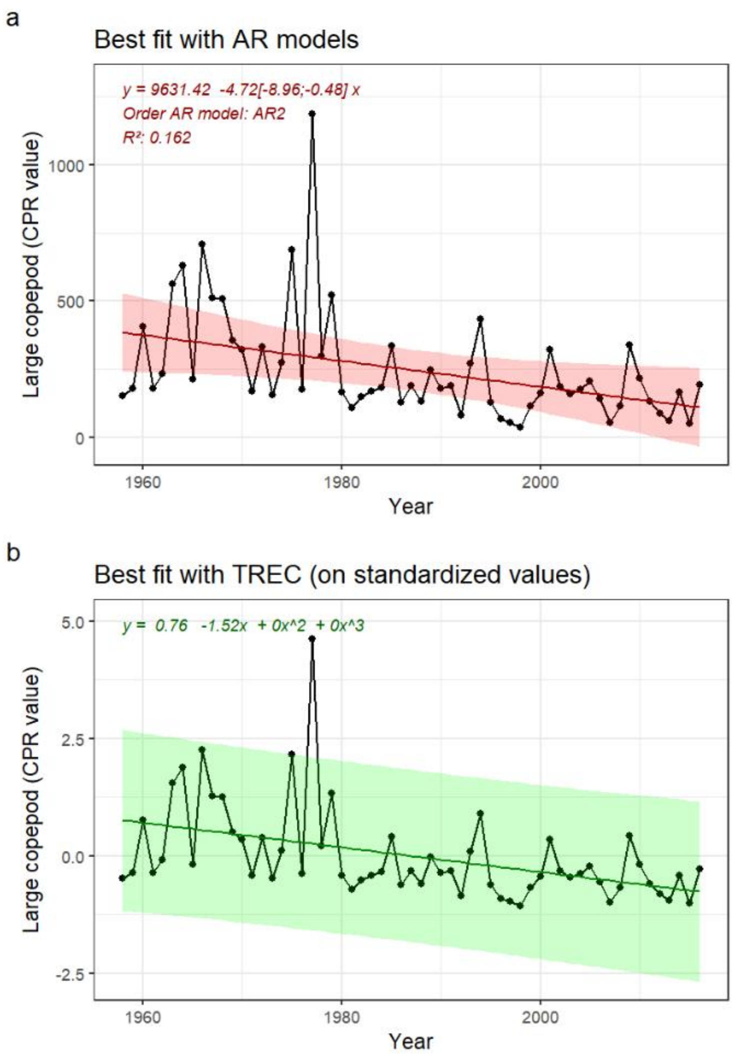


Figure 9.2: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

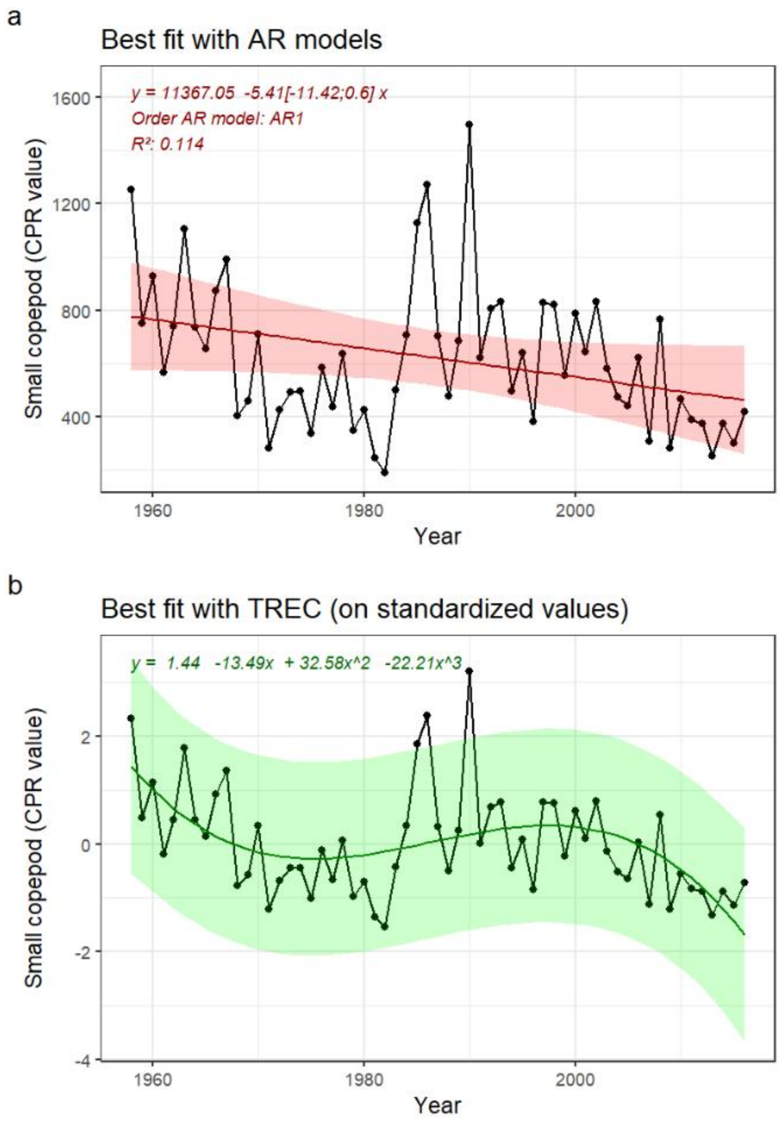


Figure 9.3: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

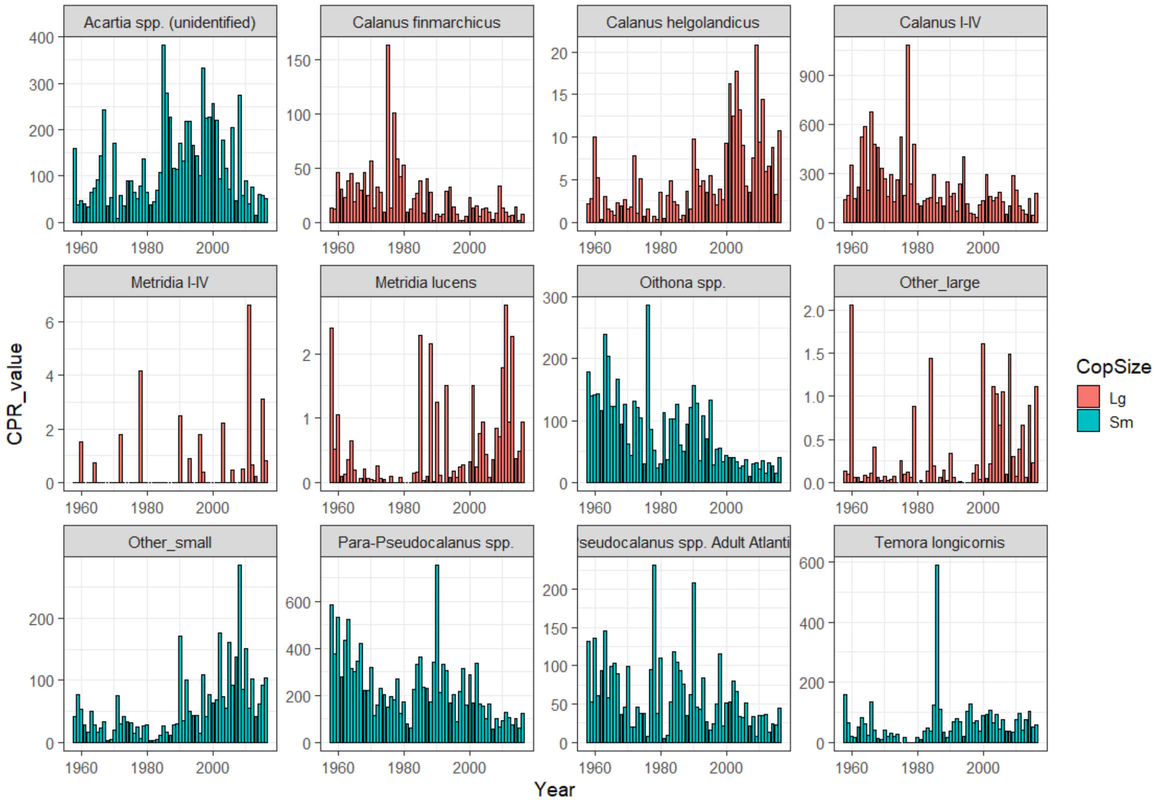


Figure 9.4: CPR abundance development of the 5 most common Small (green) and Large (red) copepod groups. All other species pooled into Other_small and Other_large.

9.5 Recommendations for future development of the indicator

10 Indicator: Gelatinous zooplankton [NI10]

Ecosystem characteristic: Functional groups within trophic levels

Phenomenon: Increasing abundances of gelatinous zooplankton [NP10]

Main driver: Climate change

10.1 Supplementary metadata

None

10.2 Supplementary methods

Taxa used in the indicators are "Periphyllidae", "*Periphylla* spp.", "*Periphylla periphylla*", "*Cyanea capillata*", "*Cyanea lamarckii*", "*Aurelia aurita*".

10.3 Plots of indicator values

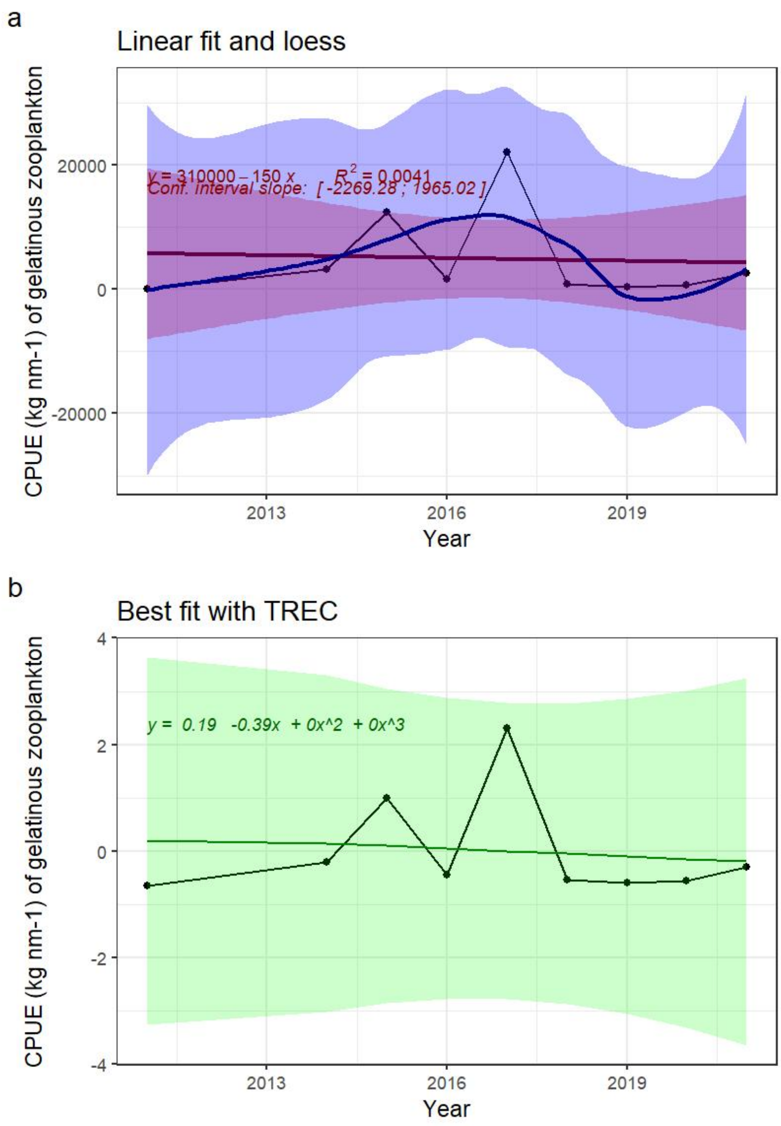


Figure 10: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

As there is no protocol for sampling of gelatinous zooplankton in the parts of the IBTS covering the Norwegian sector of the North Sea and the time series is short, it is considered that the **data are insufficient** to assess the evidence of this phenomenon.

10.4 Background data and supplementary analysis

10.5 Recommendations for future development of the indicator

11 Indicator: Fish body size [NI11]

Ecosystem characteristic: Functional groups within trophic levels

Phenomenon: Decreasing fish community mean body size [NP11]

Main driver: Fisheries

11.1 Supplementary metadata

None

11.2 Supplementary methods

None

11.3 Plots of indicator values

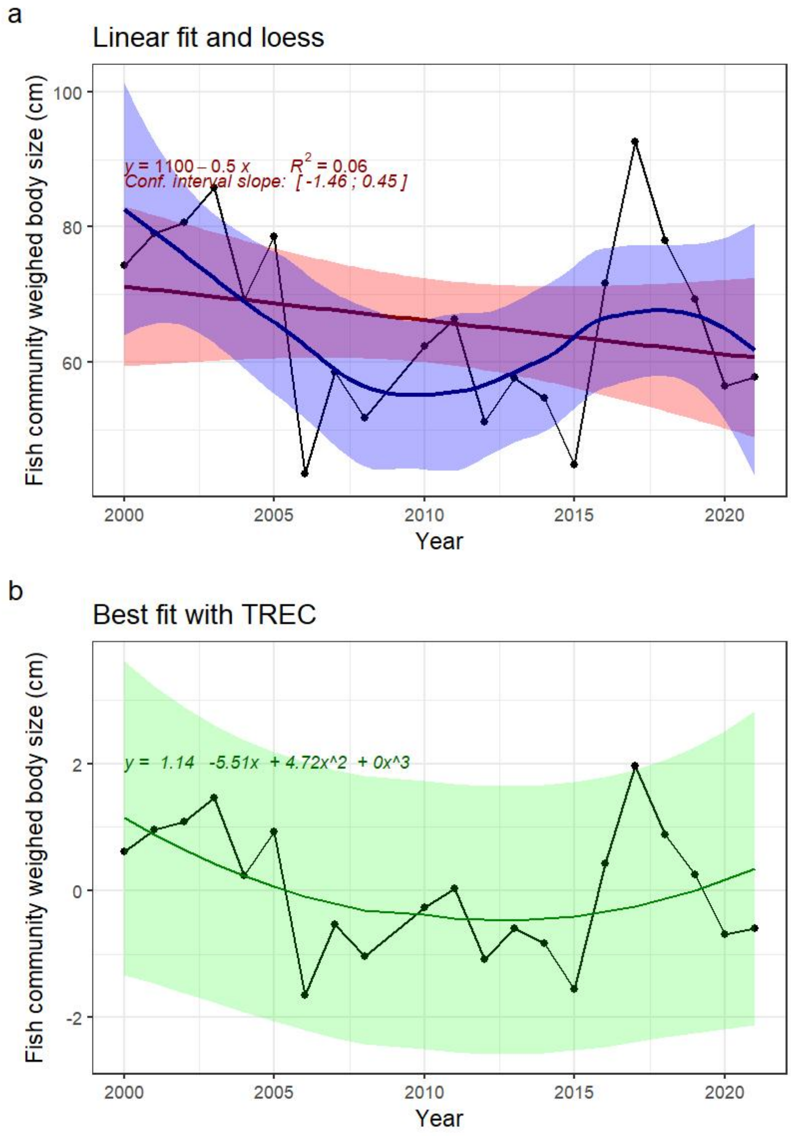


Figure 11: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

There is large interannual variability in fish community weighed body size. The linear trend is decreasing slowly, and the confidence interval of the slope shows that there might be no trend. There is thus **no evidence** of change in this indicator.

11.4 Background data and supplementary analysis

11.5 Recommendations for future development of the indicator

12 Indicator: Fish life history [NI12]

Ecosystem characteristic: Functional groups within trophic levels

Phenomenon: Decreasing proportion of slow-life species and increasing proportion of fast life species [NP12]

Main driver: Fisheries and climate change

12.1 Supplementary metadata

None

12.2 Supplementary methods

None

12.3 Plots of indicator values

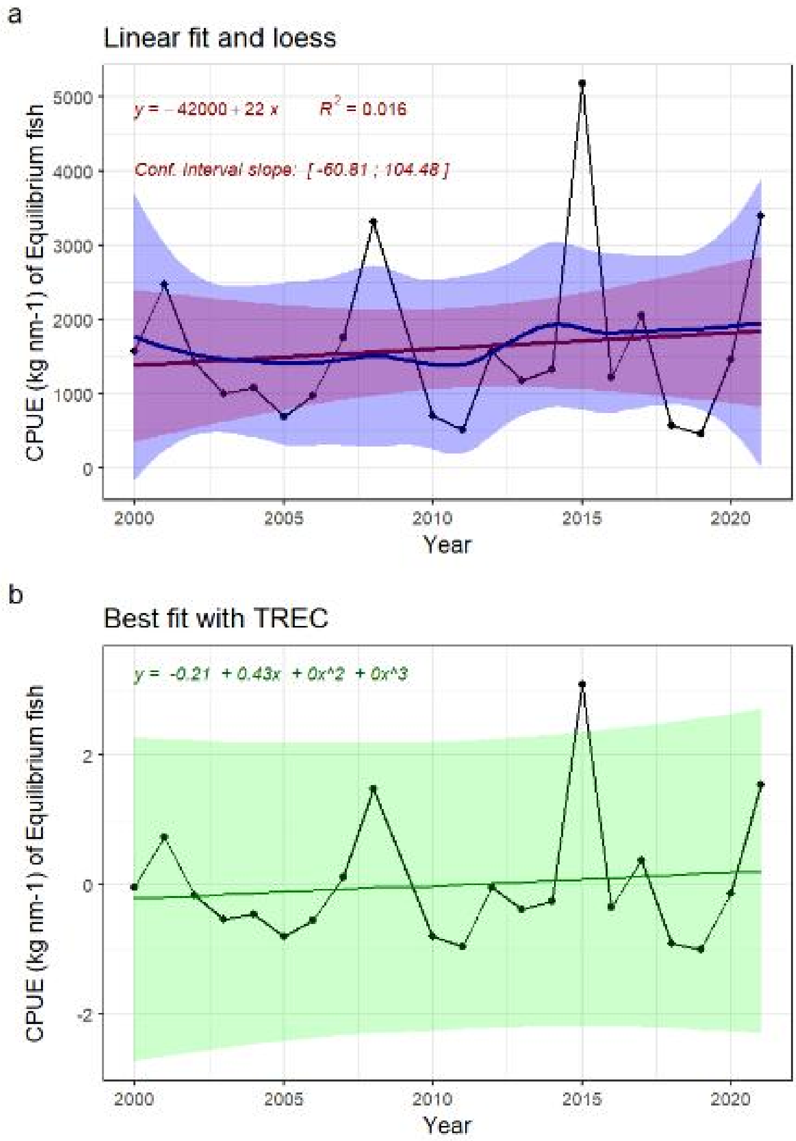


Figure 12.1: Equilibrium fish biomass time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on scaled time series

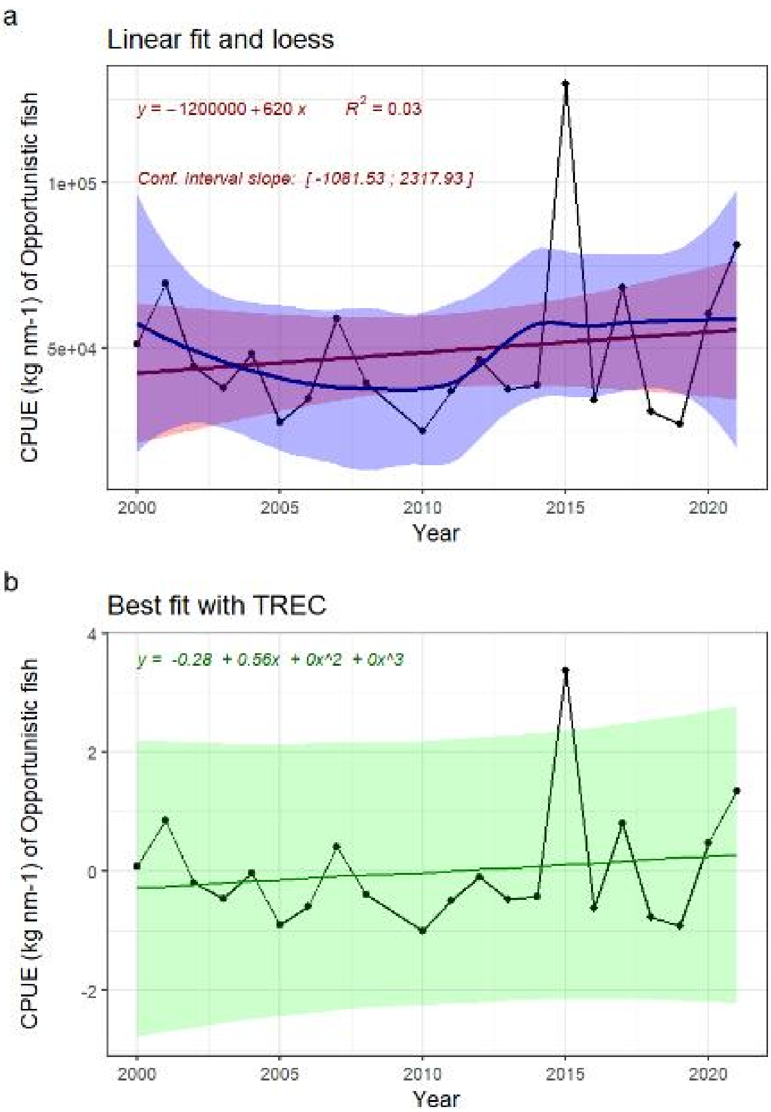


Fig. 12.2: Opportunistic fish biomass time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on scaled time series

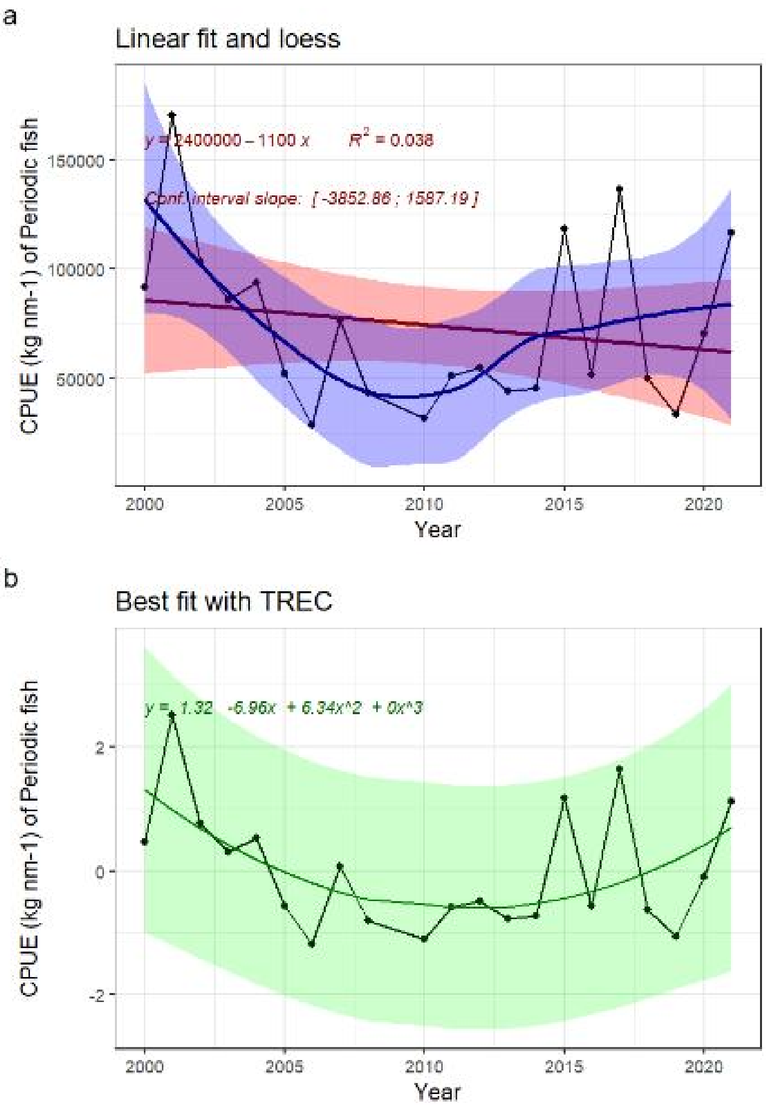


Figure 12.3: Periodic fish biomass time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on scaled time series

Assessment of the evidence for the phenomenon

All three slope confidence intervals include 0 and the obtained trends are very low. There is thus **no evidence** of change in this indicator.

12.4 Background data and supplementary analysis

12.5 Recommendations for future development of the indicator

13. Indicator: *Calanus* species [NI13]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decrease in abundance of C. finmarchicus relative to abundance of C. helgolandicus [NP13]

Main driver: Climate change

13.1 Supplementary metadata

None

13.2 Supplementary methods

None

13.3 Plots of indicator values

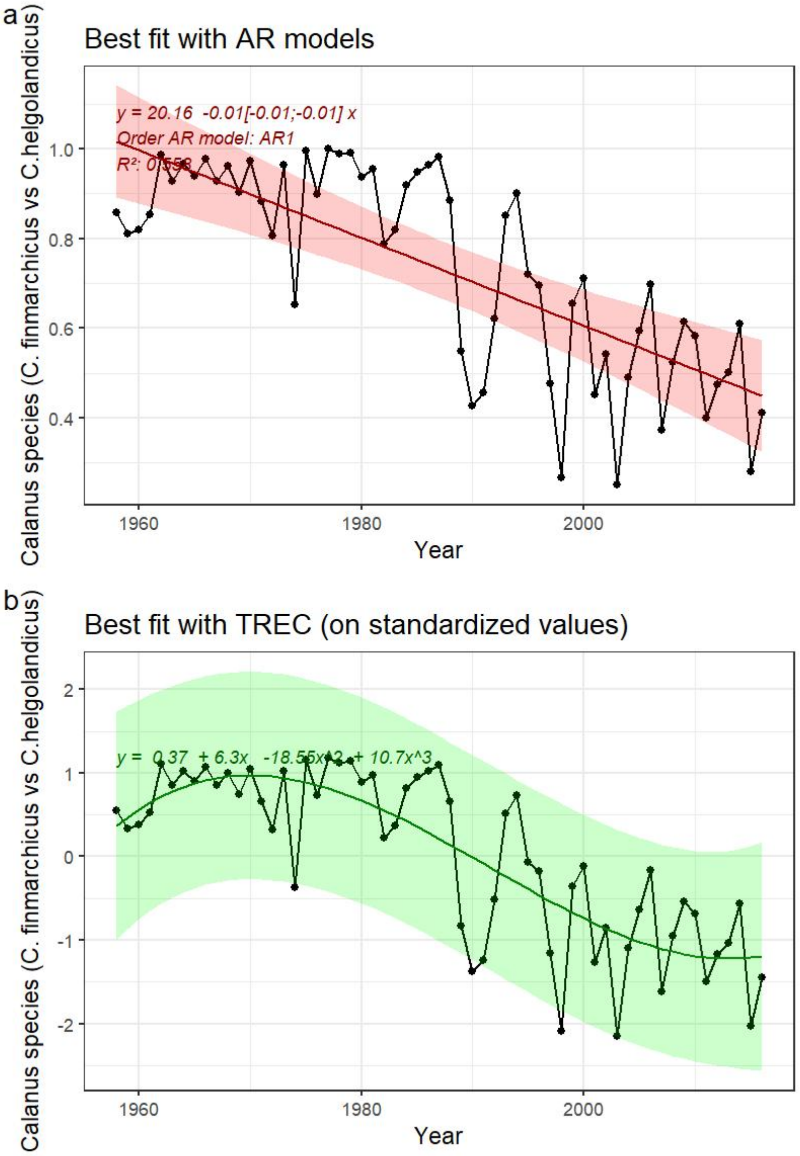


Figure13.1: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

There is a clear decline in the abundance of *C. finmarchicus* relative to that of *C. helgolandicus*. The time series of *C. helgolandicus* shows the most pronounced change (a significant increase), while the change in *C. finmarchicus* abundance is less pronounced (a decline that is not statistically significant). It should be noted that the decline of the latter species is less pronounced in the Norwegian sector of the North Sea than in other parts, probably due to advection from the Norwegian Sea and overwintering part of the population in the Norwegian Trench. The consequences of the changes for the other parts of the ecosystem are well documented and the evidence for the phenomenon this assessed as **high**.

13.4 Background data and supplementary analysis

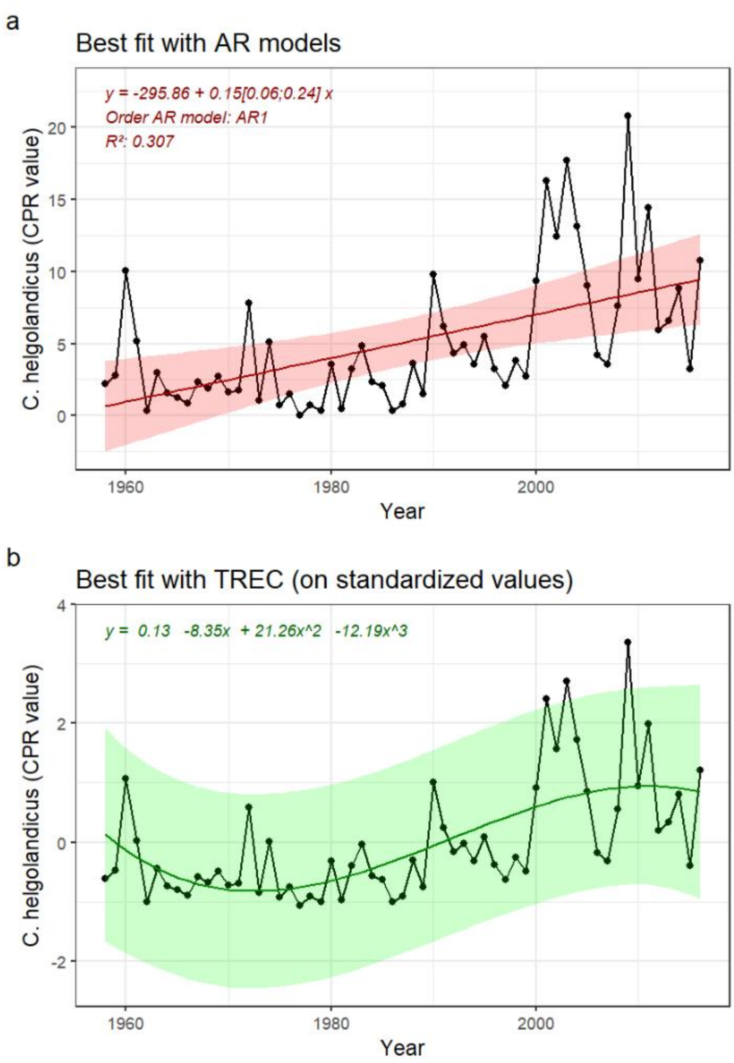


Figure 13.2: A) C. helgolandicus time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1^{st} order autoregressive model, AR2: 2^{nd} order autoregressive model, AR3: 3^{rd} order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

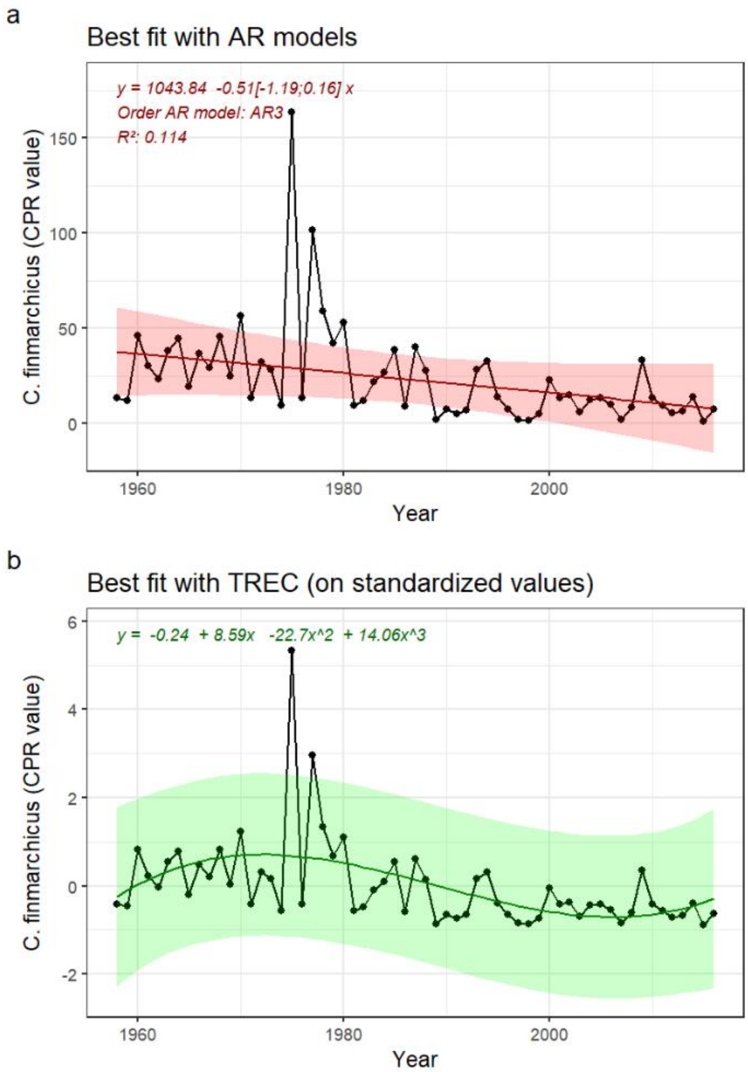


Figure 13.3: A) C. finmarchicus time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

13.5 Recommendations for future development of the indicator

14 Indicator: Abundance of *Pseudocalanus / Paracalanus* species [NI14]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Declining abundance of Pseudocalanus spp. and Paracalanus spp. [NP14]

Main driver: Climate change

14.1 Supplementary metadata

None

14.2 Supplementary methods

None

14.3 Plots of indicator values

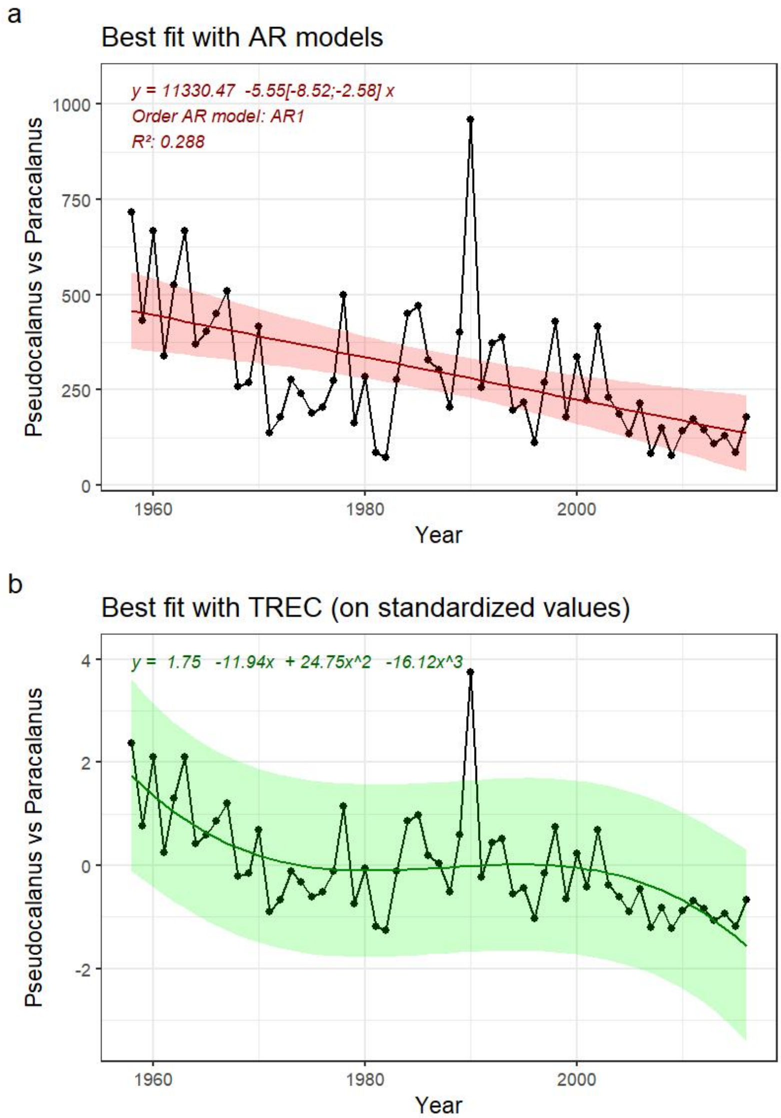


Figure 14: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

There is clear decline in the time series that can be attributed to effects of climate change. Together, the two taxa constitute the most important group of copepods for higher trophic levels after the Calanus species, and the expected consequences of the changes for other parts of the ecosystem are there considered to be large, and the evidence of the phenomenon assessed as **high**.

14.4 Background data and supplementary analysis

14.5 Recommendations for future development of the indicator

15 Indicator: Cod stock size [NI15]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decreasing cod stock size [NP15]

Main driver: Fisheries and climate change

15.1 Supplementary metadata

None

15.2 Supplementary methods

None

15.3 Plots of indicator values

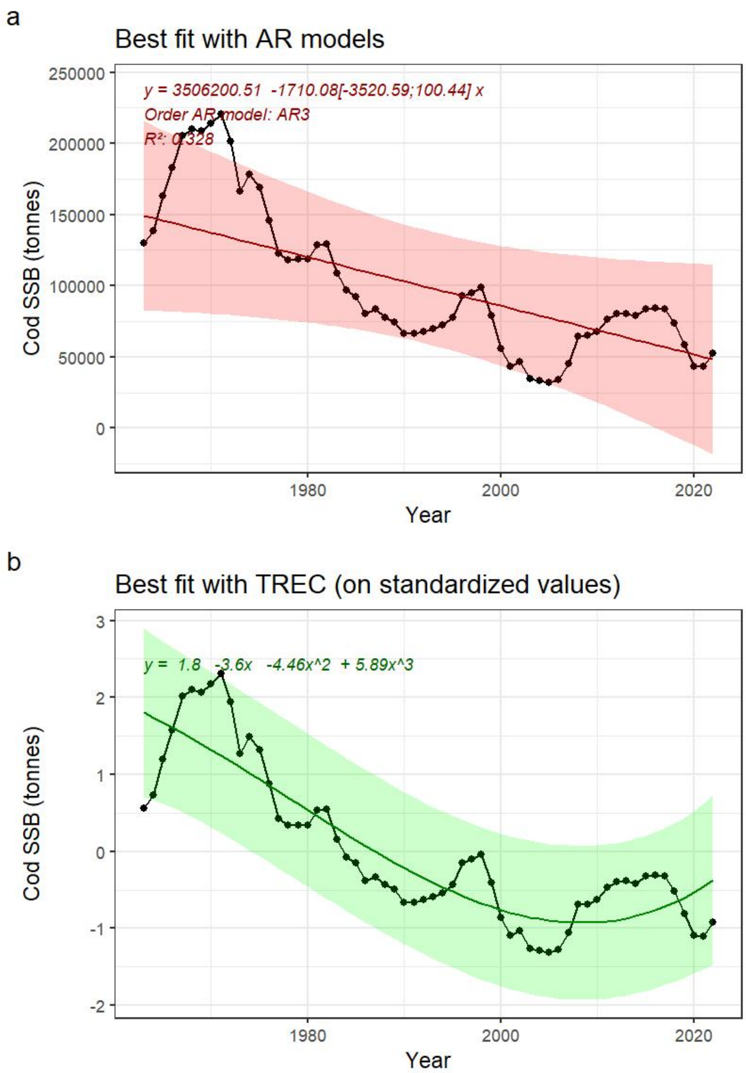


Figure 15: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

Strong fisheries pressure brought the stock to low levels until the late 1990s. Climate might currently limit the recovery of the stock (thermal pressure), also driving northward displacement out of the North Sea. There is thus **high evidence** of decreasing stock size because of human activities

15.4 Background data and supplementary analysis

15.5 Recommendations for future development of the indicator

16 Indicator: Cod recruitment [NI16]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decreasing cod recruitment [NP16]

Main driver: Fisheries and climate change

16.1 Supplementary metadata

None

16.2 Supplementary methods

None

16.3 Plots of indicator values

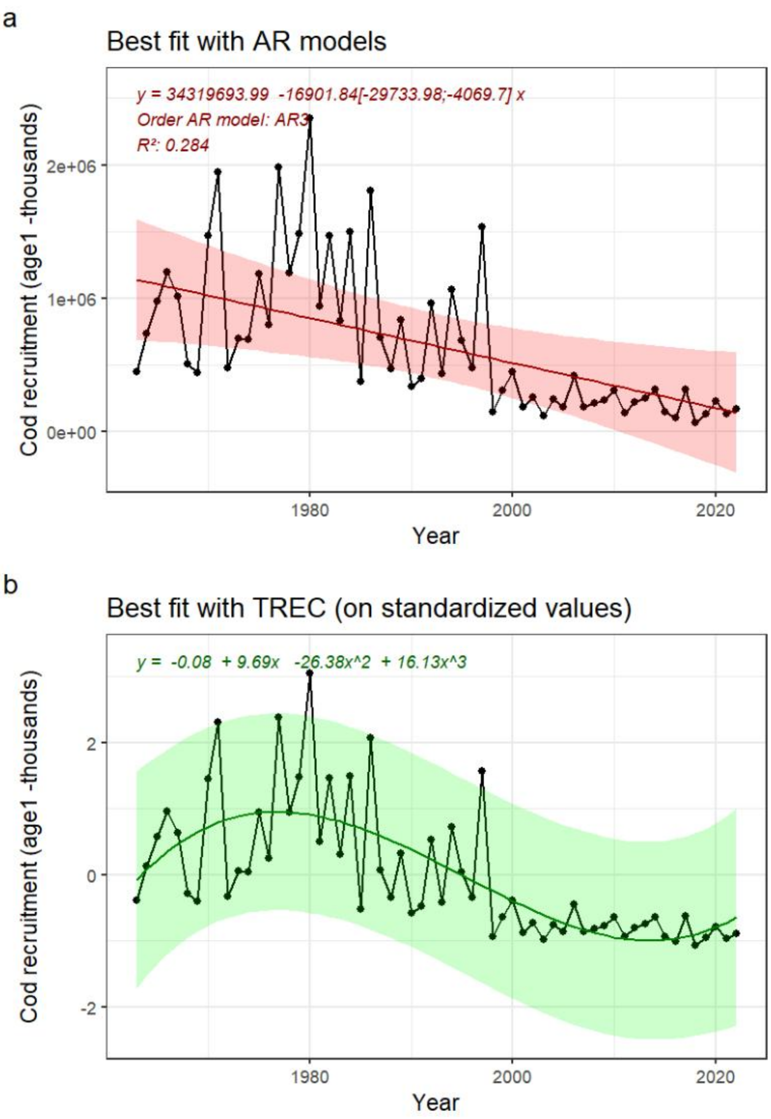


Figure 16: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

Interannual variability has largely decreased since the late 1990s likely due to climate change (Beaugrand et al., 2003; Beaugrand and Kirby, 2010). There is thus high evidence of decrease of the recruitment away from reference conditions. Although the impact on the ecosystem is potentially high (niche replacement by haddock, importance of juveniles as food items), there are considerable uncertainties about this, and the evidence for the phenomenon is therefore rated as **intermediate**.

16.4 Background data and supplementary analysis

16.5 Recommendations for future development of the indicator

17 Indicator: Haddock stock size [NI17]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decreasing haddock stock size [NP17]

Main driver: Fisheries and climate change

17.1 Supplementary metadata

None

17.2 Supplementary methods

None

17.3 Plots of indicator values

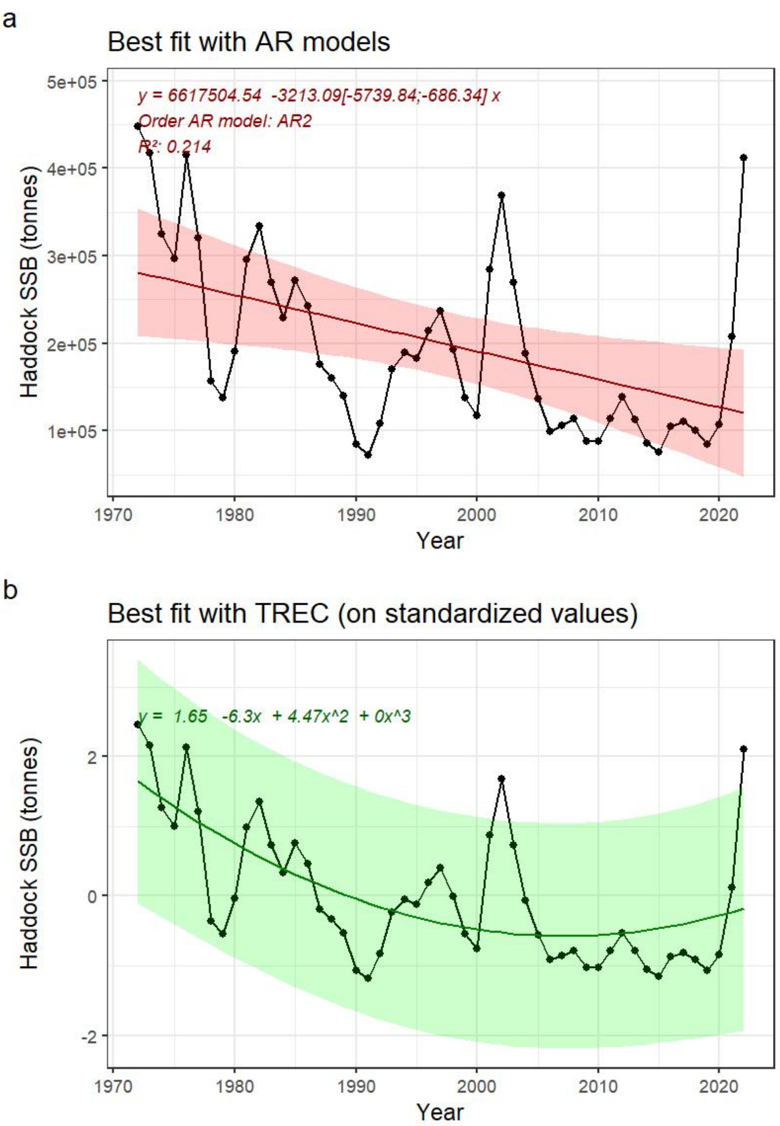


Figure 17: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

SSB was higher and very variable before 2005. It stabilized at lower levels since then but is now peaking because of good recruitment in 2019-2020. There is thus **low evidence** of a decline in haddock SSB.

17.4 Background data and supplementary analysis

17.5 Recommendations for future development of the indicator

18 Indicator: Haddock recruitment [NI18]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decreasing haddock recruitment [NP18]

Main driver: Fisheries, climate change and accidental oil blowouts

18.1 Supplementary metadata

None

18.2 Supplementary methods

None

18.3 Plots of indicator values

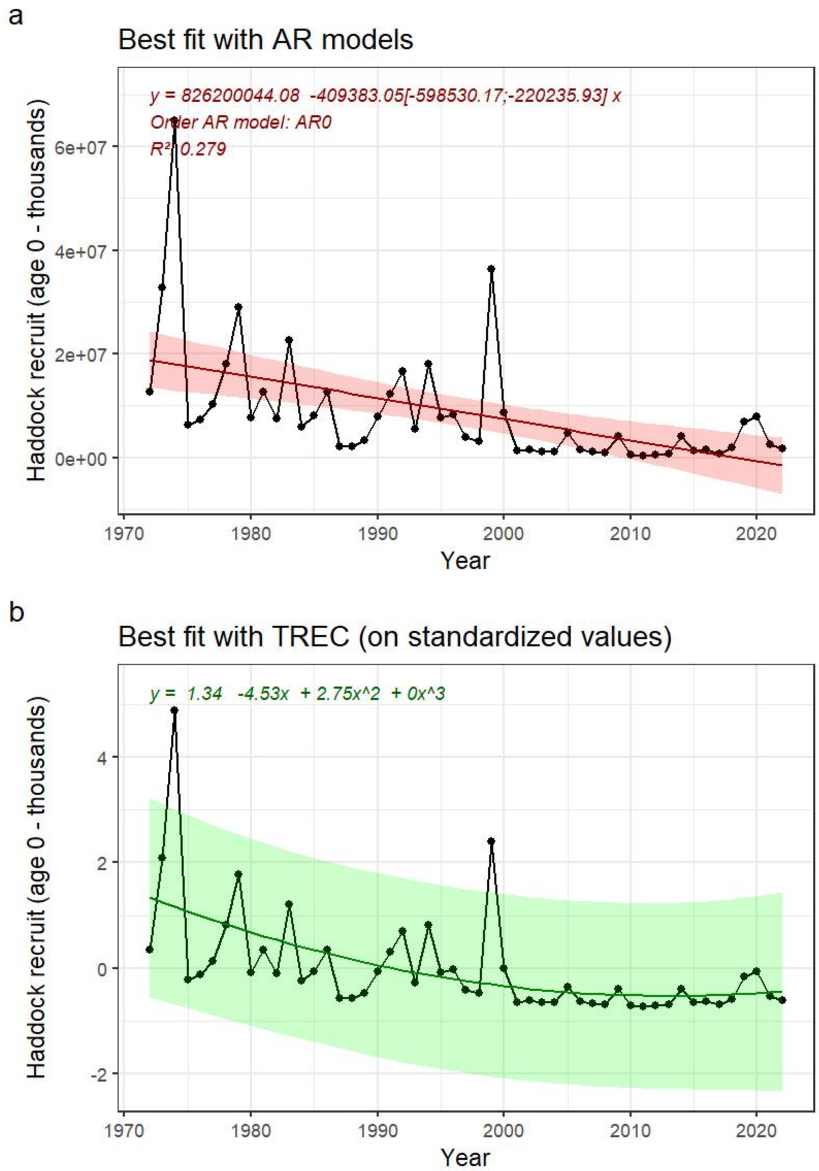


Figure 18: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

According to the assessment, the recruitment has strongly decreased over the last 50 years. The low level in the 2000s are likely linked to fishing and/or climate change. However, the drivers of the current state of haddock recruitment are hard to identify. The consequences for the ecosystem are not well understood, therefore the evidence for the phenomenon is assessed as **intermediate**.

18.4 Background data and supplementary analysis

18.5 Recommendations for future development of the indicator

19 Indicator: Saithe stock size [NI19]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decreasing saithe stock size [NP19]

Main driver: Fisheries, climate change and eutrophication

19.1 Supplementary metadata

None

19.2 Supplementary methods

None

19.3 Plots of indicator values

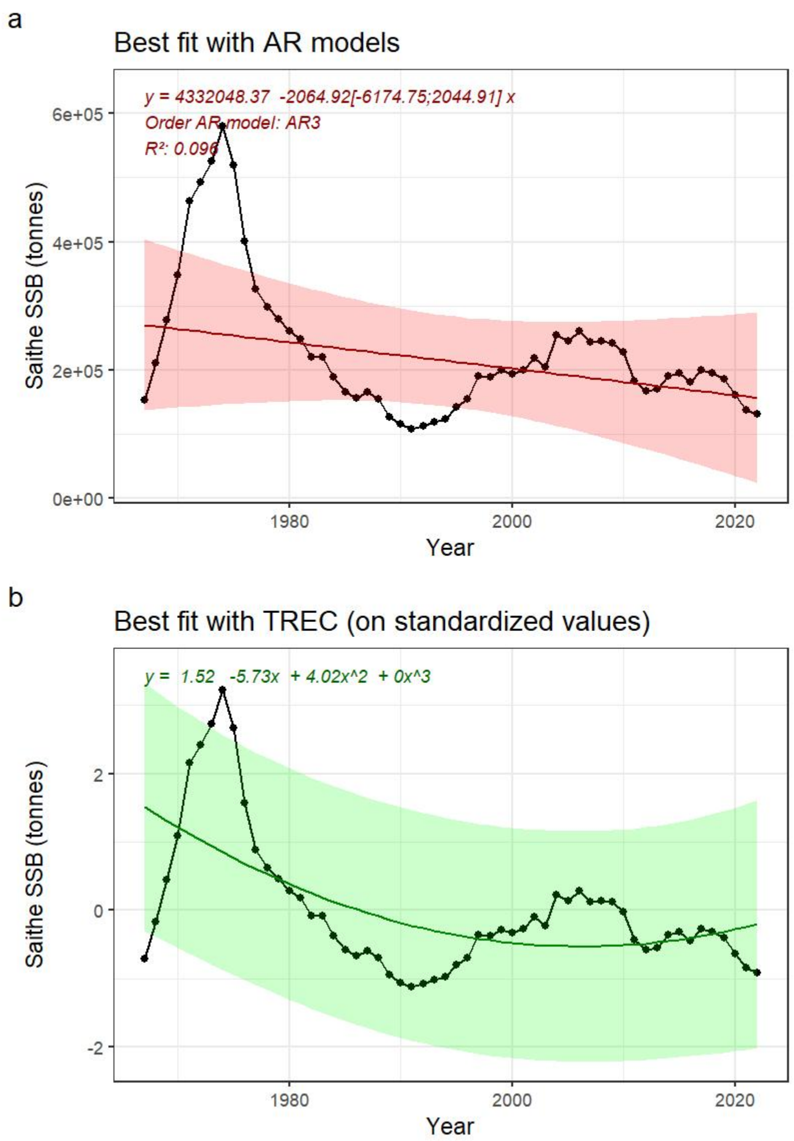


Figure 19: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

Although the overall trend is showing a decline when including the gadoid outburst, the recent trends is rather flat and stable. The low biomass of the last 10 years is concomitant with low recruitment. Moreover, due to little evidence of isolation from adjacent stocks, and the high mobility of saithe, it cannot be discounted that this may be linked to changes of the population spatial distribution (changing overlap between the population and the management unit domain). There is thus **low evidence** for a decline in Saithe SSB caused by anthropogenic activities.

19.4 Background data and supplementary analysis

19.5 Recommendations for future development of the indicator

20 Indicator : Saithe recruitment [NI20]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decreasing saithe recruitment [NP20]

Main driver: Fisheries, climate and eutrophication

20.1 Supplementary metadata

None

20.2 Supplementary methods

None

20.3 Plots of indicator values

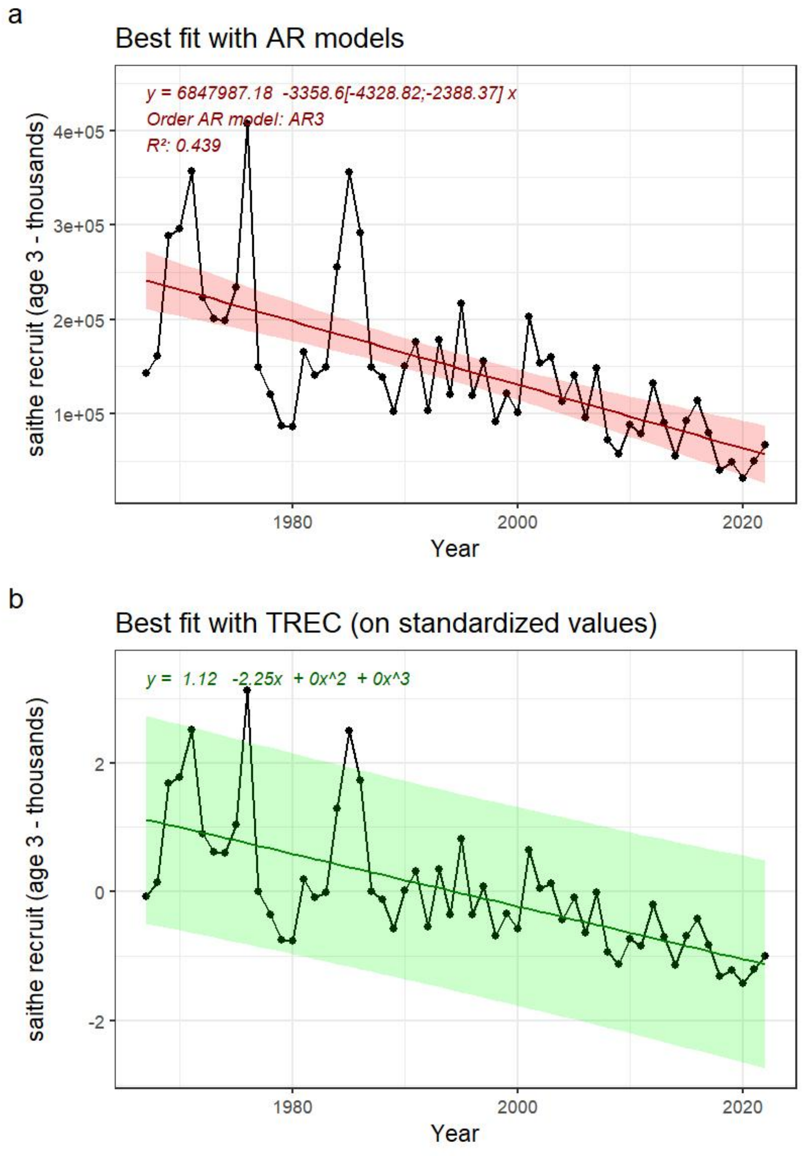


Figure 20: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1^{st} order autoregressive model, AR2: 2^{nd} order autoregressive model, AR3: 3^{rd} order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

There is quite high evidence of a decline in Saithe recruitment, and a decrease in interannual variability, but the consequences for the ecosystem are not well understood. There is thus **intermediate evidence** of a decline in saithe recruitment as a consequence of anthropogenic activities.

20.4 Background data and supplementary analysis

20.5 Recommendations for future development of the indicator

21 Indicator: Lesser sandeel stock size [NI21]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Lesser sandeel stock size [NI21]

Main driver: Fisheries, climate change and habitat degradation

21.1 Supplementary metadata

None

21.2 Supplementary methods

None

21.3 Plots of indicator values

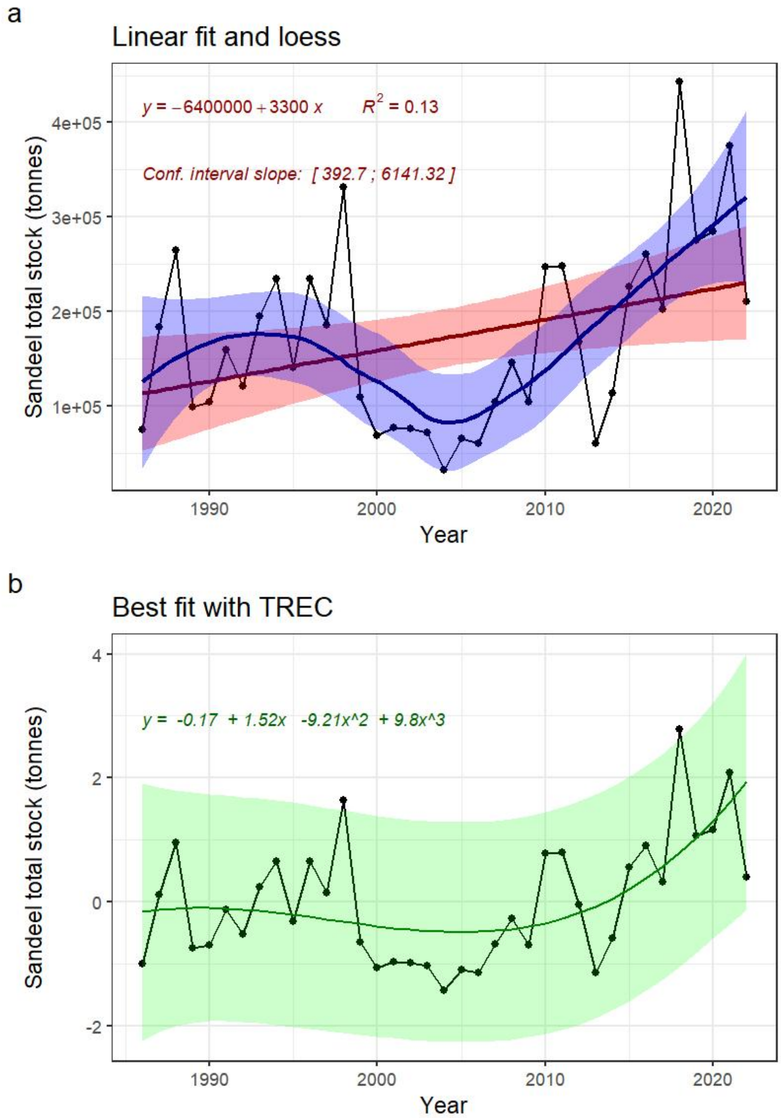


Figure 21: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

Recent management alleviated the fishing pressure and good recruitment has allowed a recovery of the stock. However, in section 5r, fishing on sandeel is prohibited as the stock size is very low and do not seem to recover. There is thus no evidence of recent decline of Lesser stock size due to anthropogenic drivers in the sector 3r, but high evidence in sector 5r.

21.4 Background data and supplementary analysis

21.5 Recommendations for future development of the indicator

22 Indicator: Lesser sandeel recruitment [NI22]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decreasing lesser sandeel recruitment [NP22]

Main driver: Fisheries, climate and pollution

22.1 Supplementary metadata

None

22.2 Supplementary methods

None

22.3 Plots of indicator values

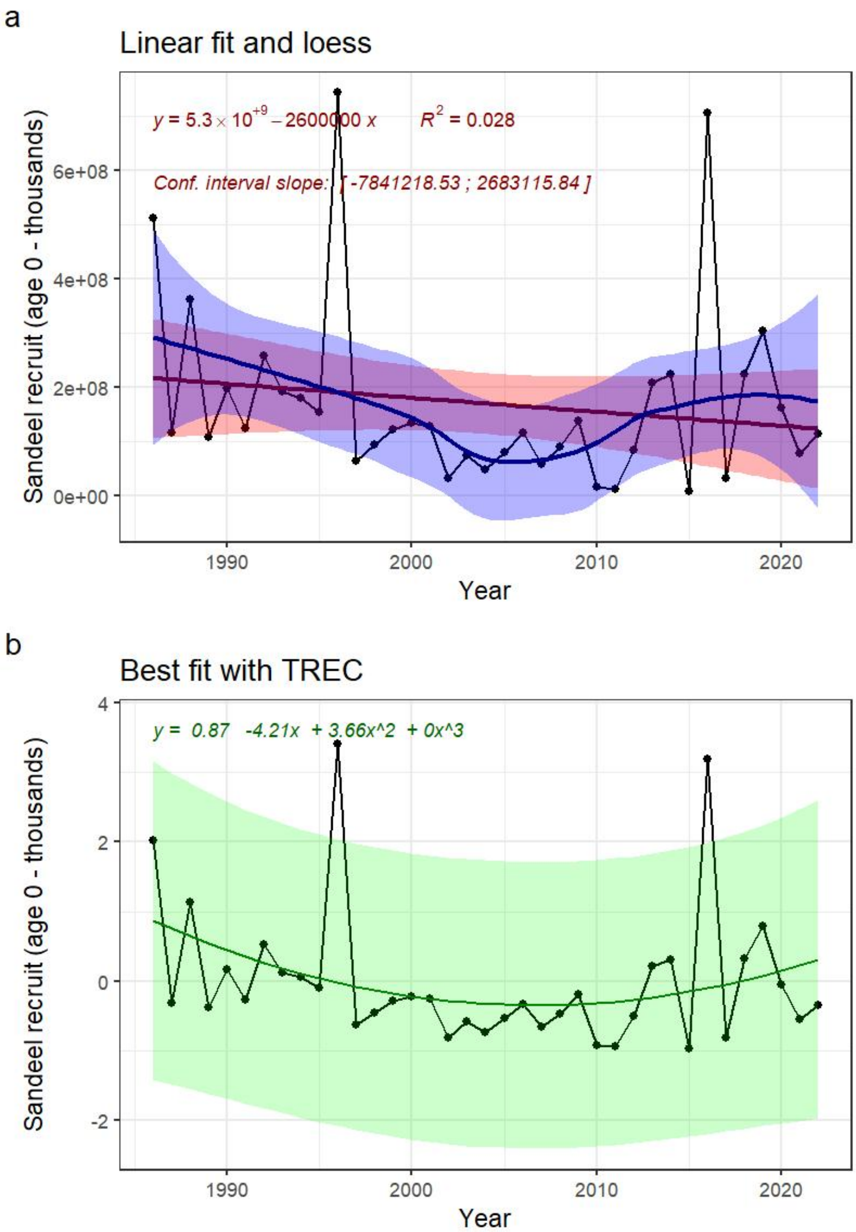


Figure 22: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

The period of low recruitment between 2000 and 2010 is likely du to overfishing. In the most recent decade, the interannual variability of recruitment is large, and the trend over the time period is not strong. There is this no evidence of a decrease in lesser sandeel recruitment in sector 3r. However, there are no data available for sector 5r so here, there are **insufficient evidence** for a decrease in recruitment of lesser sandeel.

22.4 Background data and supplementary analysis

22.5 Recommendations for future development of the indicator

23 Indicator: Norway pout stock size [NI23]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Stable Norway pout stock size [NP23]

Main driver: fisheries and climate change

23.1 Supplementary metadata

None

23.2 Supplementary methods

None

23.3 Plots of indicator values

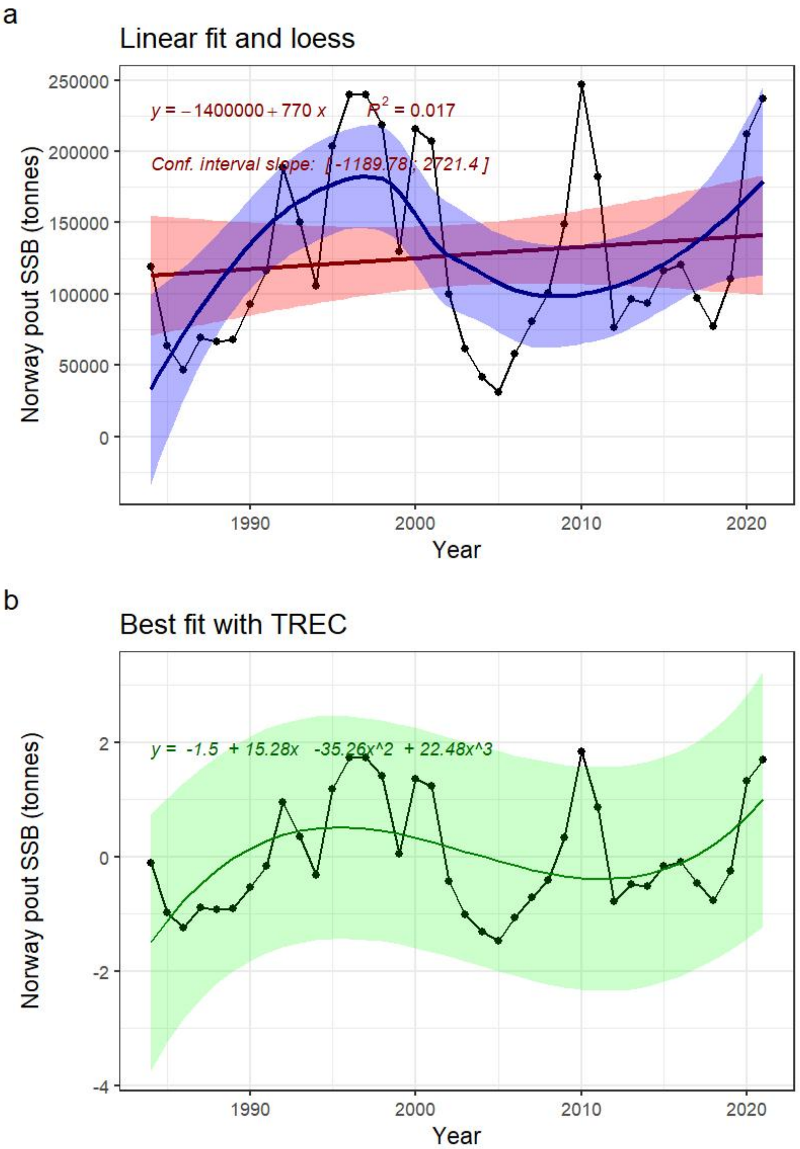


Figure 23: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on standardized time series.

Assessment of the evidence for the phenomenon

There are no strong signs of increase or decrease in the Norway pout. However, interannual variation cast large uncertainties around that statement, and the stock is currently recovering from high fishing pressure before 2000s. There is **low evidence** for a stable stock size of Norway pout.

23.4 Background data and supplementary analysis

23.5 Recommendations for future development of the indicator

24 Indicator : Norway pout recruitment [NI24]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Stable Norway pout recruitment [NP24]

Main driver: Fisheries and climate change

24.1 Supplementary metadata

None

24.2 Supplementary methods

None

24.3 Plots of indicator values

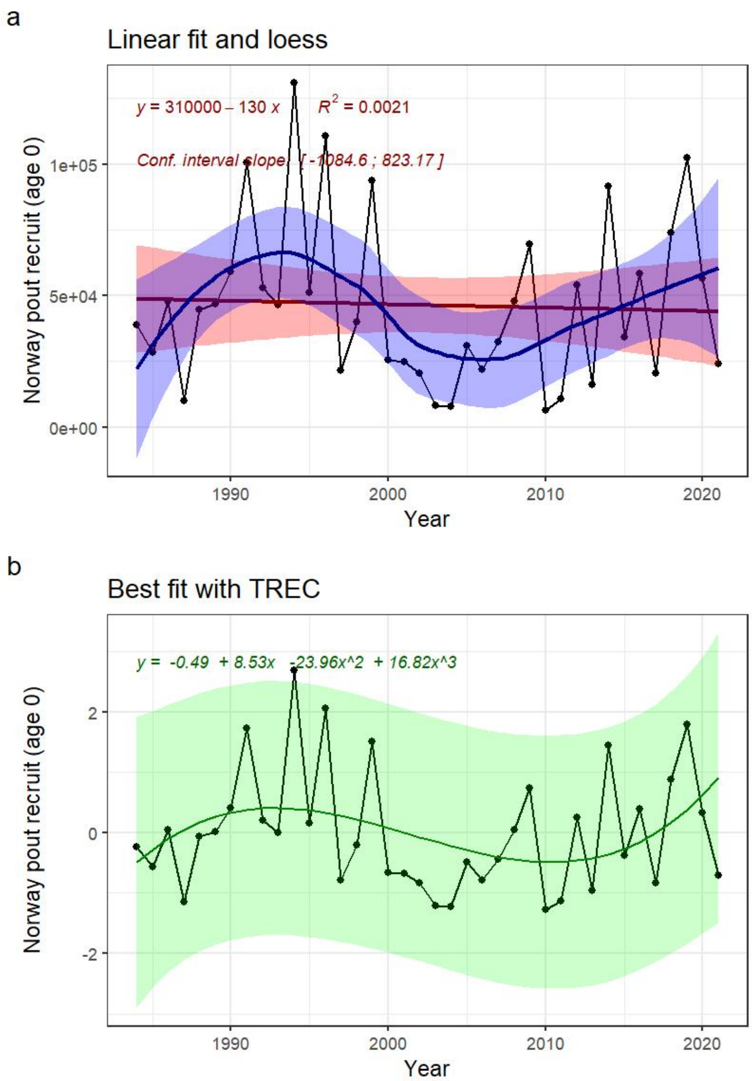


Figure 24: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

There are no strong signs of increase or decrease in the Norway pout recruitment. However, interannual variation cast large uncertainties around that statement, and the stock is currently recovering from high fishing pressure before 2000s. There is **low evidence** for a stable recruitment of Norway pout.

24.4 Background data and supplementary analysis

24.5 Recommendations for future development of the indicator

25 Indicator: Whiting stock size [NI25]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decreasing whiting stock size [NP25]

Main driver: Fisheries and climate change

25.1 Supplementary metadata

None

25.2 Supplementary methods

None

25.3 Plots of indicator values

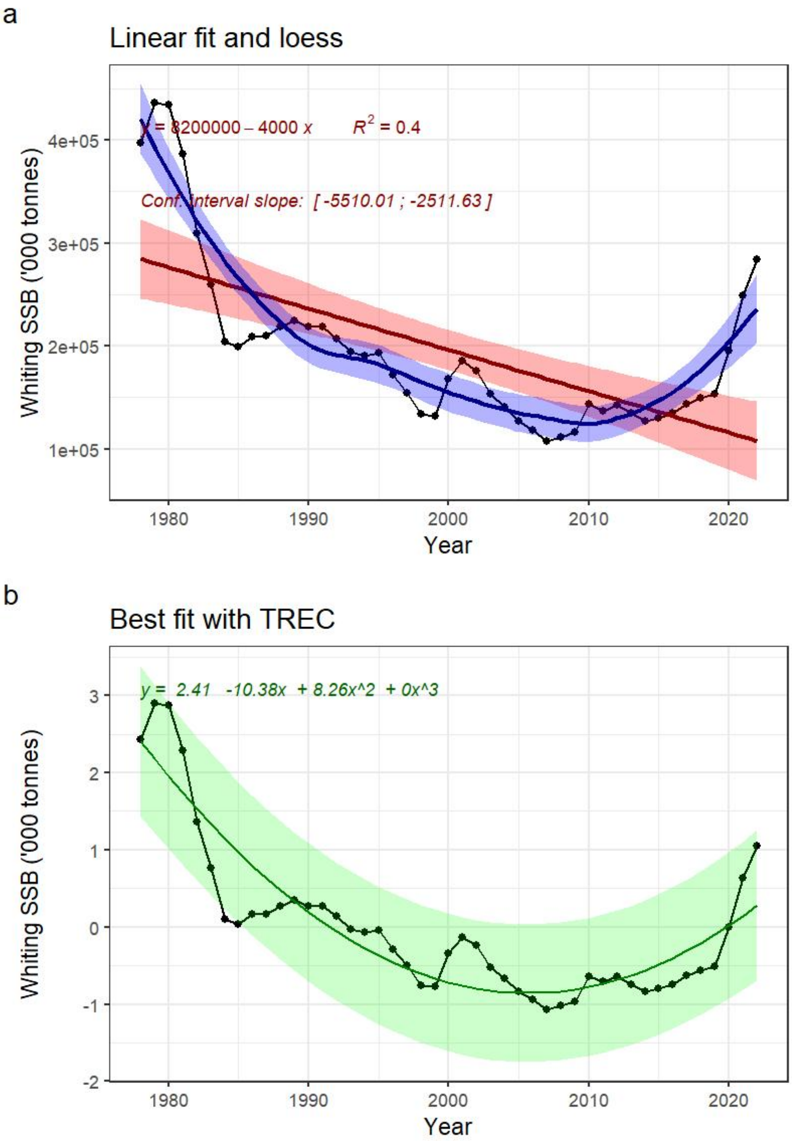


Figure 25: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

The first years of the time series may cover the end of the gadoid outburst, after which the whiting SSB continues a slower decrease until the 2010s, without strong ties to fishing pressure. The current SSB trend is increasing and there is **no evidence** of it being driven by anthropogenic pressure. Whiting remains a low-interest stock with little targeted fishing.

25.4 Background data and supplementary analysis

25.5 Recommendations for future development of the indicator

26 Indicator: Whiting recruitment [NI26]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decreasing whiting recruitment [NP26]

Main driver: Fisheries and climate change

26.1 Supplementary metadata

None

26.2 Supplementary methods

None

26.3 Plots of indicator values

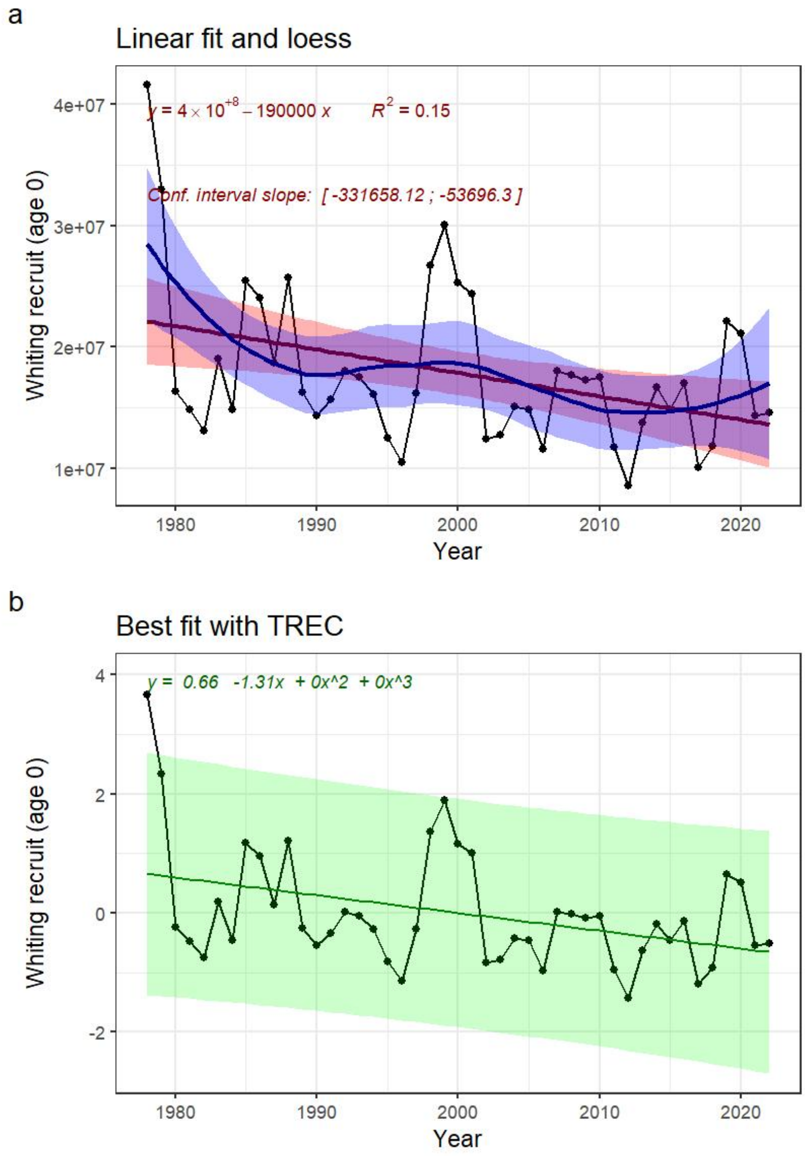


Figure 26: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

The earliest years had the highest recruitment estimates, which in turn influenced the slope. While there is high interannual variability in whiting recruitment, no significant downward trend can be seen. There is thus **low evidence** of a decrease in whiting recruitment resulting from anthropogenic impacts.

26.4 Background data and supplementary analysis

26.5 Recommendations for future development of the indicator

27 Indicator: Herring stock size [NI27]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decreasing herring stock size [NP27]

Main driver: Fisheries and climate change

27.1 Supplementary metadata

None

27.2 Supplementary methods

None

27.3 Plots of indicator values

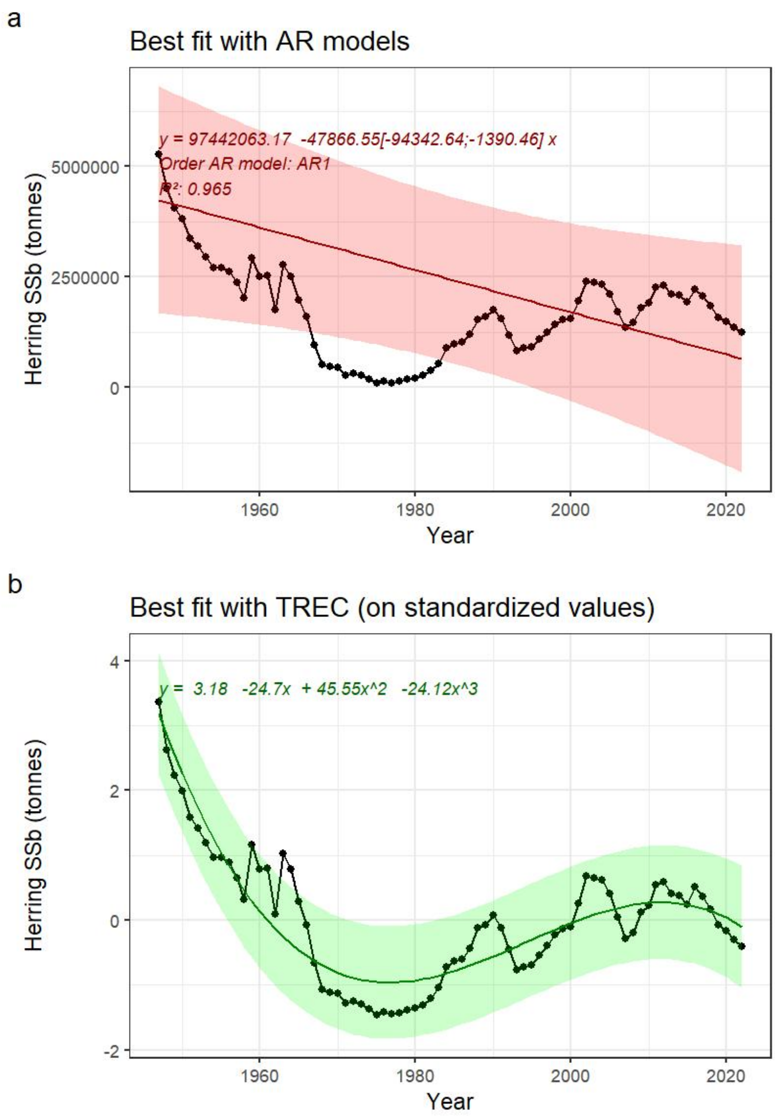


Figure 27: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

Initial decline is likely du to fisheries up to the late 1970s. Species interactions but also climate change (since 2000s: change in zooplankton community, new predators) could be hampering the recovery of the stock despite better management. Impact on the ecosystem might have occurred during the 1980s, but there is high uncertainty about this. There is this thus **intermediate evidence** for the decline of herring SSB.

27.4 Background data and supplementary analysis

27.5 Recommendations for future development of the indicator

28 Indicator: Herring recruitment [NI28]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decreasing herring recruitment [NP28]

Main driver: Fisheries and climate change

28.1 Supplementary metadata

None

28.2 Supplementary methods

None

28.3 Plots of indicator values

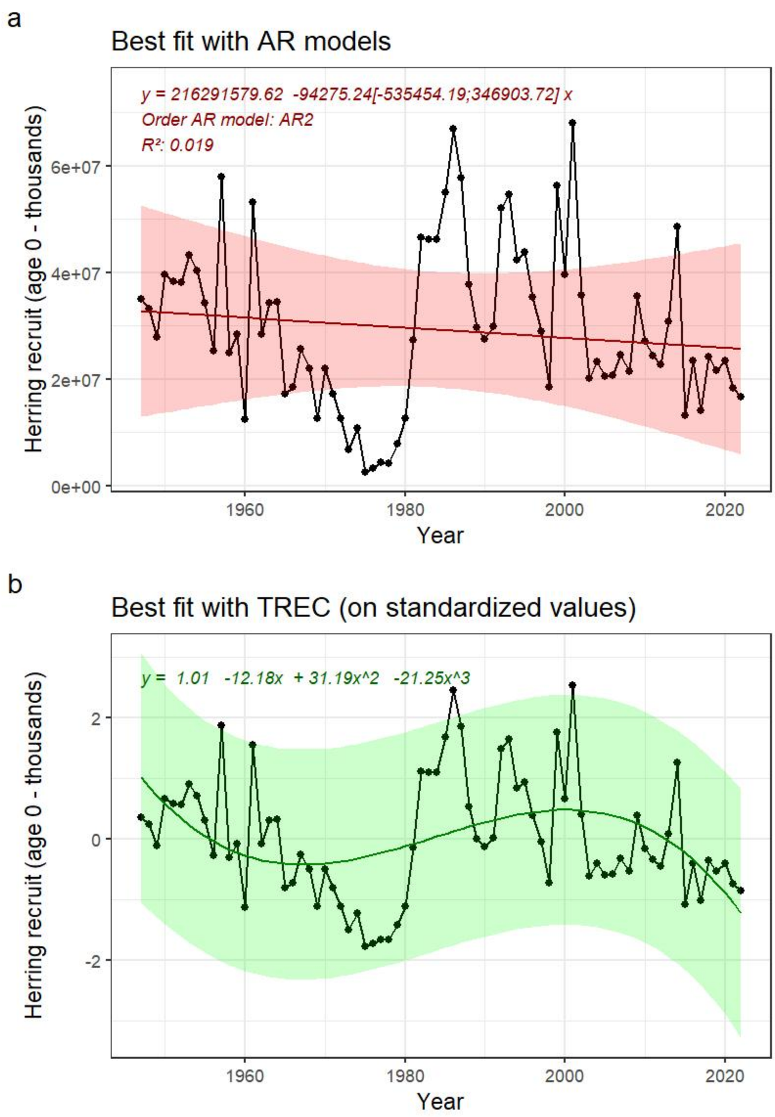


Fig 28: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

Low levels of SSB are associated with low recruitment in the late 1970s (fisheries driven probably) and since the 2000s the recruitment is at a lower level (likely linked to climate change). This has a known impact on herring SSB. The evidence for decline of herring recruitment is thus **intermediate**.

28.4 Background data and supplementary analysis

28.5 Recommendations for future development of the indicator

29 Indicator: Mackerel stock size [NI29]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decreasing mackerel stock size [NP29]

Main driver: Fisheries and climate change

29.1 Supplementary metadata

None

29.2 Supplementary methods

None

29.3 Plots of indicator values

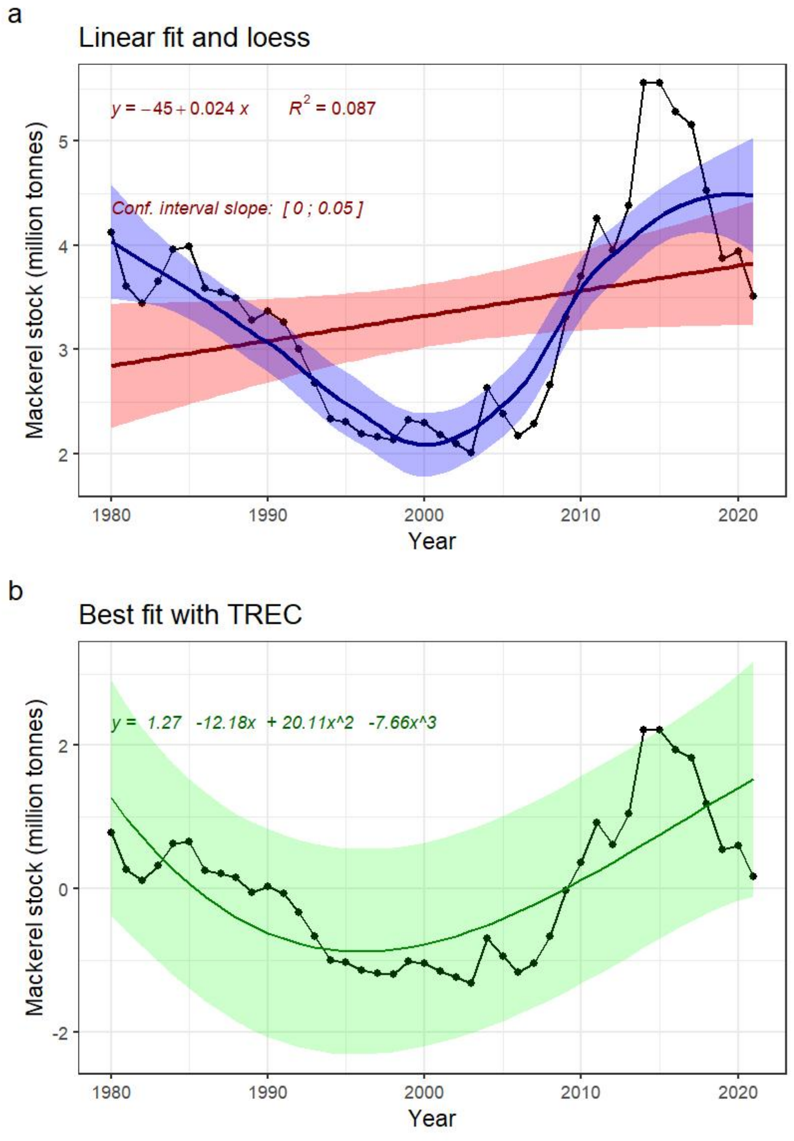


Fig.29: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

The early decline is likely link to overfishing. Prolonged overfishing in the recent years is hidden by good recruitment and years classes, but the stock size should be higher with less fishing (WGWIDE report). There is thus **intermediate evidence** for this phenomenon.

29.4 Background data and supplementary analysis

29.5 Recommendations for future development of the indicator

30 Indicator: Mackerel recruitment [NI30]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Change in mackerel recruitment [NP30]

Main driver: Fisheries and climate change

30.1 Supplementary metadata

None

30.2 Supplementary methods

None

30.3 Plots of indicator values

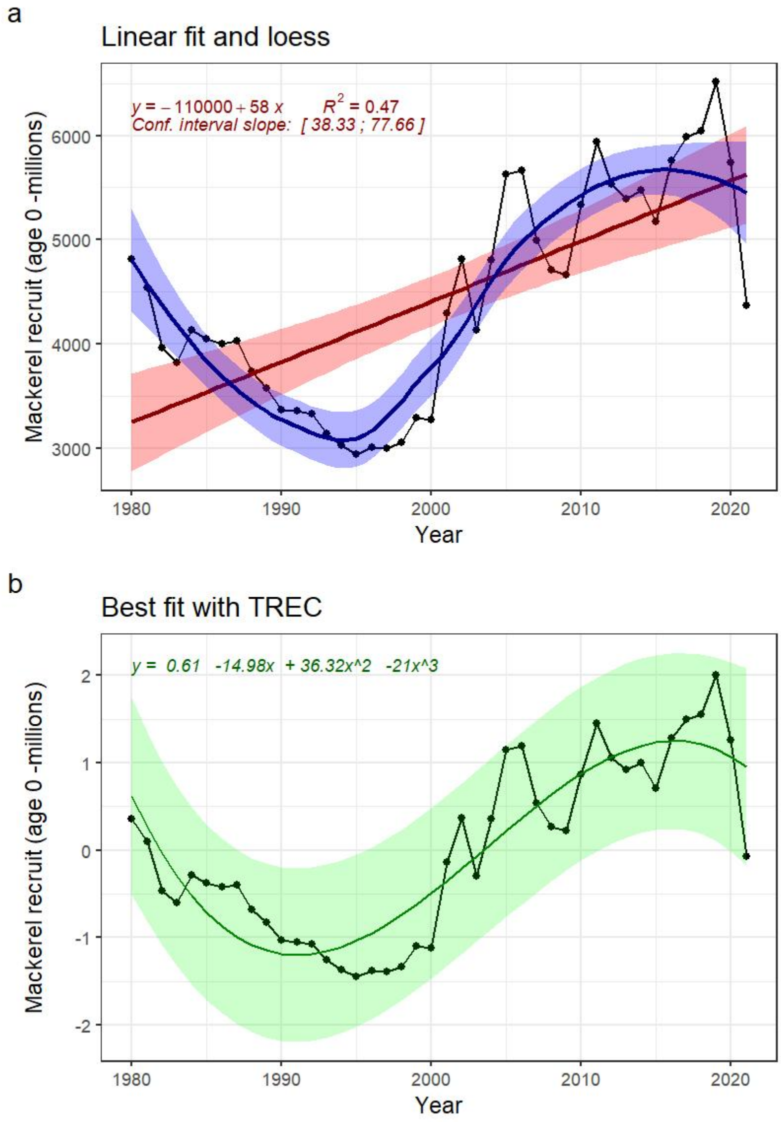


Fig. 30: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

After the 2000s, recruitment has improved, maybe because of climate change, but the processes are uncertain. There is **low/intermediate evidence**.

30.4 Background data and supplementary analysis

30.5 Recommendations for future development of the indicator

31 Indicator: Shrimp stock size [NI31]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decreasing shrimp recruitment [NP32]

Main driver: fisheries climate change and pollution

31.1 Supplementary metadata

None

31.2 Supplementary methods

None

31.3 Plots of indicator values

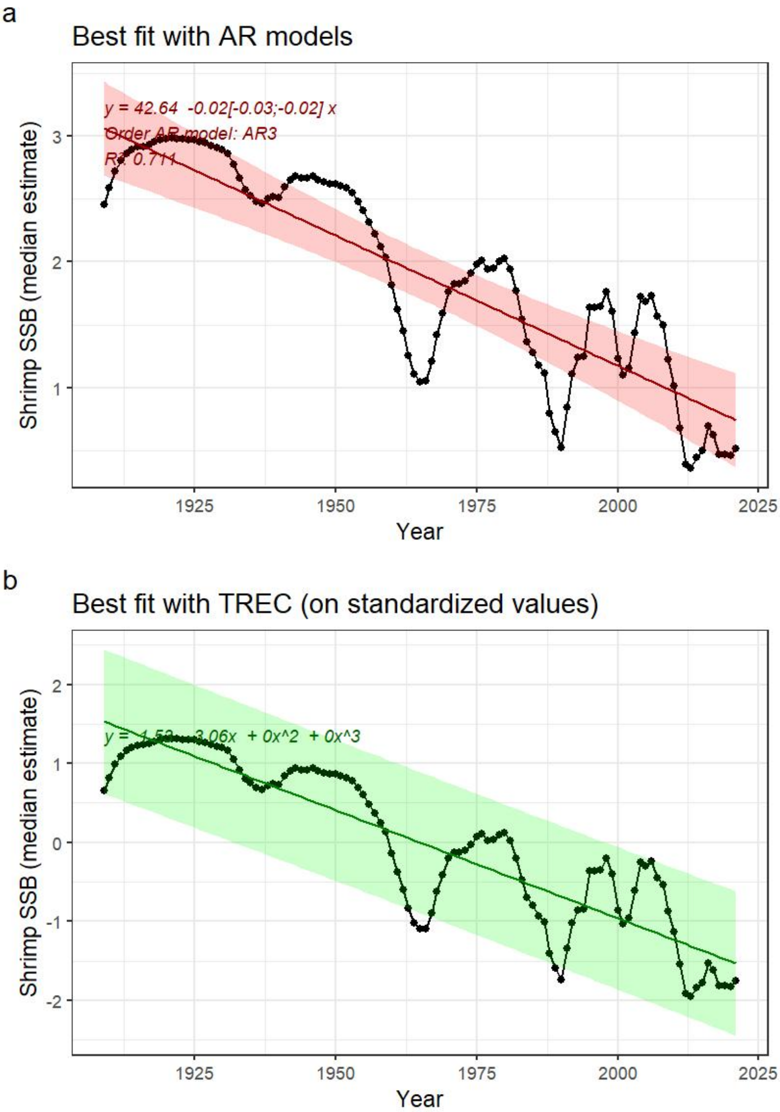


Fig. 31.1: a) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. b) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

The current stock size is very low compared to what is estimated 120 years ago. Predators' stocks are low, and higher shrimp stock levels would be expected under such conditions. Current low recruitment might be driving the low stock size. Fishing pressure is also higher now than in the past. There is **high** level of evidence that the expected changes have occurred

31.4 Background data and supplementary analysis

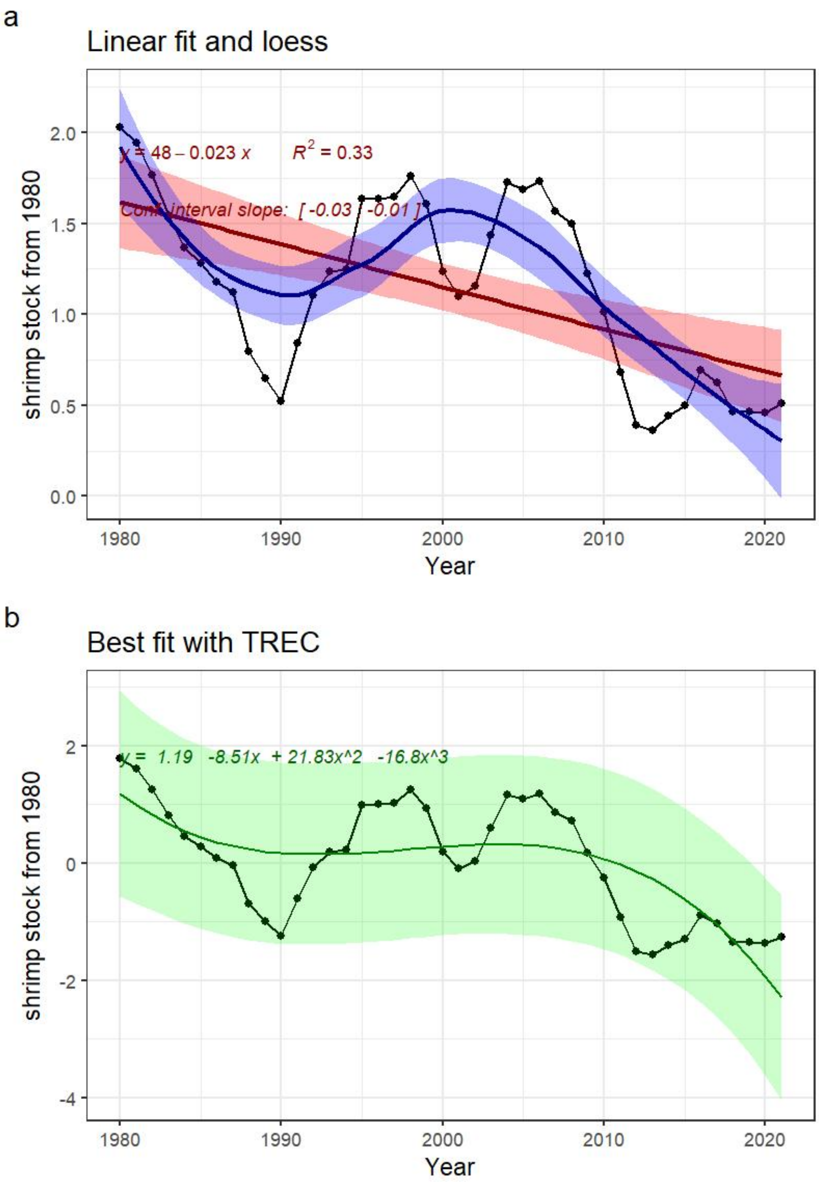


Fig. 31.2: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

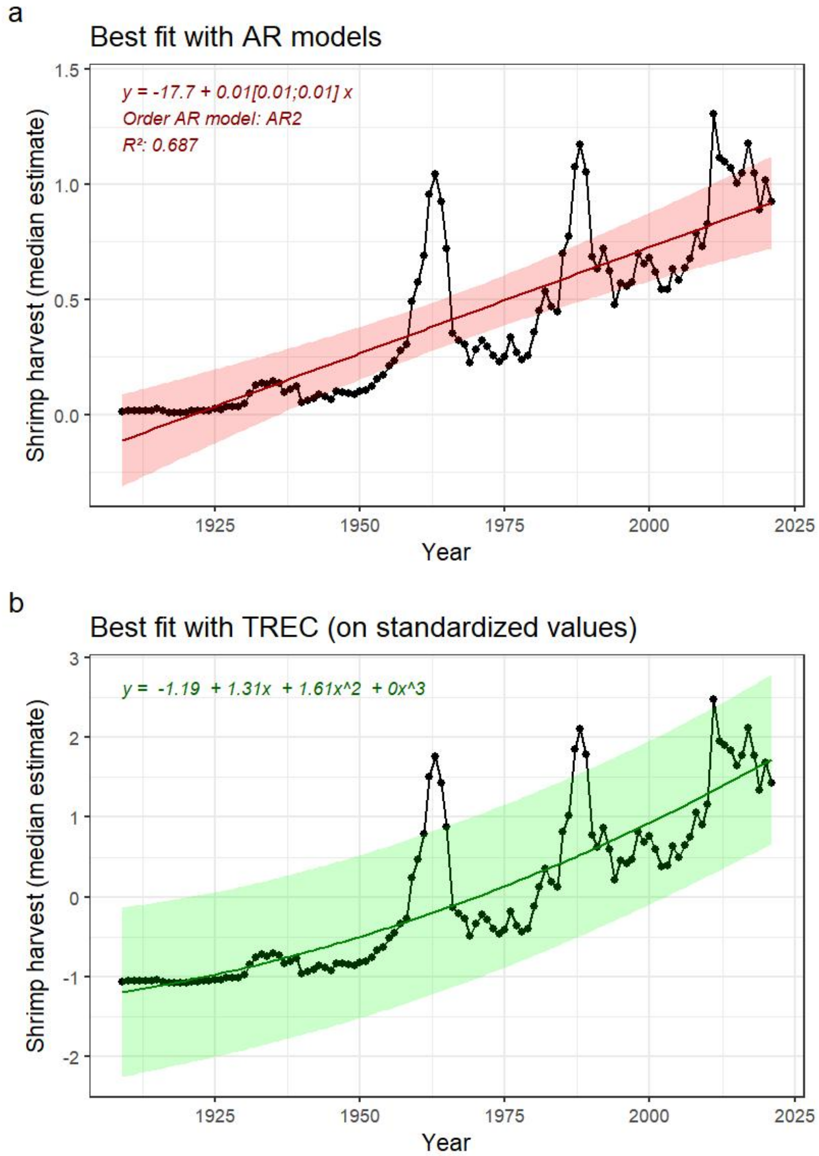


Fig. 31.3: A) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

31.5 Recommendations for future development of the indicator

32 Indicator: Shrimp recruitment [NI32]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decreasing shrimp stock size [NP31]

Main driver: fisheries, climate change and pollution

32.1 Supplementary metadata

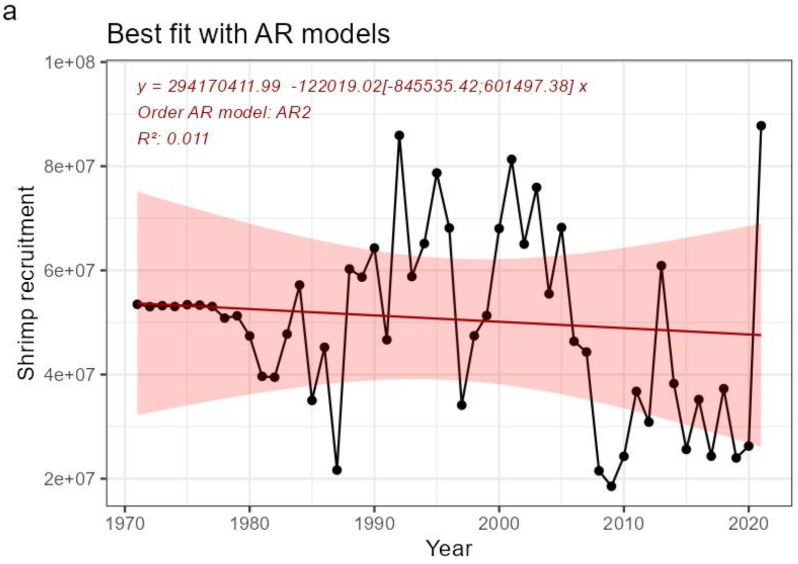
None

32.2 Supplementary methods

None

32.3 Plots of indicator values

a



b

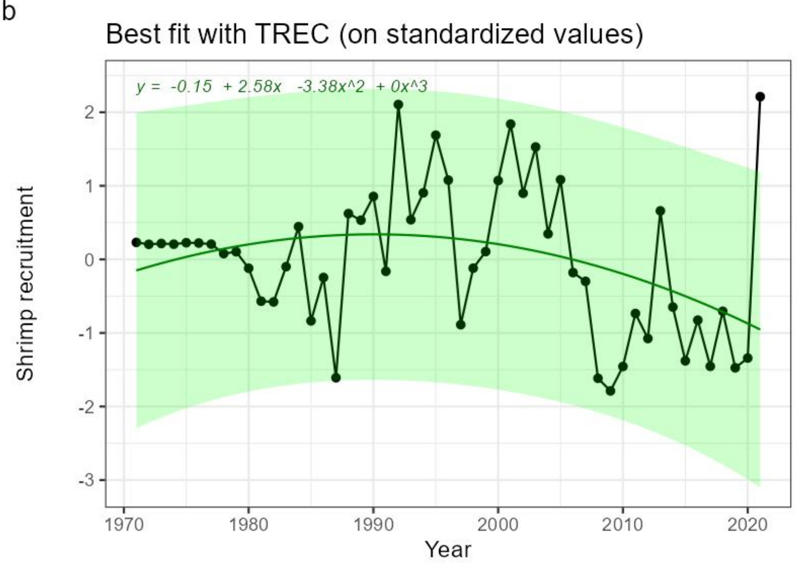


Fig.32.1: a) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. b) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

Productivity level in the stock is now lower than expected under reference conditions. Low recruitment started to occur before the stock size decreased, so the fishing mortality might not be at levels where it becomes problematic for the recruitment. In is uncertain what is driving the current low levels of recruitment. There is thus **intermediate evidence** for the phenomenon.

32.4 Background data and supplementary analysis

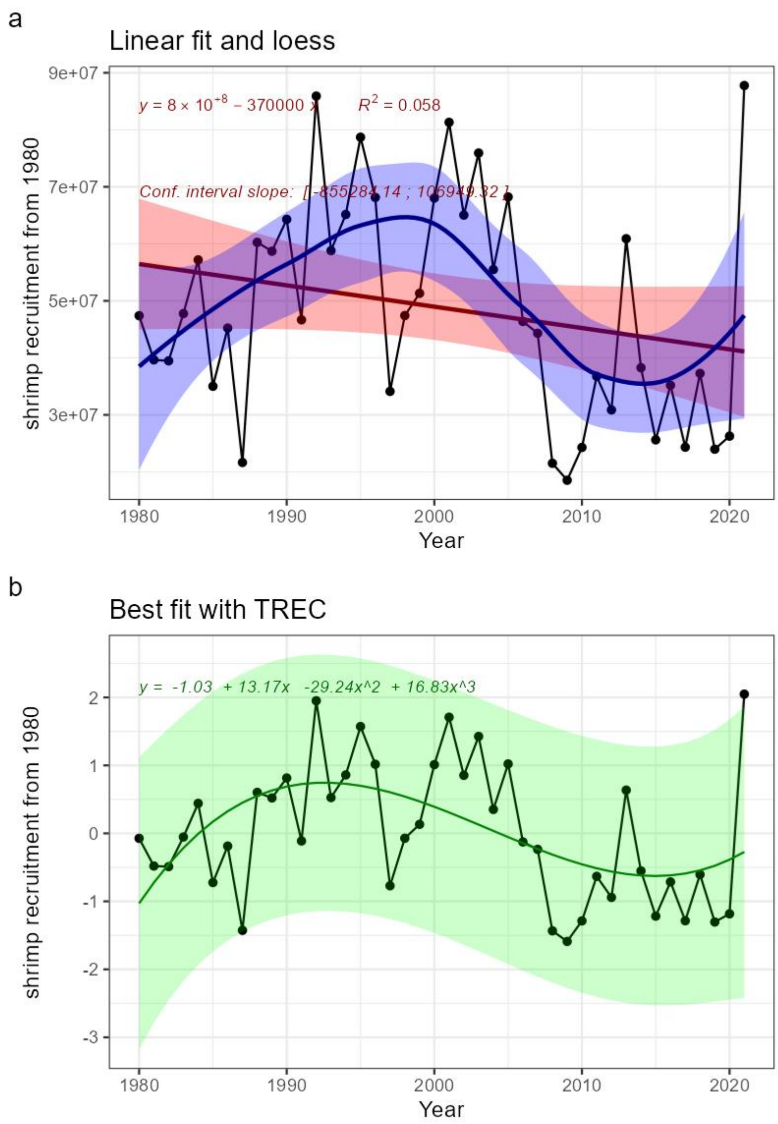


Fig. 32.2: Indicator time series and fitted trends. a) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. b) Best fitted trend using the first steps of a TREC analysis on standardized time series

32.5 Recommendations for future development of the indicator

33 Indicator: Area unimpacted by bottom trawling [NI33]

Ecosystem characteristic: Landscape-ecological patterns

Phenomenon: decreasing area unimpacted by bottom trawling

Main driver: Fisheries

33.1 Supplementary metadata

The phenomenon is evaluated using results from several publications (see below)

33.2 Supplementary methods

The phenomenon is assessed using an indicator for relative benthic status (RBS), which has been recommended as the best performing of three quantitative indicators for bottom trawling impact (Rijnsdorp et al., 2020). As the reference condition for this phenomenon is low impact of industrial scale trawling, any significant impact from the current industrial trawling fisheries is considered deviation from the reference condition.

An estimate for RBS is taken Pitcher et al. (2022). As this estimate has been made for the entire North Sea, maps showing the spatial distribution of trawling are used to assess how the estimate applies to the Norwegian sector.

33.3 Plots of indicator values

RBS varies between 0 and 1, where a value of 1 is considered to reflect a benthic community not impacted by trawling and a value of 0 the total removal of the benthic community sensitive to trawling. Using data for the years 2008-2010, the percentage of the region with RBS=1 for the North Sea was 11.2%. Fraction of the region with RBS=0 was 3.4% and average RBS for the entire region 0.82 (Pitcher et al., 2022). The corresponding figures for Skagerrak and Kattegat, which covers a part the easternmost section of the assessment area the corresponding numbers are 26.7% (fraction of region with RBS=1), 22.6% (fraction region with RBS=0) and 0.63 (average RBS for the region) (Pitcher et al., 2022). An impact has been sustained also for more recent years. Using vessel monitoring system (VMS) and logbook data ICES estimates that mobile bottom trawls used by commercial fisheries in the 12 m+ vessel category have been deployed over approximately 490 185 km2 of the North Sea ecoregion in 2018, corresponding to ca. 73.1 % of the ecoregion’s spatial extent (ICES, 2021a). Data on the geographic distribution of trawling activity for the years 2017-2020 shows that a considerable part of this takes place in the Norwegian sect or (Fig ANS.27.1).

There is clear evidence that a significant part of the assessment area is impacted by bottom trawling. This is expected to have significant ecosystem consequences. The evidence for the phenomenon is thus rated as **high**.

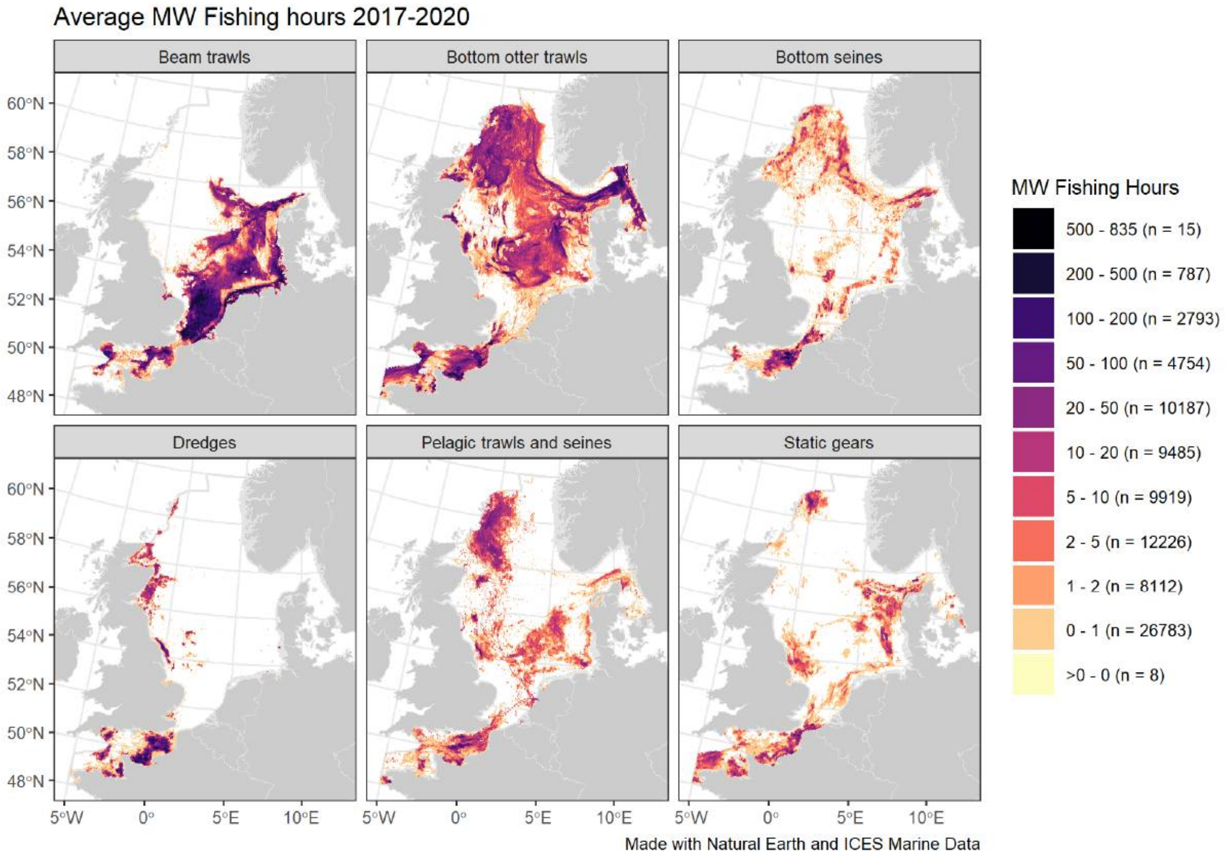


Figure 33. Spatial distribution of average annual fishing effort (MW fishing hours) in the Greater North Sea, by gear type. Fishing effort data are only shown for vessels >12 m with vessel monitoring systems (VMS). Source ICES (2021b).

33.4 Background data and supplementary analysis

33.5 Recommendations for future development of the indicator

34 Indicator : Fish species vulnerable to higher temperature [NI34]

Ecosystem characteristic: Biological diversity

Phenomenon: Decreasing biomass of fish vulnerable to higher temperatures [NP34]

Main driver: Climate change

34.1 Supplementary metadata

None

34.2 Supplementary methods

None

34.3 Plots of indicator values

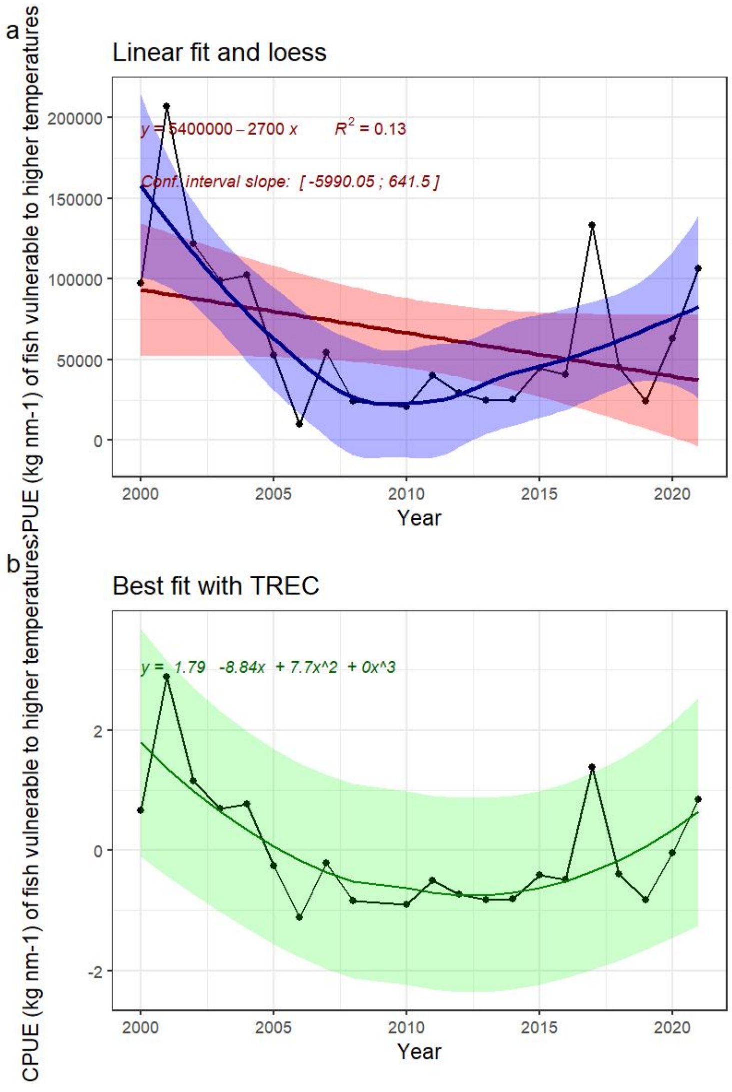


Fig.34: Indicator time series and fitted trends. a) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. b) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

The biomass of cold-water species has decreased then increased over the period. The trend is negative, but the confidence interval of the slope includes 0. There is thus **no evidence** of decrease for this indicator

34.4 Background data and supplementary analysis

34.5 Recommendations for future development of the indicator

35 Indicator: Fish species benefitting from higher temperature [NI35]

Ecosystem characteristic: Biological diversity

Phenomenon: Increasing biomass of fish species benefitting from higher temperature [NP35]

Main driver: climate change

35.1 Supplementary metadata

None

35.2 Supplementary methods

None

35.3 Plots of indicator values

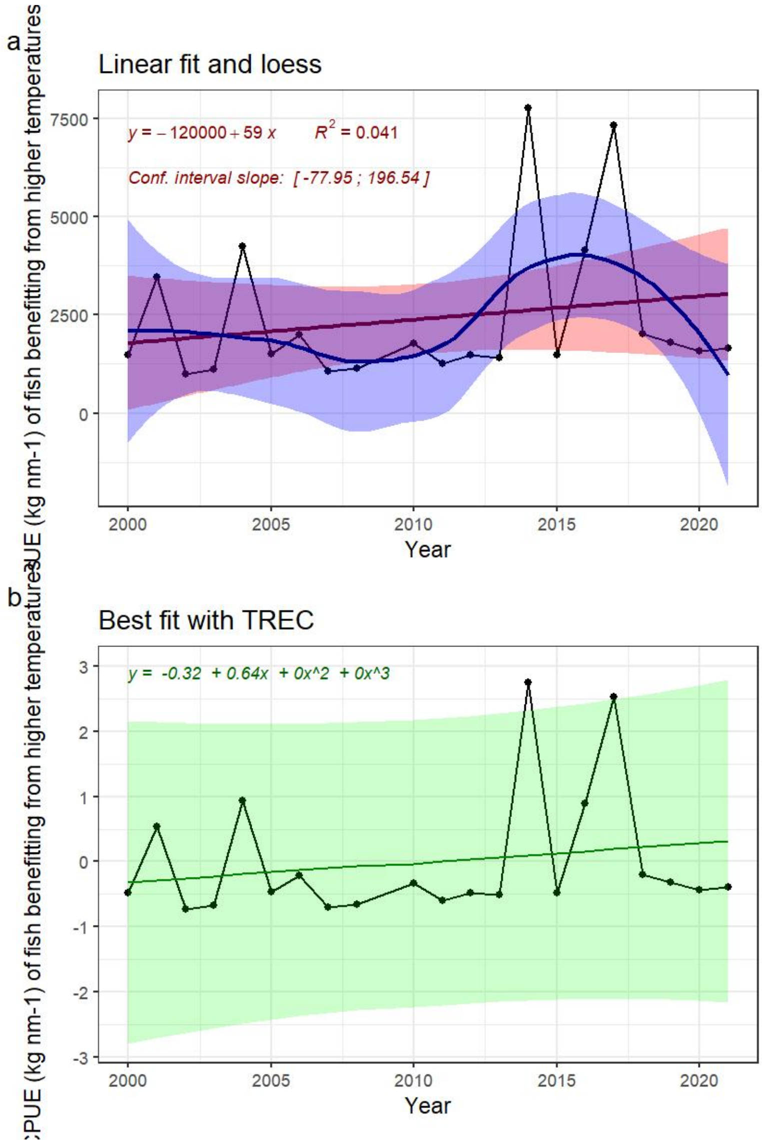


Fig.35: Indicator time series and fitted trends. a) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. b) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

There is only a slight increase in the biomass of warm-water species. The trend is positive, but the confidence interval of the slope includes 0. There is thus **no evidence** of increase for this indicator

35.4 Background data and supplementary analysis

35.5 Recommendations for future development of the indicator

36 Indicator: Copepod species vulnerable to higher temperature [NI36]

Ecosystem characteristic: Functionally important species and biophysical structures

Phenomenon: Decrease in number of species sensitive to higher temperatures [NP36]

Main driver: climate change

36.1 Supplementary metadata

36.2 Supplementary methods

Species considered to be vulnerable to higher temperature are from the following ecological groups defined by Beaugrand et al. (2002) (species names in brackets):

- Cold-temperate mixed-water species assemblage (*Aetideus armatus*, *Pleuromamma robusta*, *Acartia* spp., *Metridia lucens*)
- Subarctic species assemblage (*Heterorhabdus norvegicus*, *Scolecithricella* spp., *Euchaeta norvegica*, *Calanus finmarchicus*)
- Arctic species assemblage (*Calanus hyperboreus*, *Metridia longa*, *Calanus glacialis*)

For each CPR-sample, the total number of species present from these three groups were calculated before yearly means were calculated across all CPR-samples within years.

36.3 Plots of indicator values

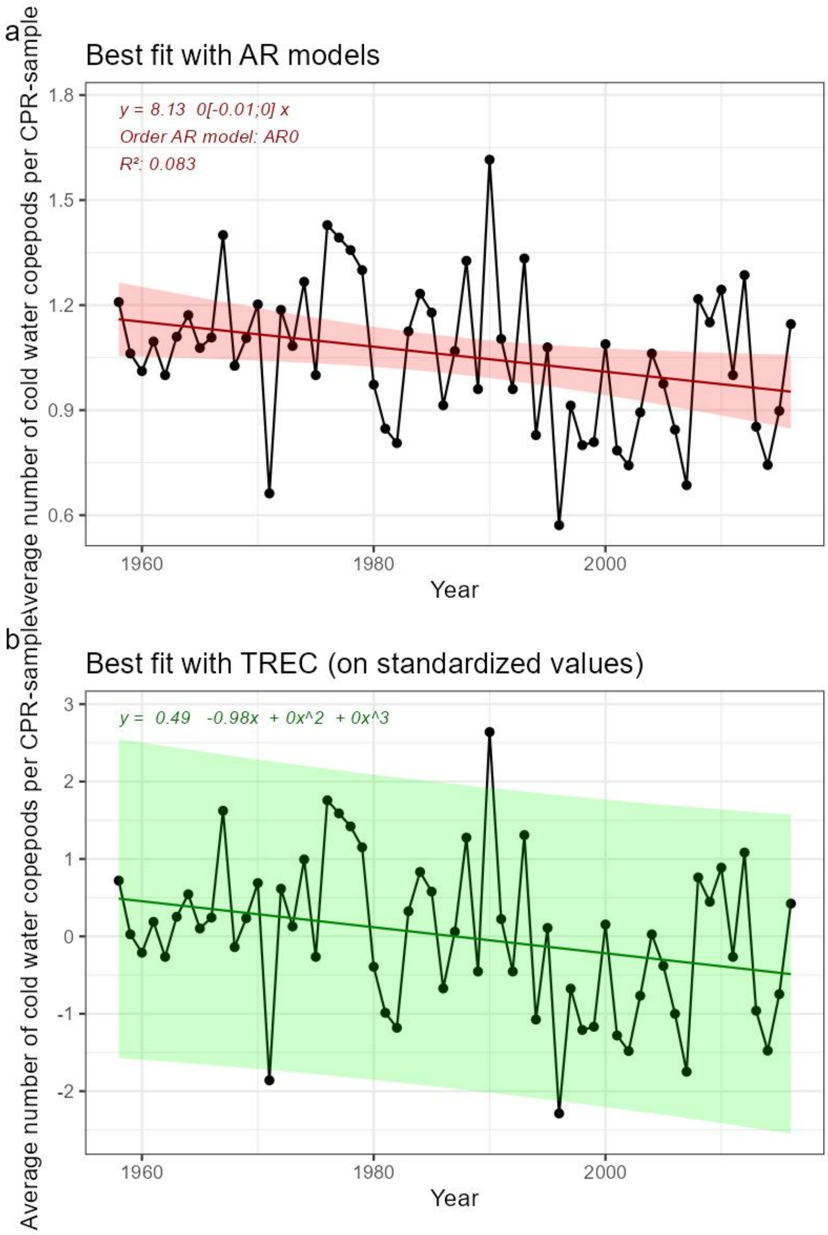


Fig. 36: a) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. b) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

There is a tendency for a decline in the time series, but the trend is not significant as the confidence interval for the regression coefficient in the linear model includes 0. There are uncertainties associated with the consequences of the change in the indicator for other parts of the ecosystem. Thus, the evidence for the phenomenon is assessed as **low**.

36.4 Background data and supplementary analysis

36.5 Recommendations for future development of the indicator

37 Indicator : Copepod species benefitting from higher temperature [NI37]

Ecosystem characteristic: Biological diversity

Phenomenon: Increase in number of “Warm-water species” [NP37]

Main driver: Climate change

37.1 Supplementary metadata

37.2 Supplementary methods

Species considered to benefit from higher temperature are from the following ecological groups defined by Beaugrand et al. (2002) (species names in brackets):

- Subtropical and warm-temperate species assemblage (*Undeuchaeta major*, *Acartia danae*, *Paracandacia bispinosa*, *Euchaeta media, Temora stylifera*, *Scolecithrix danae*, *Euchaeta marina*, *Candacia ethiopica* , *Eucalanus attenuatus*, *Lucicutia* spp., *Eucalanus elongatus*, *Candacia pachydactyla*, *Rhincalanus cornutus*, *Euchaeta pubera*, *Centropages violaceus*)
- Warm-temperate oceanic species assemblages (*Euchaeta acuta*, *Undeuchaeta plumosa*, *Euchirella rostrata*, *Neocalanus gracilis*, *Clausocalanus* spp., *Nannocalanus minor*, *Pleuromamma borealis*, *Pleuromamma gracilis*, *Pleuromamma abdominalis*, *Pleuromamma xiphias*, *Pleuromamma piseki*, *Calocalanus* spp., *Mesocalanus tenuicornis*, *Heterorhabdus papilliger*, *Centropages bradyi*, *Mecynocera clausi*)
- Warm-temperate pseudo-oceanic species assemblage (*Euchaeta gracilis*, *Euchaeta hebes*, *Ctenocalanus vanus*, *Calanoides carinatus*)
- Temperate pseudo-oceanic species assemblage (*Rhincalanus nasutus*, *Eucalanus crassus*, *Centropages typicus*, *Candacia armata*, *Calanus helgolandicus*)

For each CPR-sample, the total number of species present from these three groups were calculated before yearly means were calculated across all CPR-samples within years.

37.3 Plots of indicator values

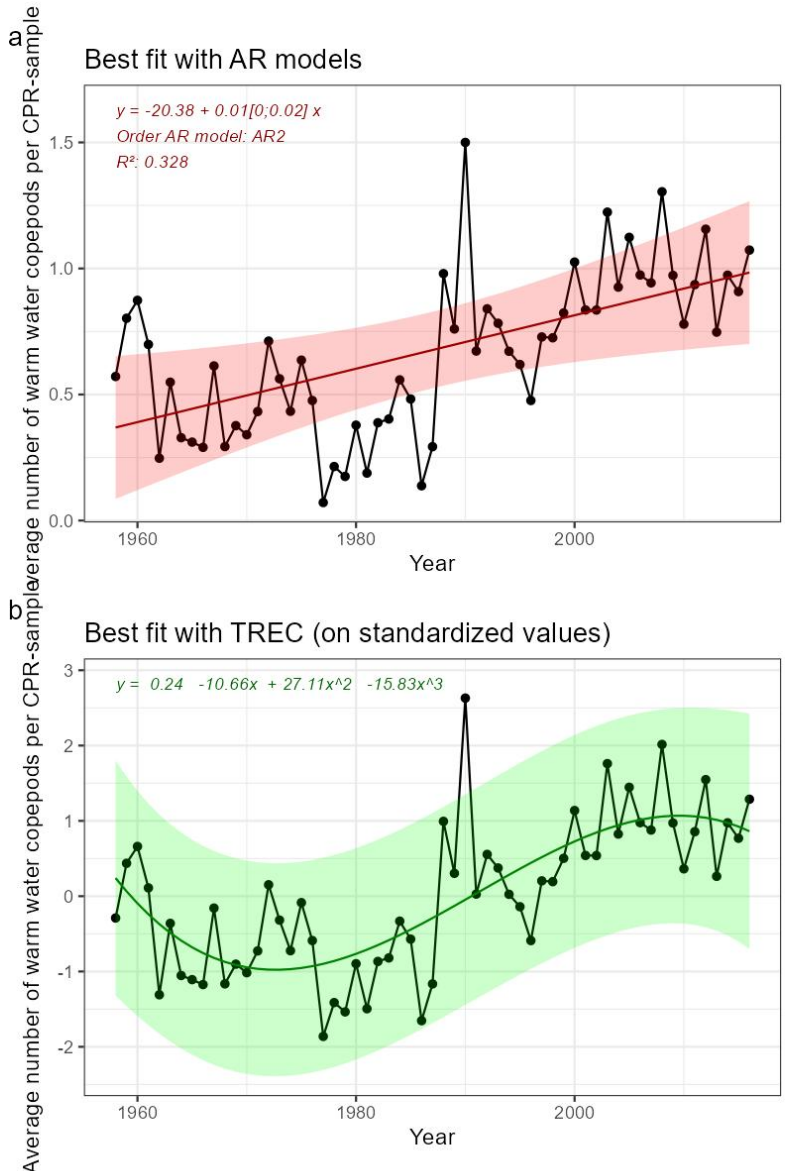


Fig. 37: a) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. b) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

There is a tendency for an increase in the time series, but the trend is not significant as the confidence interval for the regression coefficient in the linear model includes 0. There are uncertainties associated with the consequences of the change in the indicator for other parts of the ecosystem. Thus, the evidence for the phenomenon is assessed as **low**.

37.4 Background data and supplementary analysis

37.5 Recommendations for future development of the indicator

38 Indicator: Fish species vulnerable to fisheries [NI38]

Ecosystem characteristic: *Biological diversity*

Phenomenon: Decreasing biomass of fish species vulnerable to fisheries [NP38]

Main driver: Fisheries

38.1 Supplementary metadata

None

38.2 Supplementary methods

The taxa included in this indicator are: the European angler (*Lophius piscatorius*), the common ling (*Molva molva*), the megrim sole (*Lepidorhombus whiffiagonis*), the thorny skate (*Amblyraja radiata*), the Atlantic wolffish (*Anarhichas lupus*), the saithe (*Pollachius virens*), the European hake (*Merluccius merluccius*), and the pollock (*Pollachius pollachius*).

38.3 Plots of indicator values

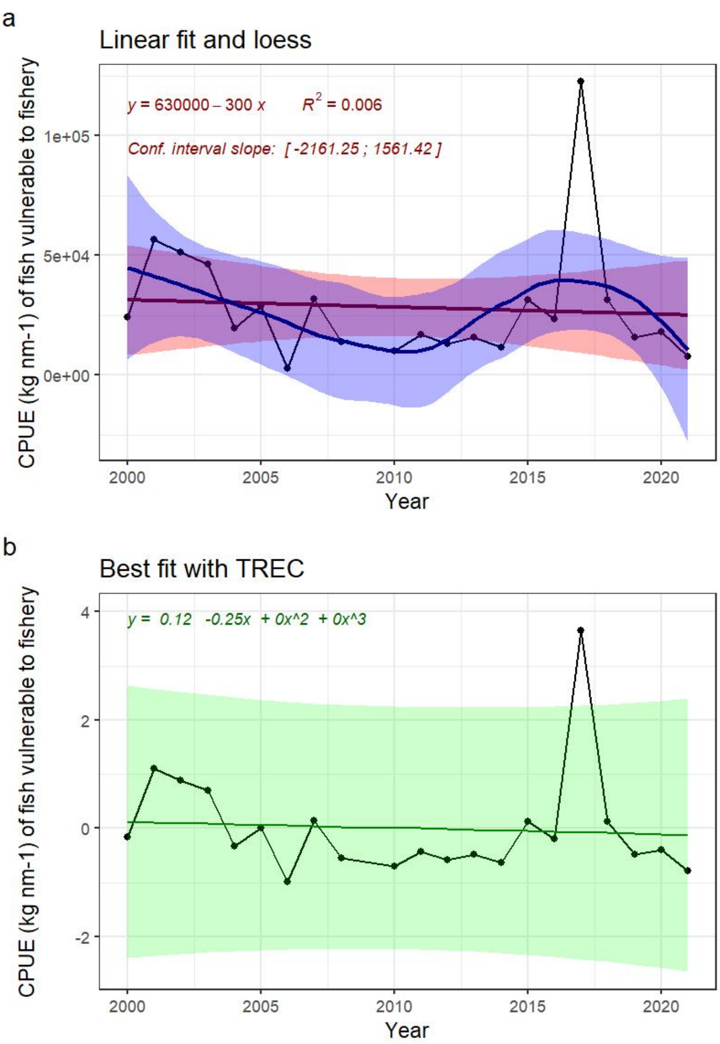


Fig.38: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

The biomass of fisheries-sensitive species has decreased then increased over the period. The trend is negative, but the confidence interval of the slope includes 0. There is thus **no evidence** of decrease for this indicator

38.4 Background data and supplementary analysis

38.5 Recommendations for future development of the indicator

39 Indicator: Temperature [NI39]

Ecosystem characteristic: Abiotic factors

Phenomenon: Warming of the water column [NP39]

Main driver: climate change

39.1 Supplementary metadata

None

39.2 Supplementary methods

None

39.3 Plots of indicator values

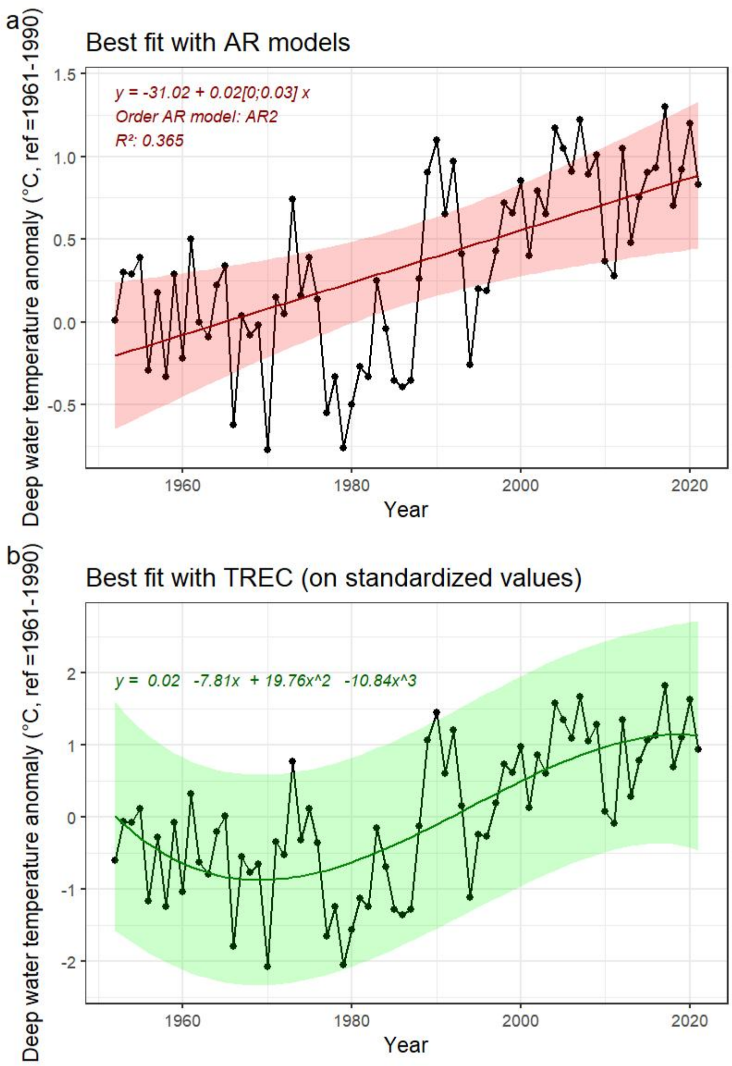


Fig. 39: Indicator time series and fitted trends. a) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. b) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

High evidence of an increase in temperature that can be linked to anthropogenic impact on the climate and high level of evidence of both observed and expected changes in the ecosystem as a consequence of this.

39.4 Background data and supplementary analysis

39.5 Recommendations for future development of the indicator

40 Indicator: Stratification [NI40]

Ecosystem characteristic: Abiotic factors

Phenomenon: Increasing stratification of the upper water column [NP40]

Main driver: climate change

40.1 Supplementary metadata

None

40.2 Supplementary methods

None

40.3 Plots of indicator values

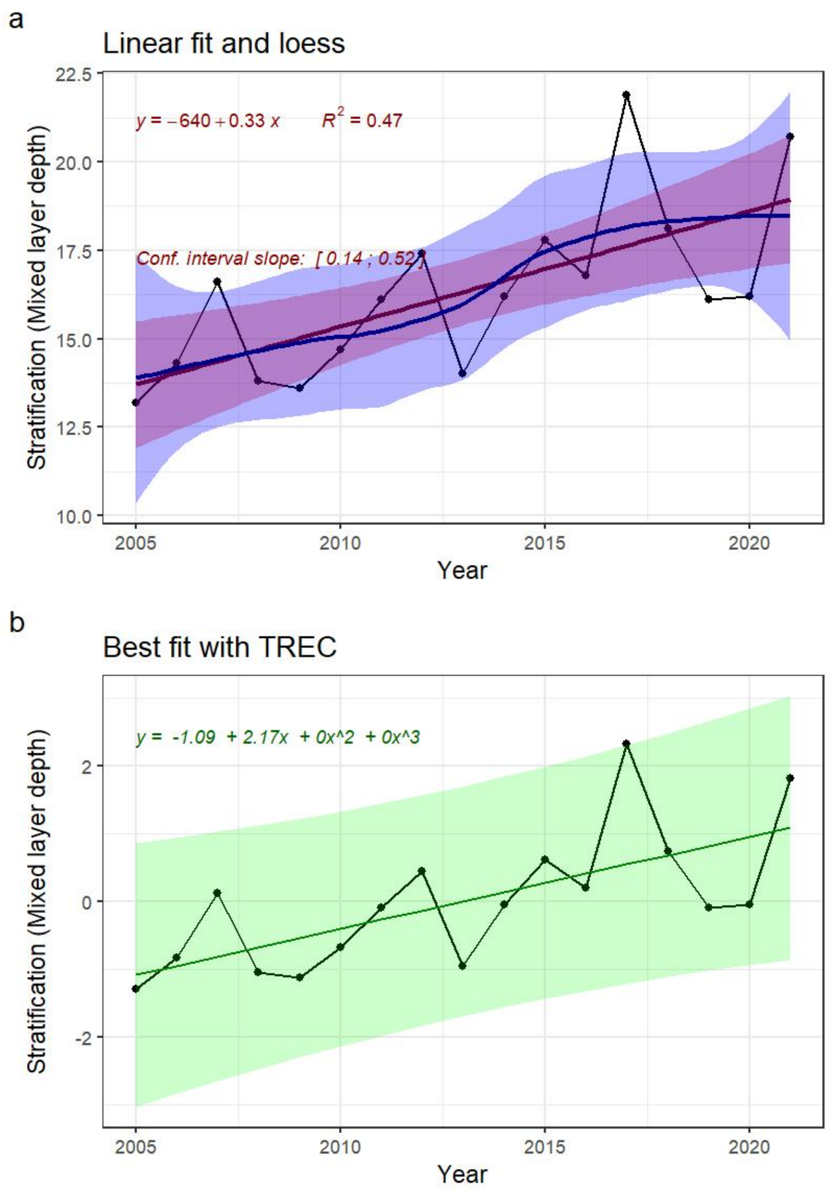


Fig. 40: a) Indicator time series and best fitted trend with autoregressive model (AR0: no autoregression; AR1: 1st order autoregressive model, AR2: 2nd order autoregressive model, AR3: 3rd order autoregressive model). Numbers in brackets indicate the confidence interval (95%) around the slope coefficient and should not include 0 to be significative. b) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

There is **no evidence** of an increased stratification (rather the evidence points towards a decrease). It should be noted that the data can be strongly influenced by atmospheric conditions (wind) and the coverage of the survey, and thus exhibit large natural year to year variation.

40.4 Background data and supplementary analysis

40.5 Recommendations for future development of the indicator

41 Indicator : Flow conditions [NI41]

Ecosystem characteristic: Abiotic factors

Phenomenon: Increasing inflow of Atlantic water to the North Sea [NP41]

Main driver: Climate change

41.1 Supplementary metadata

None

41.2 Supplementary methods

None

41.3 Plots of indicator values

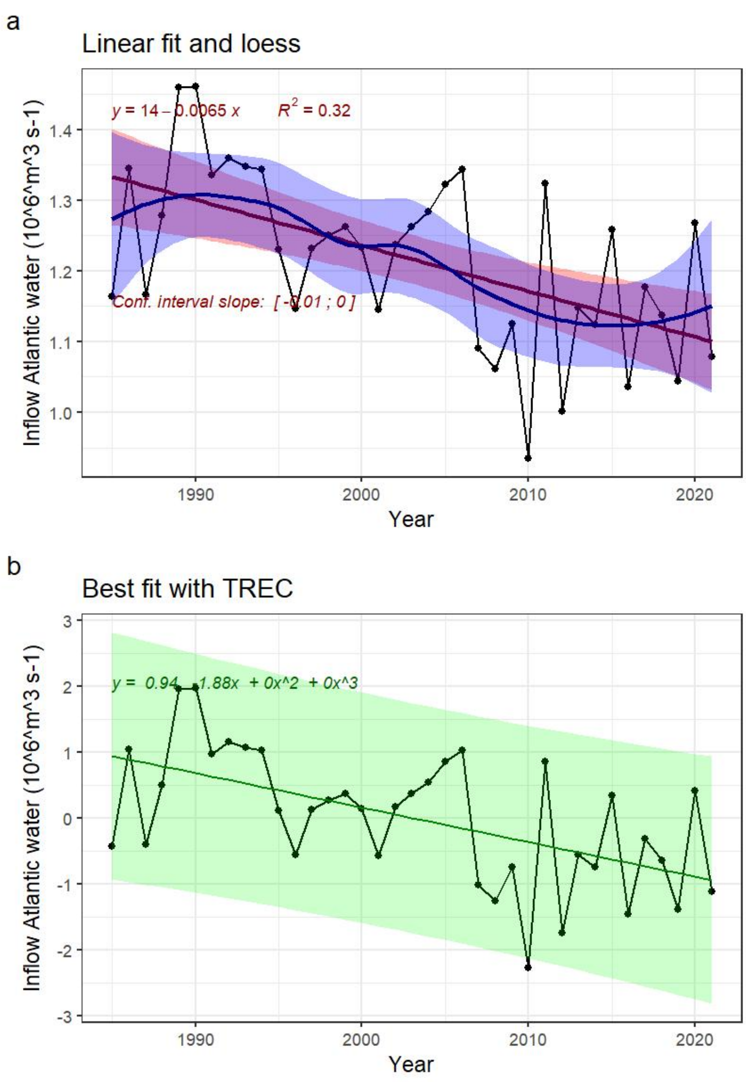


Fig. 41: Indicator time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

There is **no evidence** of an overall increase in the indicator when looking at the whole time series.

41.4 Background data and supplementary analysis

41.5 Recommendations for future development of the indicator

42 Indicator: Nutrients [NI42]

Ecosystem characteristic: Abiotic conditions

Phenomenon: Increasing concentration of nutrients [NP42]

Main driver: runoff from land

42.1 Supplementary metadata

None

42.2 Supplementary methods

None

42.3 Plots of indicator values

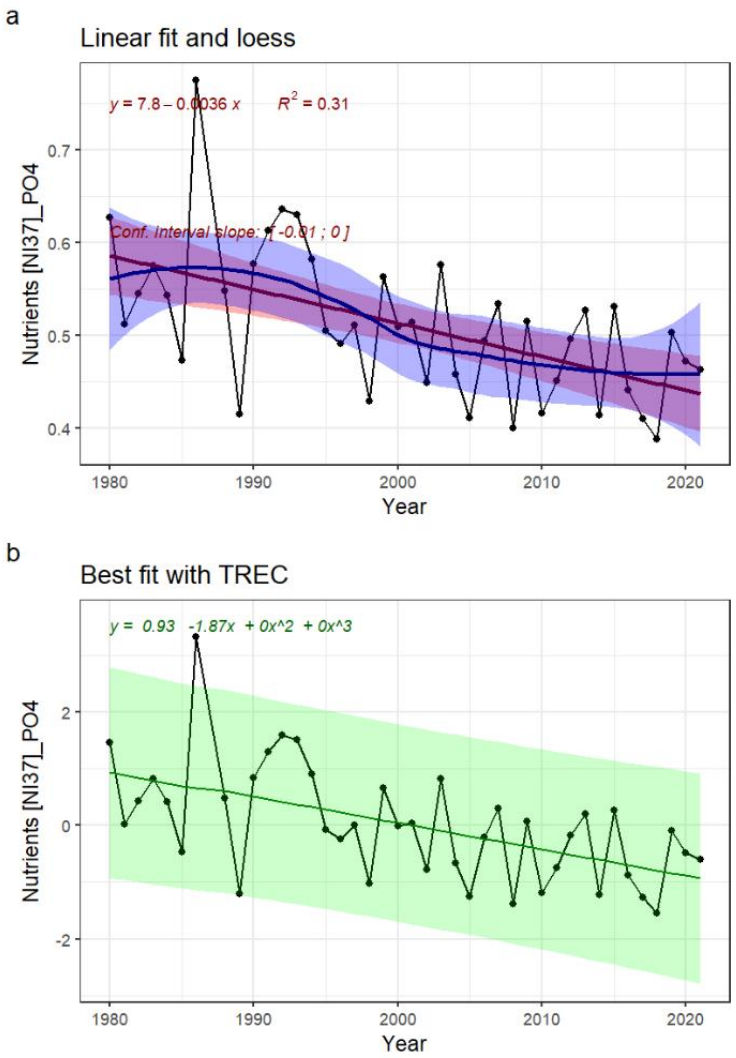


Fig. 42.1: PO_4 time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

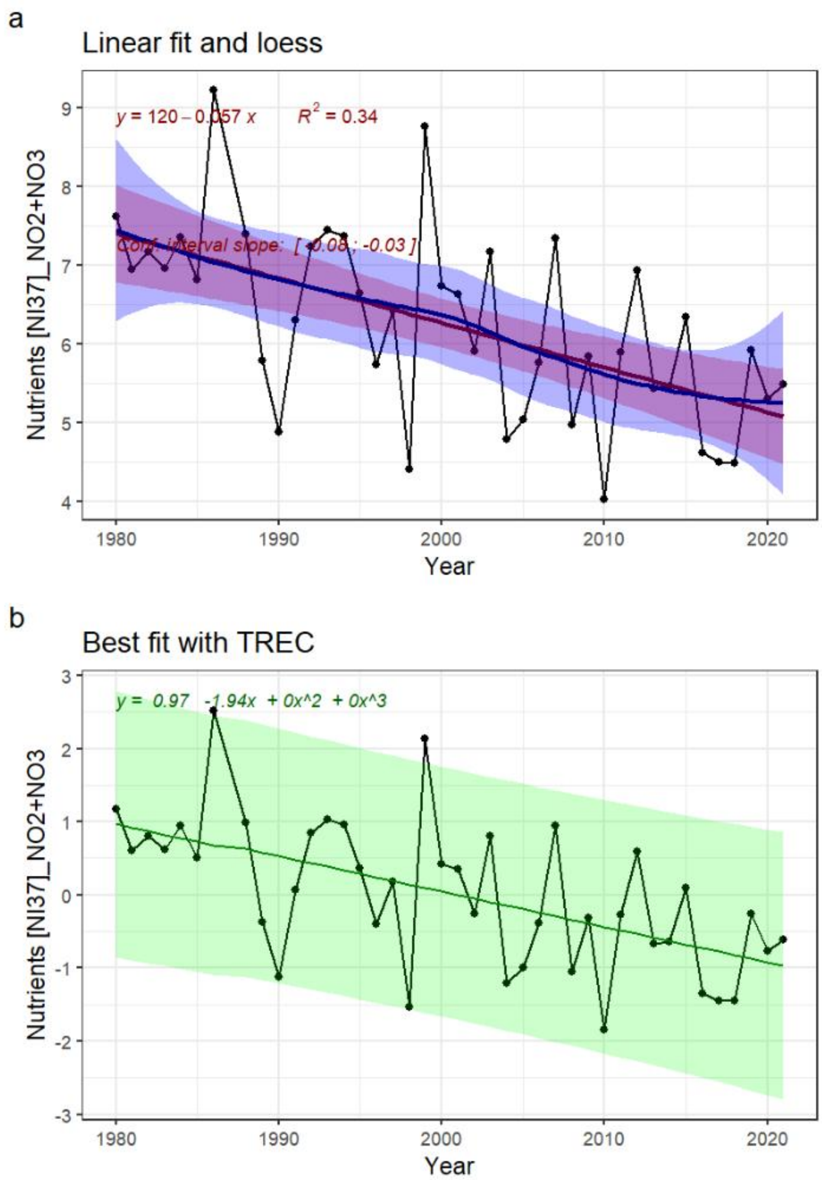


Fig. 42.2: NO_2 +NO_3 time series and fitted trends. A) linear trend fitted with Least-square method (not adapted for short time series) in red, and loess in blue, for information. B) Best fitted trend using the first steps of a TREC analysis on standardized time series

Assessment of the evidence for the phenomenon

There is a decline in both time series (PO_4 and NO_2-NO_3, respectively), thus indicating a development towards rather than away from the reference condition. This is clearly linked to decreased anthropogenic impact through runoff from land and has also had impact on other parts of the ecosystem, such as decreased chlorophyll concentrations.

42.4 Background data and supplementary analysis

42.5 Recommendations for future development of the indicator

43 Indicator: Light attenuation [NI43]

Ecosystem characteristic: Abiotic factors

Phenomenon: Increase in light attenuation [NP43]

Main driver: increased freshwater runoff and increased freshwater light attenuation linked with climate change

43.1 Supplementary metadata

None

43.2 Supplementary methods

None

43.3 Plots of indicator values

Assessment of the evidence for the phenomenon

43.4 Background data and supplementary analysis

43.5 Recommendations for future development of the indicator

44 Indicator: pH [NI44]

Ecosystem characteristic: Abiotic factors

Phenomenon: Decreasing pH

Main driver: Climate change

44.1 Supplementary metadata

The data for the North Sea are from the Norwegian ocean acidification monitoring program (2011-2012 Tilførselsprogrammet and 2013–2019 Havforsuringsprogrammet) are published in the database 'Vannmiljø' (www.vannmiljo.miljodirektoratet.no) of the Norwegian Environment Agency and are available in the Norwegian Marine Data Centre (NMDC) via https://doi.org/10.21335/NMDC-1939716216.

44.2 Supplementary methods

Mean values for the Atlantic Water (salinity □ 34.9, temperature □ 0 □ C) were calculated in the North Sea (Skagerrak) from observations of total alkalinity and total dissolved inorganic carbon between 2012 and 2020 obtained through the observational program "Monitoring ocean acidification in Norwegian waters", funded by the Norwegian Environment Agency. Details of the analytical methods and calculations for aragonite saturation (ΩAr) are found in the annual reports for the above-mentioned program in (Chierici et al., 2016; Chierici et al., 2017; Jones et al., 2018; Jones et al., 2019).

44.3 Plots of indicator values

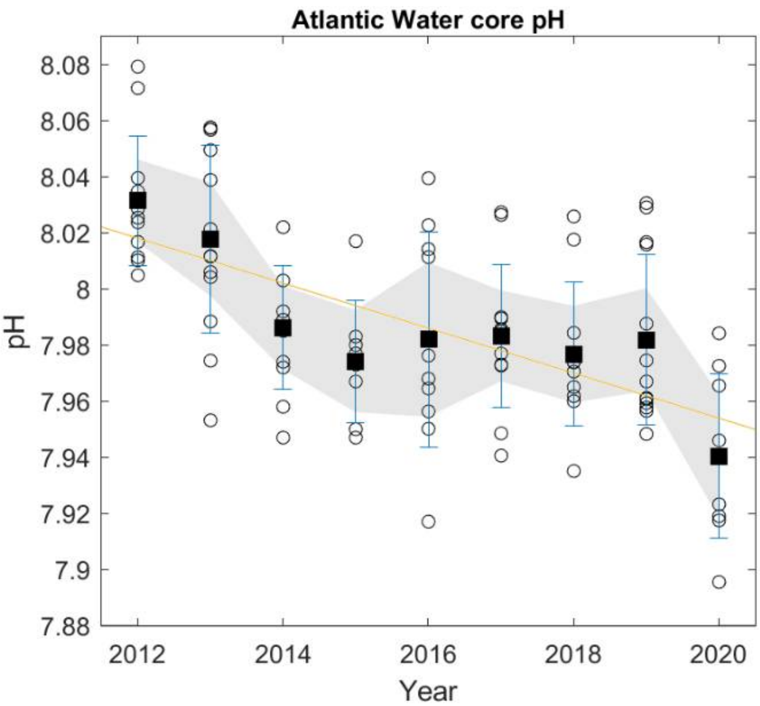


Figure 44 The time series of pH in the period 2012 to 2020 in the Atlantic Water (salinity □ 34.9 , temperature 0°C). The linear regression fit (orange line; gradient = □ 0.0080 □ 0.0019, p = 0.0042, R2 = 0.71) is based on annual mean pH values (black squares) from observational data (circles). Bars are □ 1 standard deviation for each annual mean. The grey shaded area represents the 95% confidence limits.

Intermediate evidence that the phenomenon has occurred. The linear fit in the relatively short time period from 2012 to 2020 shows a significant trend of decreasing pH of 0.0080 yr^{-1} in the Atlantic Waters of this part of the North Sea (Skagerrak). This is slightly faster rates of pH decrease determined for 0-500 m depth in the Nordic Seas (0.002-0.003 yr^{-1}; Fransner et al. (2022)) and the global ocean mean (0.002 yr^{-1}; Copernicus Marine Services (2021)). The rate differences likely result from variations in sampling period, different spatial coverage and length of the time series within the given region. From this time series it is also obvious that minimum pH values decrease with increased frequency. Consequently, the observed trend is as expected and is caused by the increased atmospheric CO_2 due to human activities.

44.4 Background data and supplementary analysis

Not relevant.

44.5 Recommendations for future development of the indicator

The observations are performed in winter (January-February) and should have small effects from biotic processes. It is crucial to continue with long term observations and should cover seasonal variability and capture processes that may influence the region of different time scales, e.g. circulation features, to be able to follow the trends and develop regional models for prediction of pH trends in the North Sea.

45 Indicator: Aragonite saturation [NI45]

Ecosystem characteristic: Abiotic factors

Phenomenon: Decreasing aragonite saturation

Main driver: Climate change

45.1 Supplementary metadata

The data for the North Sea are from the Norwegian ocean acidification monitoring program (2011-2012 Tilførselsprogrammet and 2013–2019 Havforsuringsprogrammet) are published in the database 'Vannmiljø' (www.vannmiljo.miljodirektoratet.no) of the Norwegian Environment Agency and are available in the Norwegian Marine Data Centre (NMDC) via https://doi.org/10.21335/NMDC-1939716216.

45.2 Supplementary methods

Mean values for the Atlantic Water (salinity 34.9, temperature 0 C) were calculated in the North Sea (Skagerrak) from observations of total alkalinity and total dissolved inorganic carbon between 2012 and 2020 obtained through the observational program "Monitoring ocean acidification in Norwegian waters", funded by the Norwegian Environment Agency. Details of the analytical methods and calculations for aragonite saturation (ΩAr) are found in the annual reports for the above-mentioned program in (Chierici et al., 2016; Chierici et al., 2017; Jones et al., 2018; Jones et al., 2019).

45.3 Plots of indicator values

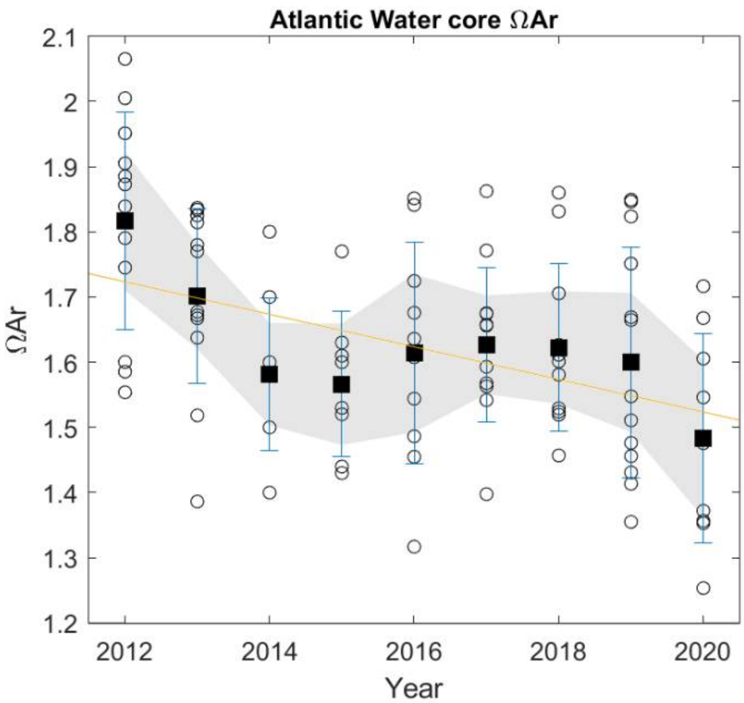


Figure 45 The time series of aragonite saturation (ΩAr) in the period 2012 to 2020 in the Atlantic Water (salinity 34.9, temperature 0 C). The linear regression fit (orange line; gradient = 0.0250 0.0086, p = 0.0234, R2 = 0.54) is based on annual mean pH values (black squares) from observational data (circles). Bars are 1 standard deviation for each annual mean. The grey shaded area represents the 95% confidence limits.

Intermediate evidence that the phenomenon has occurred. The linear fit in the relatively short time period from 2012 to 2020 shows a significant trend of decreasing aragonite saturation of 0.0250 yr^{-1} in the Atlantic Waters of this part of the North Sea (Skagerrak). This is faster than maximum rates reported for the whole Nordic seas region (0.012 yr^{-1}; Fransner et al. (2022)). The rate differences likely result from variations in sampling period, different spatial coverage and length of the time series within the given region. From this time series it can be seen that there is increased frequency of $\Omega Ar < 1.4$, which results in negative effects for calcification for winged snails. Consequently, the observed trend is as expected and is caused by the increased atmospheric CO_2 due to human activities.

45.4 Background data and supplementary analysis

Not relevant.

45.5 Recommendations for future development of the indicator

The observations are performed in winter (January-February) and should have small effects from biotic processes. It is crucial to continue with long term observations and should cover seasonal variability and capture processes that may influence the region of different time scales, e.g. circulation features, to be able to follow the trends and develop regional models for prediction of carbonate saturation trends in the North Sea. Observational evidence on the biological effects of changing calcium carbonate saturation states needs to be developed, both on organism level and ecosystem level (Rastrick et al., 2018).

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Appendix 8.2: Information on drivers –North Sea

1. Fisheries

General

ICES areas referred to in the texts are shown in Figure D.1.1, a summary of fishing mortality for different groups of stocks in Figure D.1.2 and an overview of stocks for which assessments are done in ICES is given in Table D.1.1.

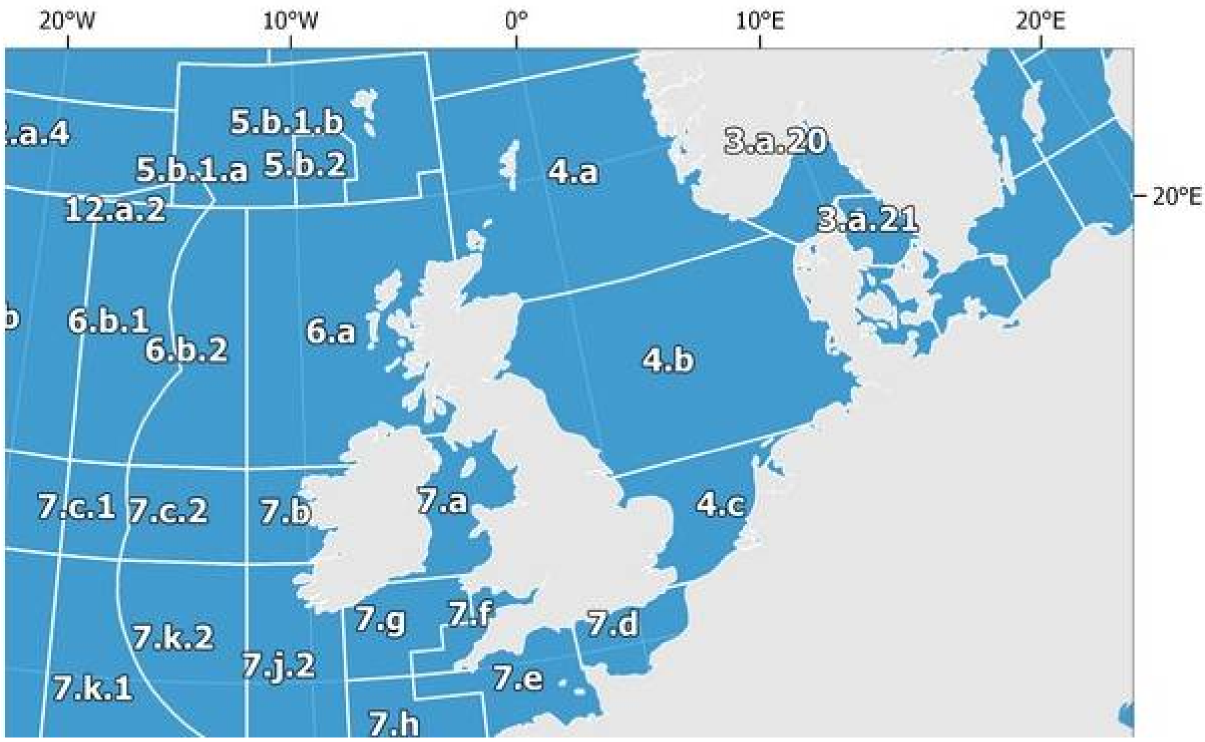


Figure D.1.1. ICES areas referred to in the texts below.

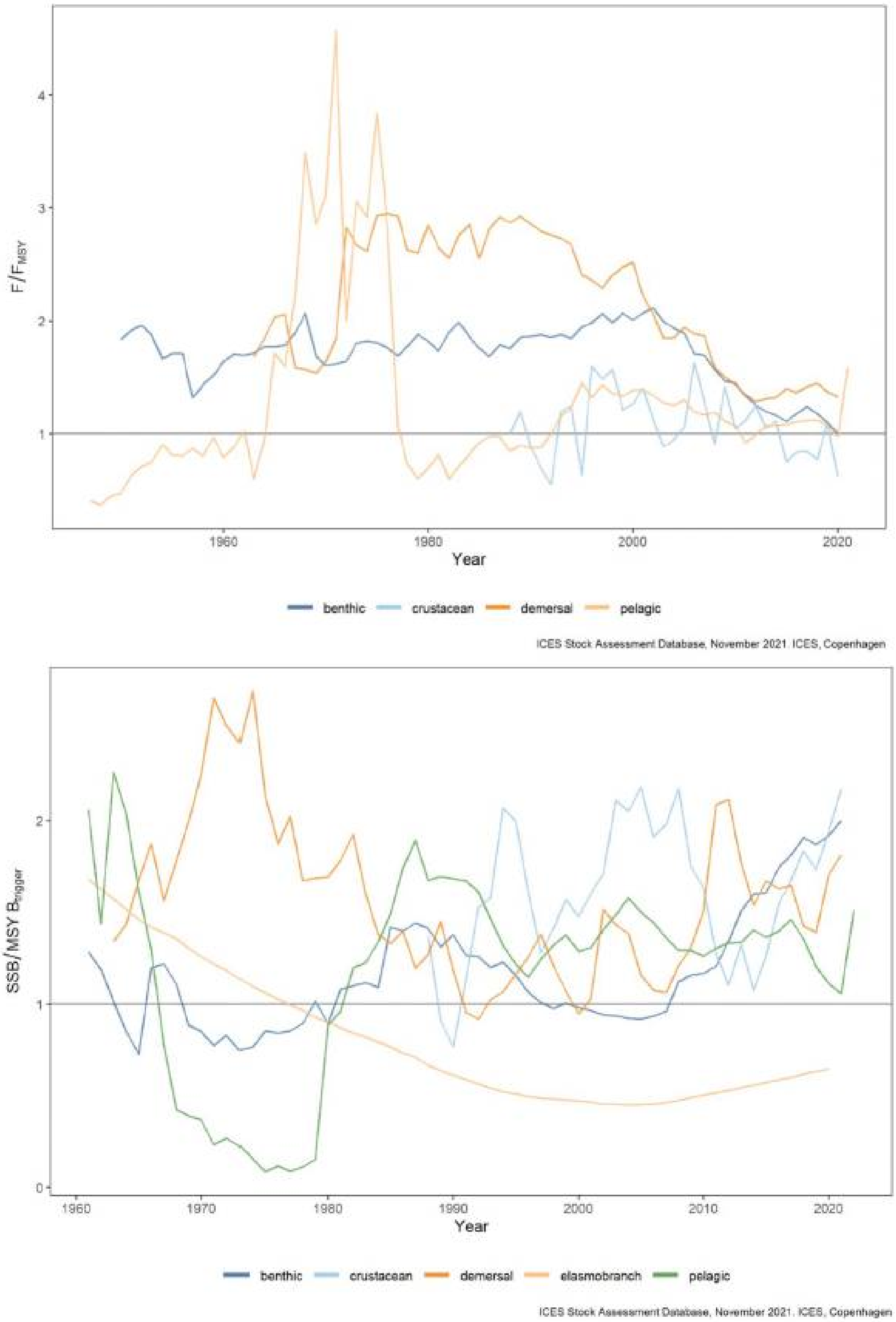


Figure D.1.2 Time-series of annual relative fishing mortality (F to FMSY ratio) and biomass (SSB to BMSY trigger ratio) by fisheries guild for benthic, demersal, crustaceans, pelagic stocks for the greater North Sea. Table D.1.1 below details which species belong to each fish category. From (ICES, 2021b).

Table D.1.1. Stocks with analytical assessments and guilds included in Figure D.1.1. From (ICES, 2021b). Detailed information on the fisheries of the Greater North Sea is provided on the Greater North Sea Fisheries Overviews (ICES, 2021c).

Stock code	**Stock name**	**Fishery Guild**
ank.27.78abd	Black-bellied anglerfish (*Lophius budegassa*) in Subarea 7 and divisions 8.a-b and 8.d (Celtic Seas, Bay of Biscay)	benthic
dab.27.3a4	Dab (*Limanda limanda*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	benthic
fle.27.3a4	Flounder (*Platichthys flesus*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	benthic
lem.27.3a47d	Lemon sole (*Microstomus kitt*) in Subarea 4 and divisions 3.a and 7.d (North Sea, Skagerrak and Kattegat, eastern English Channel)	benthic
lez.27.4a6a	Megrim (*Lepidorhombus* spp.) in divisions 4.a and 6.a (northern North Sea, West of Scotland)	benthic
meg.27.7b-k8abd	Megrim (*Lepidorhombus whiffiagonis*) in divisions 7.b-k, 8.a-b, and 8.d (west and southwest of Ireland, Bay of Biscay)	benthic
mon.27.78abd	White anglerfish (*Lophius piscatorius*) in Subarea 7 and divisions 8.a-b and 8.d (Celtic Seas, Bay of Biscay)	benthic
ple.27.21-23	Plaice (*Pleuronectes platessa*) in subdivisions 21-23 (Kattegat, Belt Seas, and the Sound)	benthic
ple.27.420	Plaice (*Pleuronectes platessa*) in Subarea 4 (North Sea) and Subdivision 20 (Skagerrak)	benthic
ple.27.7d	Plaice (*Pleuronectes platessa)* in Division 7.d (eastern English Channel)	benthic
ple.27.7e	Plaice (*Pleuronectes platessa*) in Division 7.e (western English Channel)	benthic
sol.27.20-24	Sole (*Solea solea*) in subdivisions 20-24 (Skagerrak and Kattegat, western Baltic Sea)	benthic
sol.27.4	Sole (*Solea solea*) in Subarea 4 (North Sea)	benthic
sol.27.7d	Sole (*Solea solea*) in Division 7.d (eastern English Channel)	benthic
sol.27.7e	Sole (*Solea solea)* in Division 7.e (western English Channel)	benthic
tur.27.3a	Turbot (*Scophthalmus maximus*) in Subarea 4 (North Sea)	benthic
tur.27.4	Turbot (*Scophthalmus maximus*) in Subarea 4 (North Sea)	benthic
wit.27.3a47d	Witch (*Glyptocephalus cynoglossus*) in Subarea 4 and divisions 3.a and 7.d (North Sea, skagerrak and Kattegat, eastern English Channel)	benthic
nep.fu.3-4	Nephrops (*Nephrops norvegicus*) in Division 4.b, Functional Unit 34 (central North Sea, Devil's Hole)	crustacean
nep.fu.6	Nephrops (*Nephrops norvegicus*) in Division 4.b, Functional Unit 6 (central North Sea, Farn Deeps)	crustacean
nep.fu.7	Nephrops (*Nephrops norvegicus*) in Division 4.a, Functional Unit 7 (northern North Sea, Fladen Ground)	crustacean
nep.fu.8	Nephrops (*Nephrops norvegicus*) in Division 4.b, Functional Unit 8 (central North Sea, Firth of Forth)	crustacean
nep.fu.9	Nephrops (*Nephrops norvegicus*) in Division 4.b, Functional Unit 9 (central North Sea, Moray Firth)	crustacean
pra.27.3a4a	Northern shrimp (*Pandalus borealis*) in divisions 3.a and 4.a East (Skagerrak and Kattegat and northern North Sea in the Norwegian Deep)	crustacean
bli.27.5b67	Blue ling (*Molva dypterygia*) in subareas 6-7 and Division 5.b (Celtic Seas, English Channel, and Faroes grounds)	demersal
bss.27.4bc7ad-h	Seabass (*Dicentrarchus labrax*) in Divisions 4.b-c, 7.a, and 7.d-h (central and southern North Sea, Irish Sea, English Channel, Bristol Channel, and Celtic Sea)	demersal
cod.27.21	Cod (*Gadus morhua*) in Subdivision 21 (Kattegat)	demersal
cod.27.47d20	Cod (*Gadus morhua*) in Subarea 4, Division 7.d, and Subdivision 20 (North Sea, eastern English Channel, Skagerrak)	demersal
cod.27.7e-k	Cod (*Gadus morhua*) in divisions 7.e-k (eastern English channel and southern Celtic Seas)	demersal
gug.27.3a47d	Grey gurnard (*Eutrigla gurnardus*) in Subarea 4 and divisions 7.d and 3.a (North Sea, eastern English Channel, Skagerrak and Kattegat)	demersal

had.27.46a20	Haddock (*Melanogrammus aeglefinus*) in Subarea 4, Division 6.a, and Subdivision 20 (North Sea, West of Scotland, Skagerrak)	demersal
had.27.7b-k	Haddock (*Melanogrammus aeglefinus*) in Divisions 7.b-k (southern Celtic Seas and English Channel)	demersal
hke.27.3a46-8abd	Hake (*Merluccius merluccius*) in subareas 4, 6, and 7, and divisions 3.a, 8.a-b, and 8.d, Northern stock (Greater North Sea, Celtic Seas, and the northern Bay of Biscay)	demersal
pok.27.3a46	Saithe (*Pollachius virens*) in subareas 4, 6 and Division 3.a (North Sea, Rockall and West of Scotland, Skagerrak and Kattegat)	demersal
san.sa.1r	Sandeel (*Ammodytes* spp.) in Divisions 4.b and 4.C. Sandeel Area 1r (central and southern North Sea, Dogger Bank)	demersal
san.sa.2r	Sandeel (*Ammodytes* spp.) in Divisions 1.b and 4.c. and Subdivision 20, Sandeel Area 2r (Skagerrak, central and southern North Sea)	demersal
san.sa.3r	Sandeel (*Ammodytes* spp.) in Divisions 4.a and 4.b. and Subdivision 20, Sandeel Area 3r (Skagerrak, northern and central North Sea)	demersal
san.sa.4	Sandeel (*Ammodytes* spp.) in divisions 4.a and 4.b, Sandeel Area 4 (northern and central North Sea)	demersal
whg.27.47d	Whiting (*Merlangius merlangus*) in Subarea 4 and Division 7.d (North Sea and eastern English Channel)	demersal
whg.27.7b-ce-k	Whiting (*Merlangius merlangus*) in divisions 7.b-c and 7.e-k (southern Celtic Seas and eastern English Channel)	demersal
dgs.27.nea	Spurdog (*Squalus acanthias*) in Subareas 1-10, 12 and 14 (the Northeast Atlantic and adjacent waters)	elasmobranchs
boc.27.6-8	Boarfish (*Capros oper*) in subareas 6-8 (Celtic Seas, English Channel, and Bay of Biscay)	pelagic
her.27.1-24a514a	Herring (*Clupea harengus*) in subareas 1, 2, 5 and divisions 4.a and 14.a, Norwegian spring-spawning herring (the Northeast Atlantic and Arctic Ocean)	pelagic
her.27.20-24	Herring (*Clupea harengus*) in subdivisions 20-24, spring spawners (Skagerrak, Kattegat, and western Baltic)	pelagic
r.27.3a47d	Herring (*Clupea harengus*) in Subarea 4 and divisions 3.a and 7.d, autumn spawners (North Sea, skagerrak and Kattegat, eastern English Channel)	pelagic
hom 27.2a4a5b6a7a- ce-ks	Horse mackerel (*Trachurus trachurus*) in Subarea 8 and divisions 2.a, 4.a. 5.b, 6.a, 7.a-c, 7.e-k (the Northeast Atlantic)	pelagic
hom.27.3a4bc7d	Horse mackerel (*Trachurus trachurus*) in divisions 3.a, 4.b-c, and 7.d (Skagerrak and Kattegat, southern and central North Sea, eastern English Channel)	pelagic
mac.27.nea	Mackerel (*Scomber scombrus*) in subareas 1-8 and 14 and division 9.a (the Northeast Atlantic and adjacent waters)	pelagic
nop.27.3a4	Norway pout (*Trisopterus esmarkii*) in Subarea 4 and Division 3.a (North Sea, Skagerrak and Kattegat)	pelagic
spr.27.3a4	Sprat (*Sprattus sprattus*) in Division 3.a and Subarea 4 (Skagerrak, Kattegat and North Sea)	pelagic
spr.27.7de	Sprat (*Sprattus sprattus*) in divisions 7.d and 7.e (English Channel)	pelagic
whb.27.1-91214	Blue whiting (*Micromesistius poutassou*) in subareas 1-9, 12, and 14 (Northeast Atlantic and adjacent waters)	pelagic

Cod

Fishing pressure has increased since 2016 and is below F_{lim} in 2020. Spawning-stock biomass has decreased since 2016 and is now below B_{lim}. Recruitment since 1998 remains poor. Currently, fishing pressure on the stock is above FMSY, but below F_{pa} and F_{lim} ; the spawning-stock size is below MSY $B_{trigger}$, B_{pa} and B_{lim} (ICES, 2021h). Historic development in catches, recruitment, fishing pressure and SSB are shown in figure D.1.3. Summary of the state of the stock and fishing pressure relative to reference points are shown in figure D.1.4.

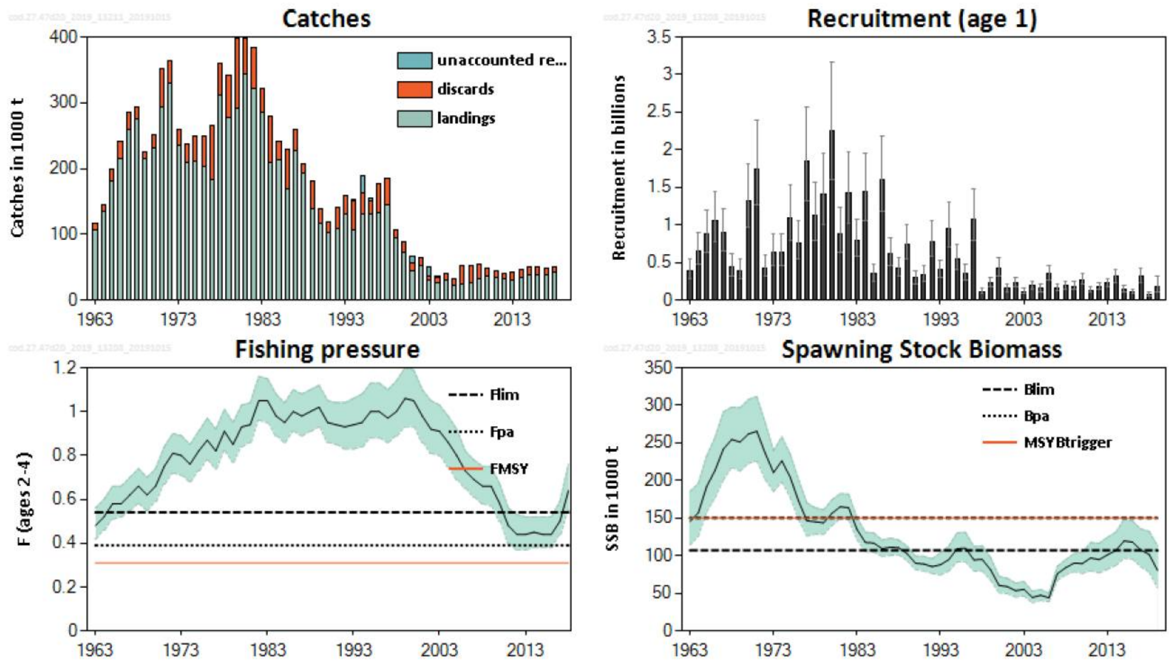


Figure D.1.3. Cod in Subarea 4, Division 7.d, and Subdivision 20. Summary of the stock assessment. Catches are assessment estimates. Only positive unaccounted removals are plotted. Shaded areas (F; SSB) and error bars (R) indicate 95% confidence intervals. From (ICES, 2021a). Note that fishing pressure is shown for age groups 2-4. The pattern is similar for older age groups (ICES, 2021h).

	Fishing pressure					Stock size				
		2016	2017	2018			2017	2018	2019	
Maximum sustainable yield	F_{MSY}	✖	✖	✖	Above	MSY $B_{trigger}$	✖	✖	✖	Below trigger
Precautionary approach	F_{pa},F_{lim}	O	O	✖	Harvested unsustainably	B_{pa},B_{lim}	O	✖	✖	Reduced reproductive capacity
Management plan	F_{MGT}	–	–	–	Not applicable	B_{MGT}	–	–	–	Not applicable

Figure D.1.4. Cod in Subarea 4, Division 7.d, and Subdivision 20. State of the stock and fishery relative to reference points. From (ICES, 2021a)

Haddock

Fishing pressure has declined since the beginning of the 2000s, but it has been above F_{MSY} for most of the entire time-series. Only since 2019, fishing pressure has been below F_{MSY}. Spawning-stock biomass has been above MSY $B_{trigger}$ in most of the years since 2002. Recruitment since 2000 has been low with occasional larger year classes. The 2019 and 2020 year-classes are estimated to be two of the largest since 2000. Currently, fishing pressure on the stock is below F_{MSY}, F_{pa} and F_{lim}, and spawning stock size is above MSY $B_{trigger}$, B_{pa} and B_{lim} (ICES, 2021h). Historic development is shown in figure D.1.5.

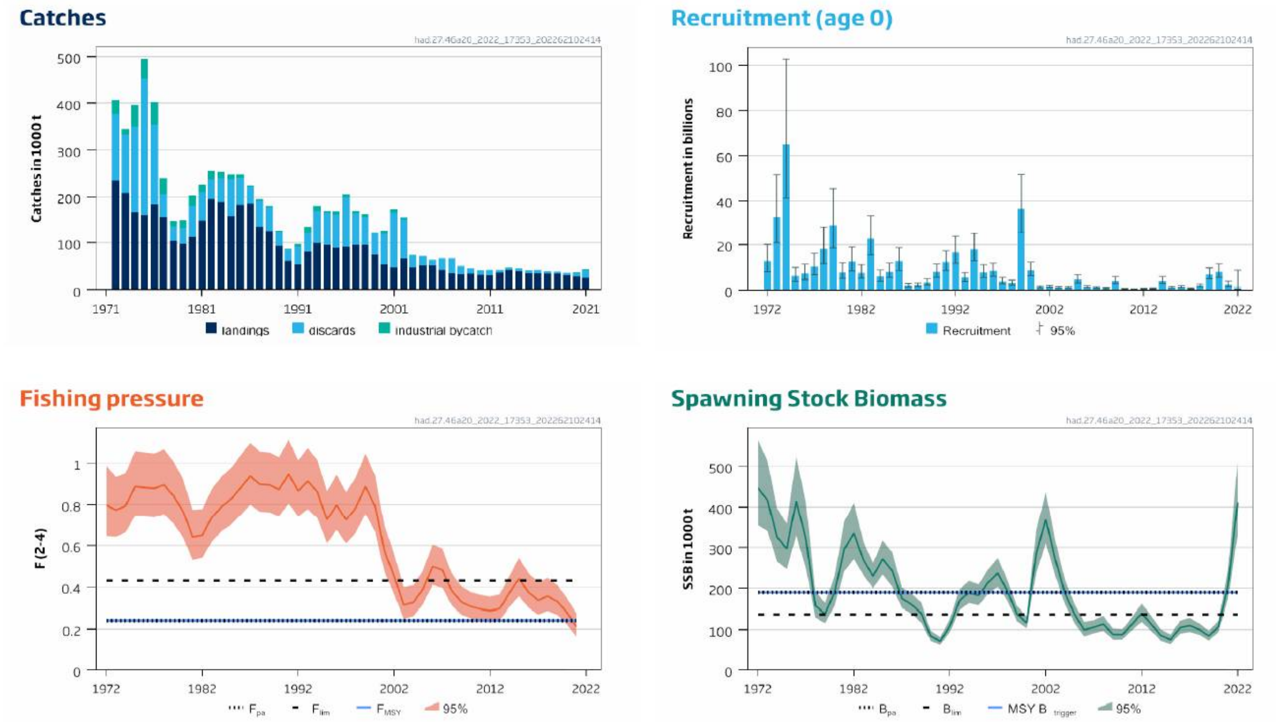


Figure D.1.4. Haddock in Subarea 4, Division 6.a, and Subdivision 20. Summary of the stock assessment. The assumed recruitment value for 2022 is shaded in a lighter colour. Discards include BMS landings. From (ICES, 2021d).

Saithe

Spawning-stock biomass has fluctuated without trend and has been above MSY $B_{trigger}$ in 1996-2020. Fishing pressure has decreased and stabilized above F_{MSY} since 2000. Recruitment has shown an overall decreasing trend over time with lowest levels in the past 10 years. Currently, fishing pressure on the stock is above F_{MSY}, but below F_{pa} and F_{lim}; spawning-stock size is below MSY $B_{trigger}$ and B_{pa} but above B_{lim} (ICES, 2021h). Historic development in stock and fisheries is shown in figure D.1.6.

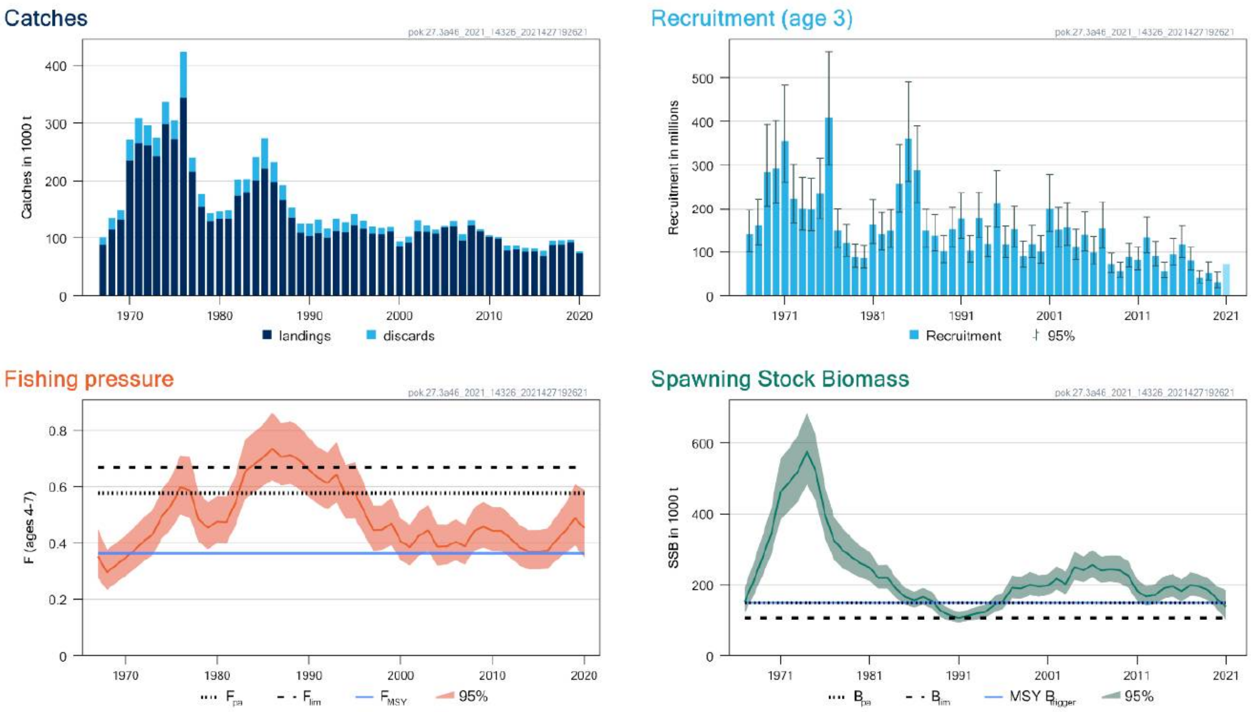
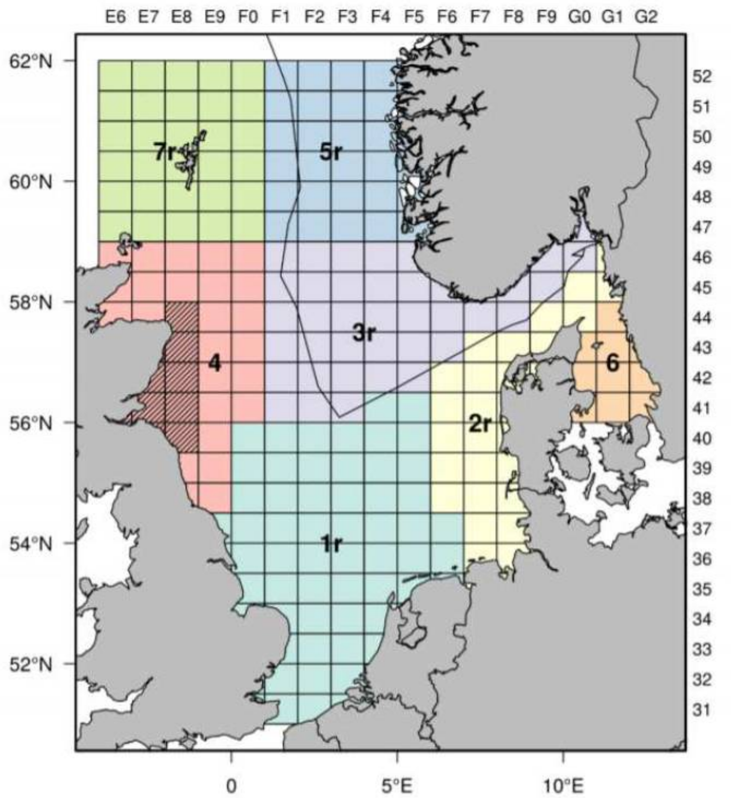


Figure D.1.6. Saithe in subareas 4 and 6, and in Division 3.a. Summary of the stock assessment. The assumed recruitment value for 2021 is shaded in a lighter colour. Landings and discards are for ages 3–10+ only, as used in the assessment. From (ICES, 2021f).

Lesser sandeel

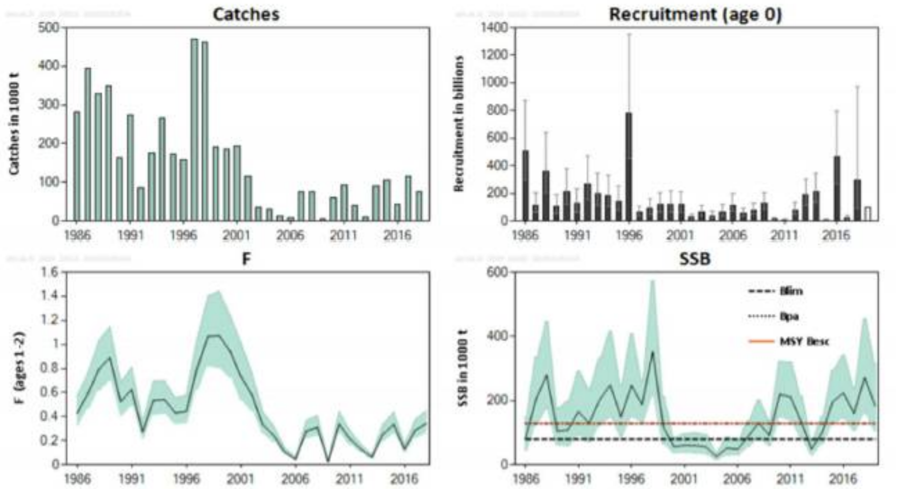
For this species, the area assessed for Norwegian management is 3r, which lies within ICES area 4a and 4b and subdivision 20.



Sandeel in divisions 4.a–b and Subdivision 20, Sandeel Area 3r. Stock areas for the seven sandeel stocks. The border of the Norwegian Exclusive Economic Zone (EEZ) is also shown. The closed part of Sandeel Area 4 is shown with hatched markings.

Figure D.1.7 Sandeel in area 3r (Northern and Central North Sea).

Sandeel in area 3r (Northern and Central North Sea). The spawning-stock biomass (SSB) has been above Bpa = MSY Bescapement since 2015. The recruitments (R) in 2016 and 2018 were among the five highest on record, whereas recruitment in 2017 was very low. Fishing mortality (F) declined in the early 2000s and has been low since then. The stock is at full reproductive capacity and at a high level. Stock status is generally unchanged compared to recent years, Figure D.1.7.



Sandeel in divisions 4.a–b and Subdivision 20, Sandeel Area 3r. State of the stock and fishery relative to reference points.

		Fishing pressure				Stock size			
		2016	2017	2018			2017	2018	2019
Maximum sustainable yield	F_{MSY}	?	?	?	Undefined	MSY $B_{escapement}$	✓	✓	✓ Above escapement
Precautionary approach	F_{pa},F_{lim}	?	?	?	Undefined	B_{pa},B_{lim}	✓	✓	✓ Full reproductive capacity
Management plan	F_{MGT}	–	–	–	Not applicable	B_{MGT}	–	–	– Not applicable

Figure D.1.7. North Sea Sandeel area 3r. Stock status and stock trends. From (ICES, 2019).

Norway pout

The stock size is highly variable from year to year, due to recruitment variability and a short life span. Spawning-stock biomass is estimated to have been fluctuating above B_{pa} for most of the time-series. Fishing pressure declined between 1985 and 1995 and has been fluctuating at a lower level since 1995. Recruitment in 2018, 2019 and 2020 was above the long-term average, but was estimated to be low in 2021. Currently, spawning stock size is above B_{pa} and B_{lim}; no reference points for fishing pressure or for MSY $B_{trigger}$ have been defined for this stock (ICES, 2021h).

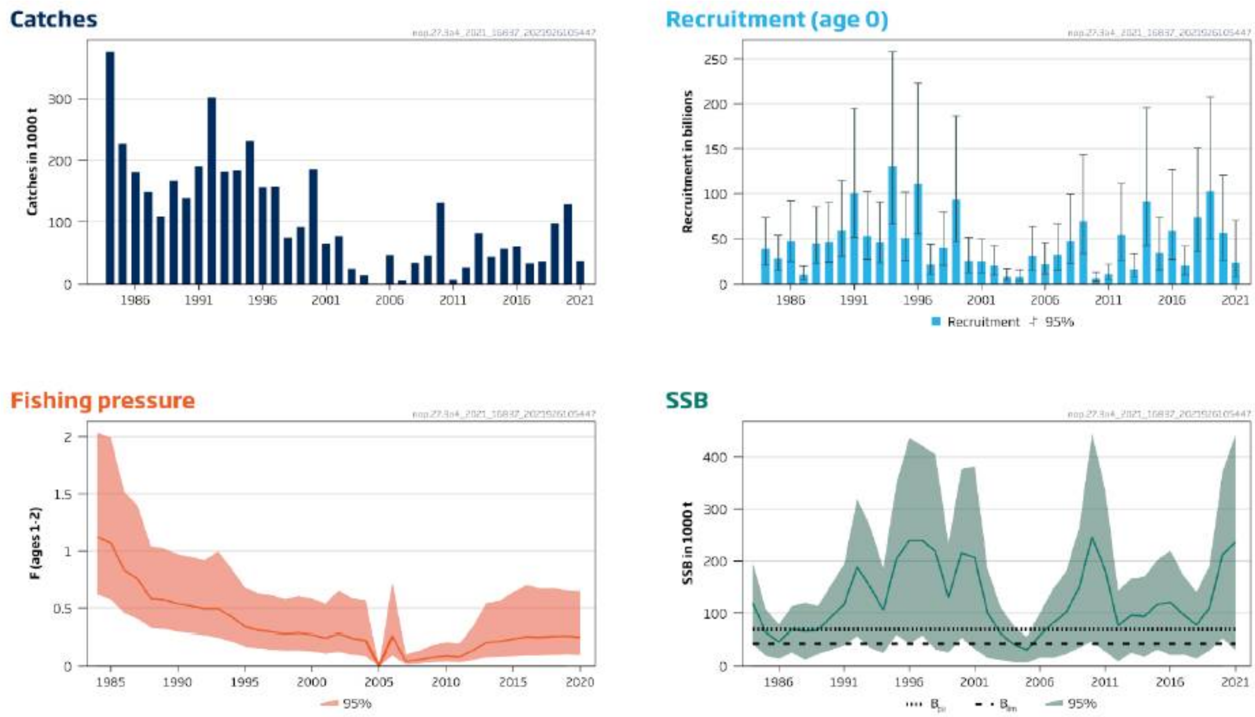


Figure D.1.8. Norway pout in Subarea 4 and Division 3.a. Summary of the stock assessment. Catches in 2021 are up to mid-September. SSB is estimated at the beginning of quarter 4. From (ICES, 2021g)

Whiting

For whiting there is one advice for the North Sea and English Channel and one for Skagerrak and Kattegat.

For the North Sea and English Channel, spawning-stock biomass has fluctuated around MSY $B_{trigger}$ since the mid-1980s and has been above it since 2019. Fishing pressure has been below FMSY since the early 2000s. Recruitment (R) has been fluctuating without trend, but the 2019 and 2020 year-classes are estimated to be the largest since 2002. Currently, fishing pressure on the stock is below FMSY, F_{pa} and F_{lim}; spawning-stock size is above MSY $B_{trigger}$, B_{pa} and B_{lim} (ICES, 2021h).

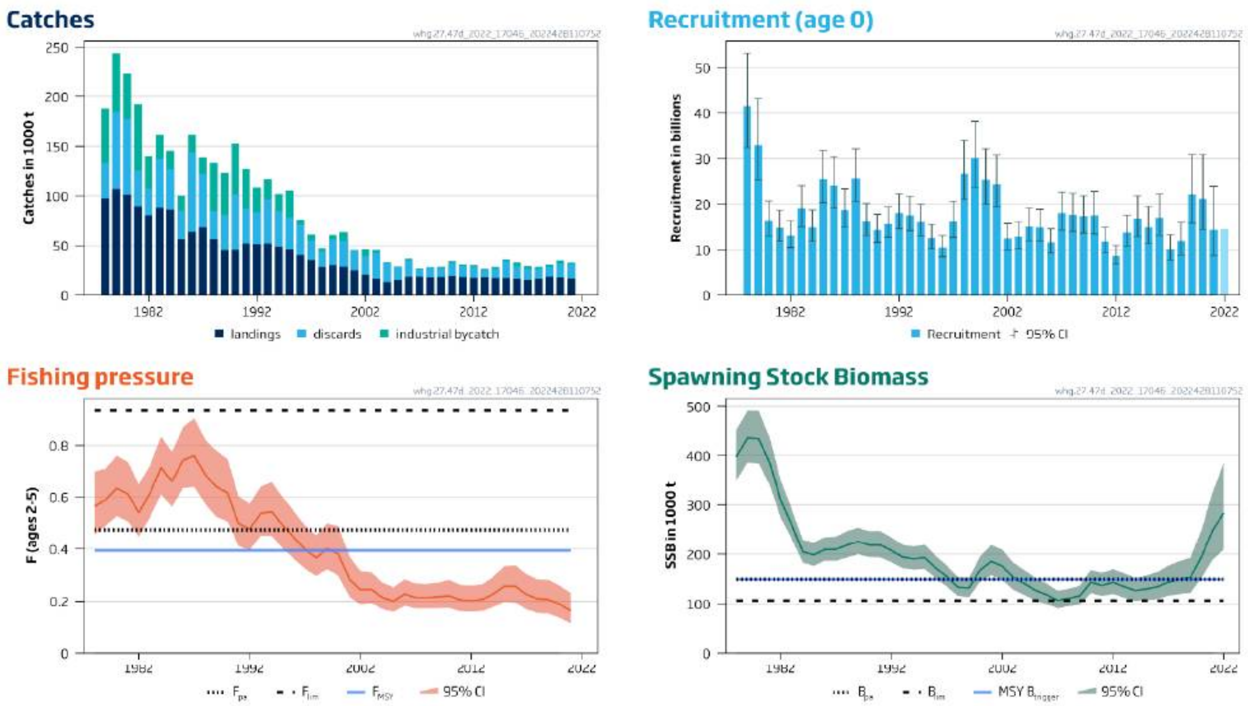


Figure D.1.9a. Whiting in Subarea 4 and Division 7.d. Summary of the stock assessment. The assumed recruitment value for 2022 is shaded in a lighter colour. From (ICES, 2022c).

For Skagerrak and Kattegat, development in catches and biomass index are given in figure D.1.9b. No reference points for fishing pressure have been identified for the stoc. There is an unknown degree of stock mixing with whiting in Subarea 4 and the western Baltic. Linkages between this stock and the neighboring whiting stocks remain a source of bias.

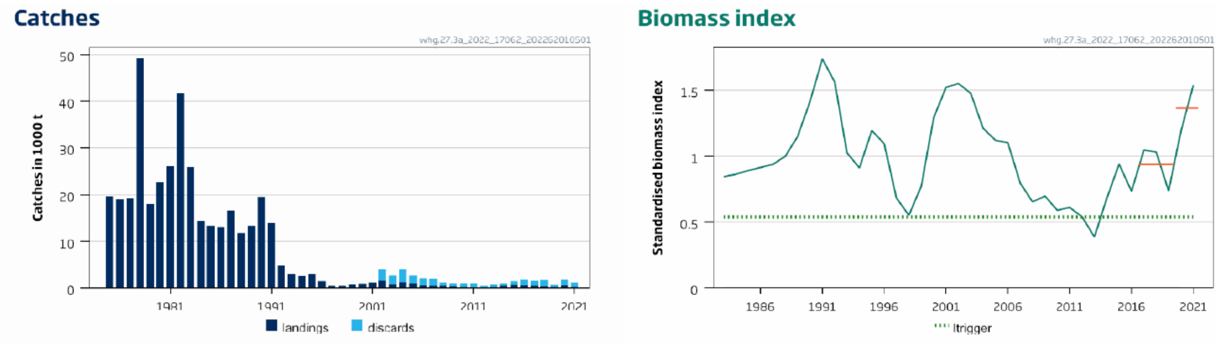


Figure D.1.9b. Whiting in Division 3a (Skagerrak and Kattegat). Summary of the stock assessment. From (ICES, 2022b).

Herring

Fishing pressure on the stock is below FMSY, F_{pa}, and F_{lim}; and the spawning-stock size is above MSY $B_{trigger}$, B_{pa}, and B_{lim} (ICES, 2021e).

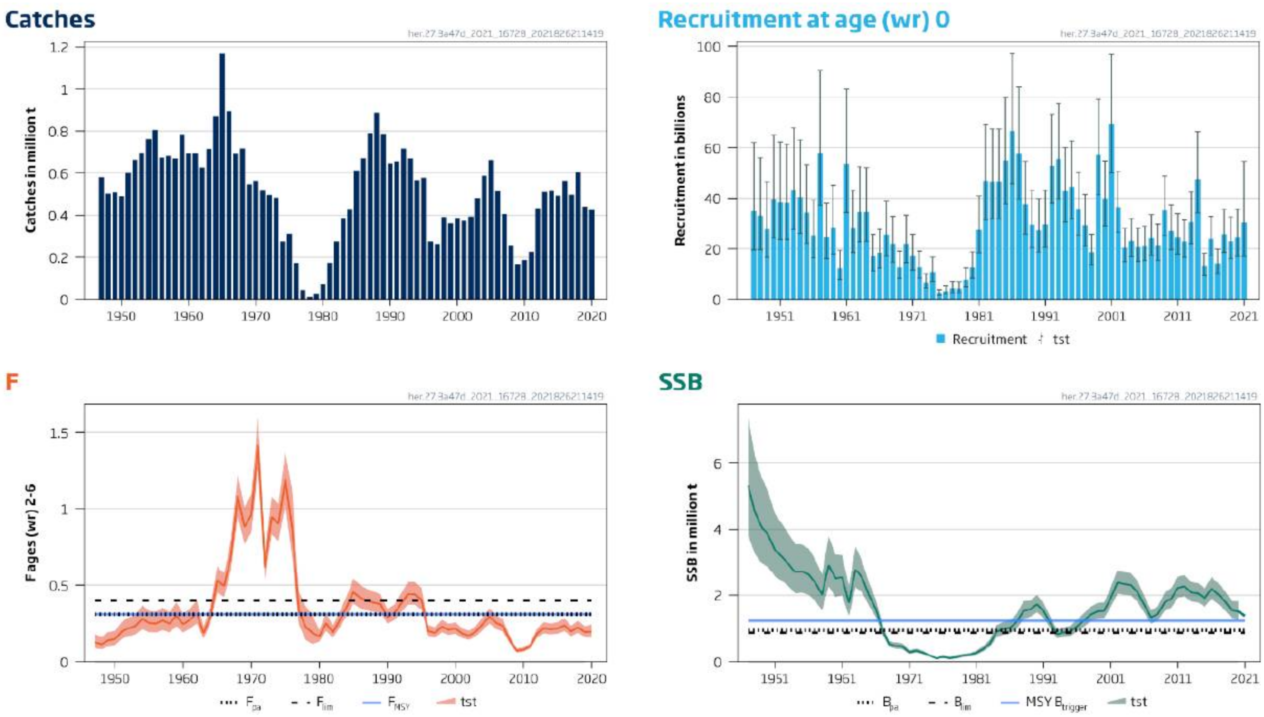


Figure D.1.10. Herring in Subarea 4 and divisions 3.a and 7.d, autumn spawners. Summary of the stock assessment; 95% confidence intervals are shown for SSB, F, and recruitment.

Mackerel

Fishing pressure on the stock is above F MSY but below F pa and Flim; spawning-stock size is above MSY Btrigger , B pa , and Blim.

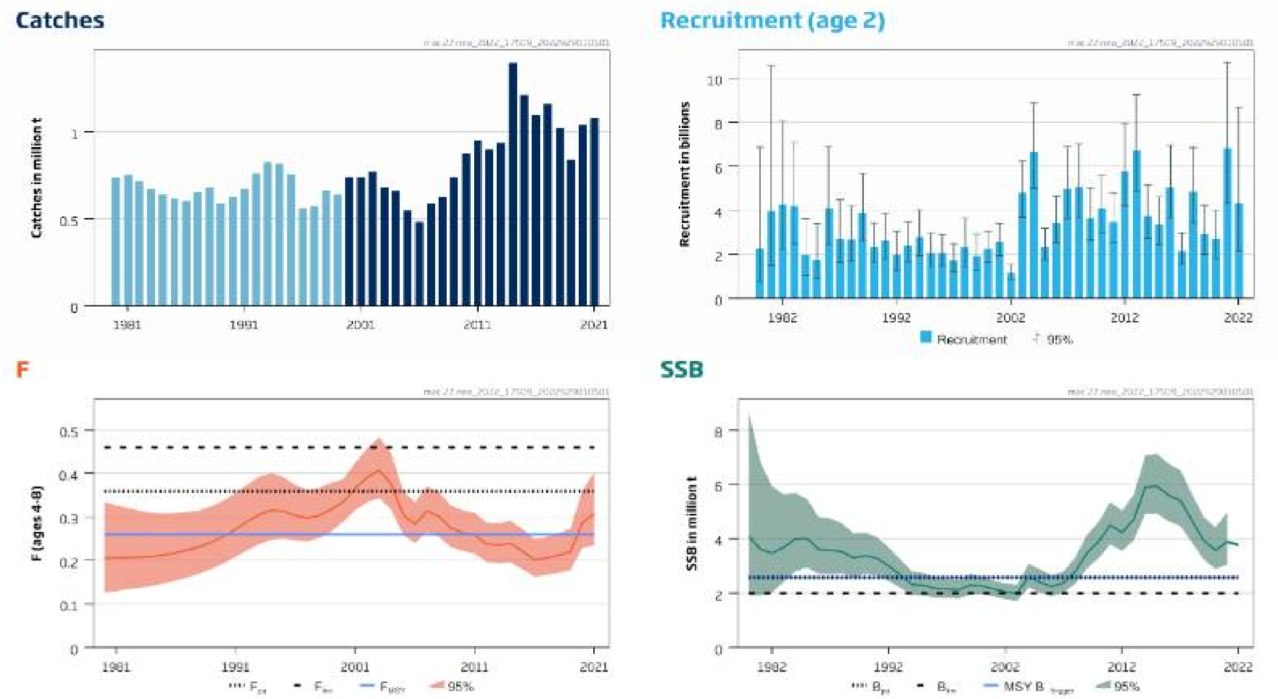


Figure D.1.11 Mackerel in subareas 1–8 and 14, and in Division 9.a. Summary of the stock assessment. Catches prior to 2000 have been down-weighted in the assessment because of the considerable underreporting suspected to have taken place in this period. Abundance estimates of age 0 and 1 from the assessment model poorly reflect year-class strength and therefore recruitment is shown at age 2

Northern Shrimp

Fishing pressure on the stock is below F MSY , and spawning-stock size is below MSY B trigger and B pa but above B lim. (ICES, 2022a).

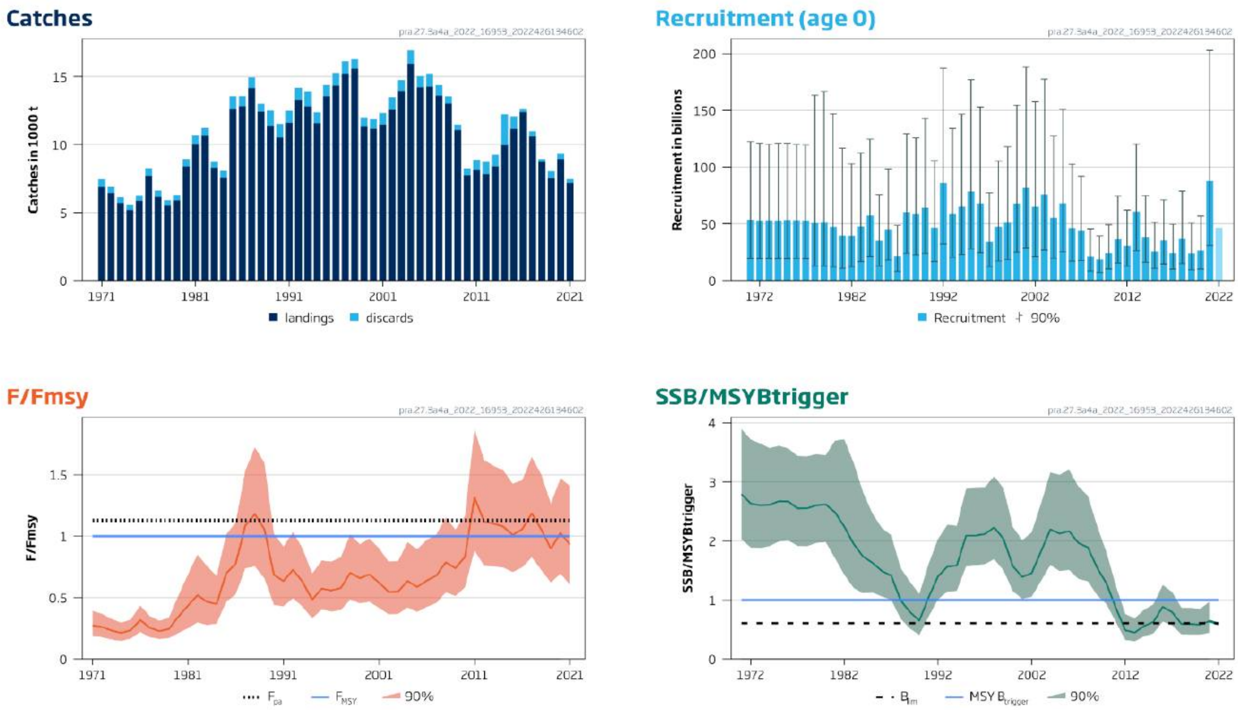


Figure D.1.12 Northern shrimp (Pandalus borealis) in divisions 3.a and 4.a East. Summary of the stock assessment. Assumed recruitment is shown in a lighter shade of blue. [Note: Bmgt = Bpa = MSY Btrigger].

2. Pollution

Local emissions from the petroleum industry

With production of oil and gas follows water from the reservoir, so called produced water. This contains small amounts of oil, and some of this is discharged to the environment. Estimates are made of the amount of oil discharged yearly (Fig D.2.1.) and also of radioactive substances, which occur in elevated concentrations in produced water (Fig D.2.2.).

Impact of accidental discharges of oil is monitored through registrations of oil contaminated stranded common murre (*Uria aalge*) on the coast of the county Rogaland (South-West Norway). The discharges can have many sources, including oil and gas production and ship traffic. There has been a decline in the fraction of oil contaminated individuals among the stranded birds (Fig D.2.3.)

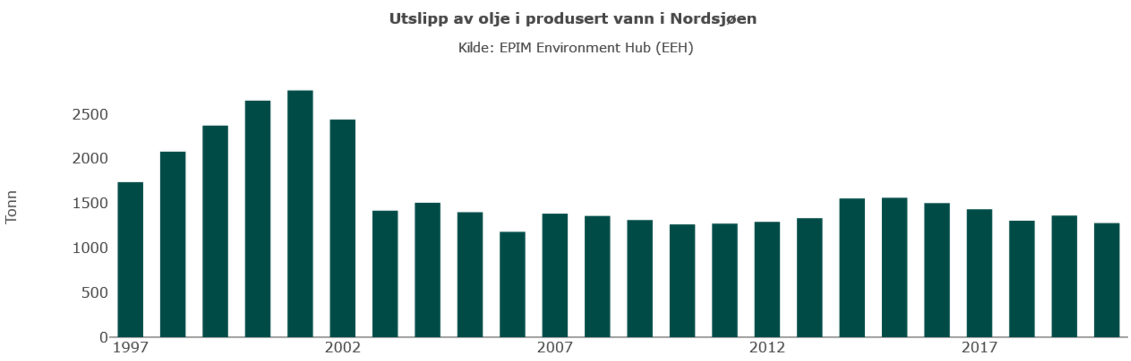


Figure D.2.1. Operational discharges of oil from produced water from oil and gas production in the North Sea. Source: (Norsk petroleum, 2022) and (Miljøstatus, 2022b).

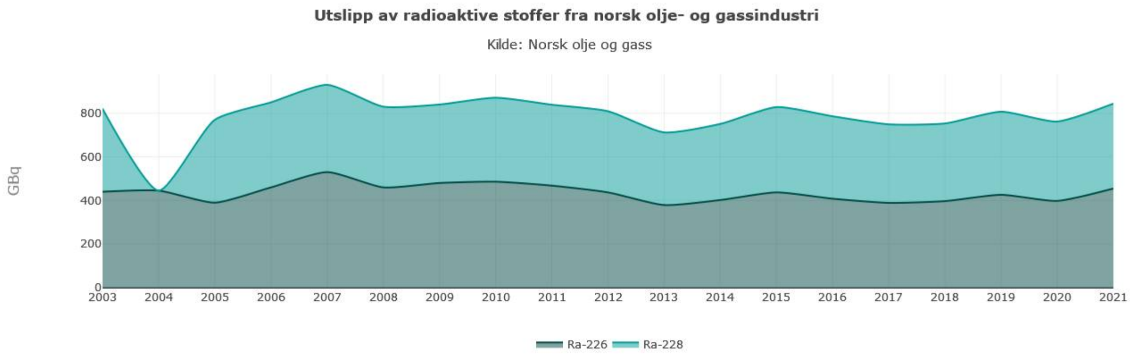


Figure D.2.2. Operational discharges of radioactive substances (Radium-226 and Radium-228) through produced water from oil and gas production in the North Sea. Source: (Norsk petroleum, 2022) and (Miljøstatus, 2022b).

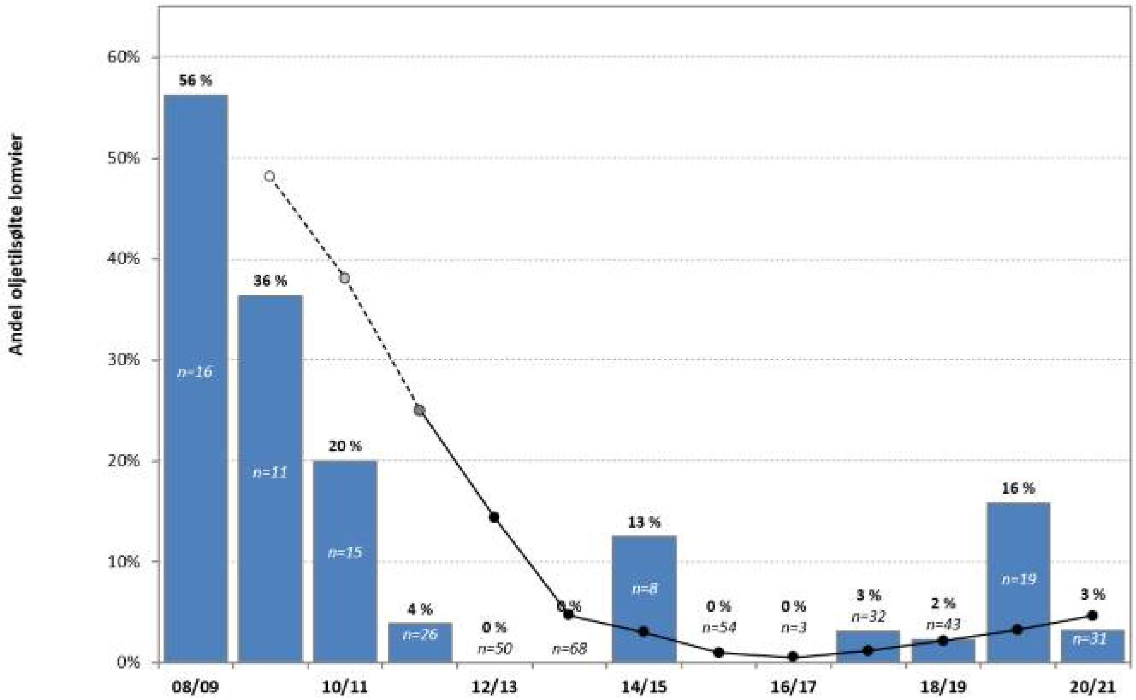


Figure D.2.3. Fraction of stranded common murre (Uria aalgae) retrieved on the coast of Rogaland, South-West Norway. Source Norwegian institute for nature research.

Long range transported contaminants

Figure D.2.4. shows the development in emissions through air of PCB to south Norway, reflecting the emissions to the North Sea. The general trend is a decline that has levelled off in the most recent years.

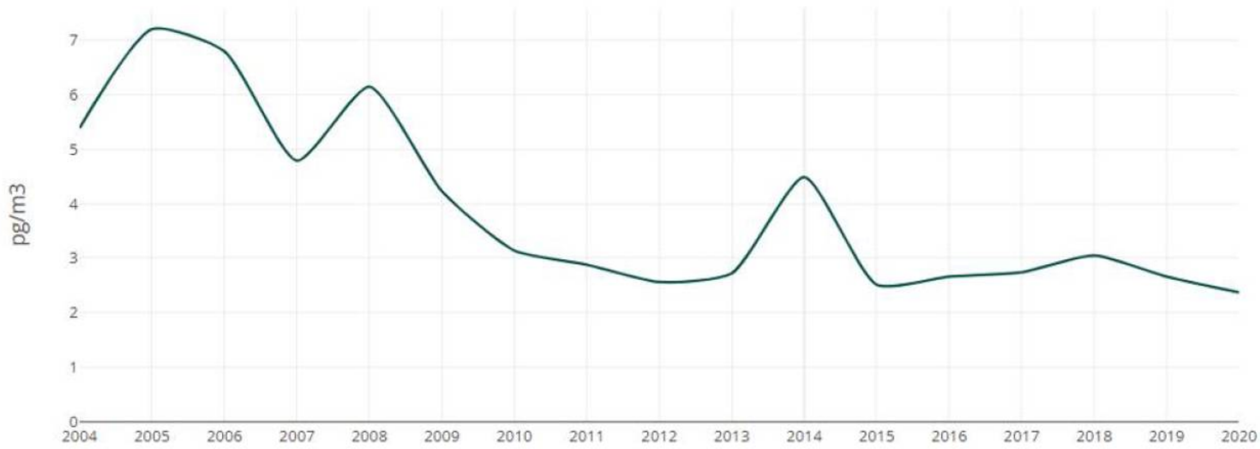


Figure D.2.4. Concentration of PCB in air measured at the Birkenes station in south-east. Source: (Miljøstatus, 2022a).

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Appendix 8.3 : Footnotes for table 7.1

Primary production

1. Fulfilled, satellite data coverage of entire population.

2. Fulfilled, entire area covered by systematic sampling.

3. Not fulfilled, sampling can depend on cloud cover.

4. Not fulfilled, sampling design is not model based.

5. Partially adequate coverage, long time series, but does not overlap with the reference condition.

6. Adequate coverage, seasonal variation is very relevant and taken into account.

7. Total indicator coverage for the characteristic "primary productivity" is considered adequate.

Biomass across trophic levels indicator

8. (herbivorous zooplankton) Considered fulfilled as sampling is done across most of the area, thus making it possible for the entire population to be included. It is assumed that the depths sampled (0-7 meters) is representative for the parts of the water column where the population is found. * For carnivorous zooplankton, the spatial coverage is less good because carnivorous species tend to distribute lower in the water column than the portion sampled by the CPR.

9. (herbivorous zooplankton) Considered fulfilled, as the ship routes can be considered a random element.

10. (herbivorous zooplankton) Considered fulfilled, as the probability of sampling can be estimated from position of ship routes.

11. (herbivorous zooplankton) Not fulfilled, as model-based sampling has not been applied.

12. (herbivorous zooplankton) The time series is long relative to relevant dynamics of the indicator. The main anthropogenic driver is climate change, and the time series overlaps with the climate reference period with a start in 1960.

13. (herbivorous zooplankton) Data is collected throughout the main grazing season (May-September) and therefore covers the seasonal variation that is most important for other parts of the ecosystem.

14. (Composite indicators on fish from IBTS) Data come from the IBTS surveys Q3. The stations cover the whole study area.

15. (Composite indicators on fish from IBTS) Data from the IBTS survey use a randomized sampling design.

16. (Composite indicators on fish from IBTS) There is a known probability for each sampling unit to be covered.

17. (Composite indicators on fish from IBTS) the sampling design is not model based.

18. (Composite indicators on fish from IBTS) the time series is long enough to identify trends in link with species dynamics, but does not cover reference conditions.

19. (Composite indicators on fish from IBTS) the seasonality is not relevant at the scale of the whole fish community.

20. (High trophic level seabirds) Not a design-based sampling where the entire sampling population has possibility of being included.

21. (High trophic level seabirds) Not a design-based sampling based on randomisation.

22. (High trophic level seabirds) Not a design-based sampling, with known probability of including each sampling unit.

23. (High trophic level seabirds) model-based sampling using a statistical model for taking into account variation in time and space of the sampling.

24. (High trophic level seabirds), long time series relative to relative dynamics but not overlapping with reference period.

25. (High trophic level seabirds), Seasonality is not relevant.

Functional groups withing trophic levels

Footnotes are given above.

Functionally important species and biophysical structures

26. (cod SSB) IBTS survey covering enough of the population. But ongoing effort to divide in subpopulation structure.

27. (cod SSB) randomized sampling design.

28. (cod SSB) known probability of sampling each unit.

29. (cod SSB) not a model based design.

30. (cod SSB) partially adequate: long enough for relevant dynamics but not covering the reference conditions.

31. (cod SSB) seasonality important and taken into account.

32. (cod recruitment) IBTS survey covering age 0 in q3, assessment model forced with age 0. Some subpopulations are not well covered, and there are large uncertainties, but the population coverage is large enough.

33. (cod recruitment) randomization sampling design.

34. (cod recruitment) known probability of sampling each unit.

35. (cod SSB) not a model based design.

36. (cod recruitment) partially adequate: long enough for relevant dynamics but not covering the reference conditions.

37. (cod recruitment) season important and taken into account but gear not optimal.

38. (haddock SSB) IBTS survey, Q1 and Q3, covering the entire North Sea population.

39. (haddock SSB) randomization sampling design.

40. (haddock SSB) known probability of sampling each unit.

41. not a model based design.

42. (haddock SSB) partially adequate: long enough for relevant dynamics but not covering the reference conditions.

43. (haddock SSB) seasonality not important.

44. (haddock recruitment) IBTS survey, Q1 and Q3. No obvious issues.

45. (haddock recruitment) randomization sampling design.

46. (haddock recruitment) known probability of sampling each unit.

47. not a model based design.

48. (haddock recruitment) partially adequate: long enough for relevant dynamics but not covering the reference

conditions.

49. (haddock recruitment): no problem with seasonality.

50. (saithe SSB) design based for IBTS a3 with bad coverage of saithe population. Commercial catches (model based) with more weight in the assessment.

51. (saithe SSB) partially adequate: long enough for relevant dynamics but not covering the reference conditions.

52. (saithe SSB) season important as adults are mainly in winter, and there are no sampling then, but there is commercial fisheries.

53. (saithe recruitment) design based sampling of age 3 only. Younger stages at the coast and not covered: not fulfilled.

54. (saithe recruitment) randomization sampling design.

55. (saithe recruitment) known proba of sampling each unit.

56. Not model based sampling.

57. (saithe recruitment) partially adequate: long enough for relevant dynamics but not covering the reference conditions.

58. (saithe recruitment) seasonality important and not well taken into account.

59. (sandeel SBB) stratified random optimized survey on habitat of sandeel.

60. (sandeel SSB): Acoustic survey started in 2009, enough to observe effect of fishing effort, maybe not climate, but the assessment date back to 1983 so it is long enough.

61. (sandeel SSB) seasonality optimized.

62. (sandeel recruitment) Poor spatial coverage of the winter dredge survey of 0gp and age 1. Coverage lacks the northernmost areas.

63. (sandeel recruitment) Selected stations repeated every year.

64. (sandeel recruitment) Selected stations repeated every year.

65. Not model based sampling.

66. (sandeel recruitment) Temporal coverage: 2004 but lower quality in the beginning. Better since 2014, but changes over time in the effort -> partly adequate.

67. (sandeel recruitment) Seasonality optimized.

68. (Norway pout) IBTS survey covering enough of the population.

69. (Norway pout) randomized sampling design.

70. (Norway pout) known probability of sampling each unit.

71. Not model based sampling.

72. (Norway pout) assessment since the 1970s, which is long enough to assess relevant dynamics, but does not cover the reference conditions.

73. (Norway pout) index covering 0gp and all age classes. Seasonal stock assessment, so the seasonality is taken into account.

74. (Norway pout recruitment) IBTS survey covering enough of the population.

75. (Norway pout recruitment) randomized sampling design.

76. (Norway pout recruitment) known probability of sampling each unit.

77. Not model based sampling.

78. (Norway pout recruitment) assessment since the 1970s, which is long enough to assess relevant dynamics, but does not cover the reference conditions.

79. (Norway pout recruitment) index covering 0gp and all age classes. Seasonal stock assessment , so the seasonality is taken into account.

80. (whiting SSB) IBTS survey, Q1 and Q3, covering the entire population of whiting in the North Sea.

81. (whiting SSB) randomization sampling design.

82. (whiting SSB) known probability of sampling each unit.

83. Not model based sampling.

84. (whiting SSB) partially adequate: long enough for relevant dynamics but not covering the reference conditions.

85. (whitting SSB) seasonality not so important.

86. (whiting recruitment) IBTS survey, Q1 and Q3. No obvious issues.

87. (whiting recruitment) randomization sampling design.

88. (whiting recruitment) known probability of sampling each unit.

89. Not model based sampling.

90. (whiting recruitment) partially adequate: long enough for relevant dynamics but not covering the reference conditions.

91. (whiting recruitment): indirect recruitment index. Seasonality is ok, but maybe gear not optimal.

92. (herring SSB) the model is based on areas with more fish, and provides an estimate of the spawning stock. It is fit to represent the indicator on fish SSB.

93. (herring SSB) assessment model starts in 1947 but much more uncertainty in the beginning of the period, where less data are available. We consider that the overlap with low to moderate fishing pressure is too short and with high uncertainty. The temporal coverage is thus partially adequate.

94. (herring SSB) seasonal variations are not relevant for this indicator.

95. (herring recruitment) larvae survey and IBTS survey used to get recruitment data. The IBTS survey is randomized sampling covering the whole area. The acoustic survey is also used and is model based (see herring stock indicator).

96. (herring recruitment) the sampling is randomized.

97. (herring recruitment) each sampling unit has a known probability of being included.

98. Not model based sampling.

99. (herring recruitment) the temporal coverage does not overlap (enough) with the reference conditions but is long

enough to cover relevant dynamics.

100. The seasonal aspect is important but the sampling is taking that into account.

101. (mackerel SSB) Most of the data come from catch data and tag studies. Others come from the IBTS trawl survey. Those data are suitable to estimate mackerel population.

102. (mackerel SSB) Trawl in IBTS survey, tagging of individual provide a randomized sampling. Catch data can be considered to be based on a model of fish distribution.

103. (mackerel SSB) each sampling unit has a known probability of being sampled.

104. (mackerel SSB) the time series is long enough to cover relevant dynamics. Trends in the stock are quite robust. More weight was put on the catch and tag data before the 2000s. Now it is more and more relying on the surveys.

105. (mackerel SSB) the survey follow the stock. Aggregation in autumn make it easier for the fisherman to capture them. Trawl sampling is adapted to periods when it is known that they are more in surface.

106. (mackerel recruitment) Data comes from IBTS trawl survey and eggs survey. Those data are suitable to estimate mackerel recruitment.

107. (mackerel recruitment) Trawl in IBTS survey follows a randomized sampling. Catch data can be considered to be based on a model of fish distribution.

108. (mackerel recruitment) each sampling unit has a known probability of being sampled.

109. (mackerel recruitment) the time series is long enough to cover relevant dynamics. Trends in the stock are quite robust. More weight was put on the catch and tag data before the 2000s. Now it is more and more relying on the surveys.

110. (mackerel recruitment) the survey follow the stock. Aggregation in autumn make it easier for the fisherman to capture them. Trawl sampling is adapted to periods when it is known that they are more in surface. Eggs surveys in winter allow a good recruitment estimation.

111. (shrimp stock) both model based sampling and design based. The whole population of the Norwegian sector of the north sea is covered.

112. (shrimp stock) the sampling from survey is following a grid design.

113. (shrimp stock) every station has a known probability to be sampled.

114. (shrimp stock) model based sampling (catch from Sweden, danemark, Norway) are relevant for supporting the assessment. Survey only from 1984.

115. (shrimp stock) stock index time series is very long. Shrimp biomass is very sensitive to predators in the North Sea. There was no fishing on shrimp yet, so no direct effects, but maybe indirect effect through fisheries of predator. Partially adequate.

116. (shrimp stock) There are changes in depth use across the year. The survey has changed season of sampling. But the assessment model is able to take seasonality into account.

117. (shrimp recruitment) time series: not reliable before 1980 (recruitment forced by model). Before mid-2000s can be considered as reference period.

Landscape ecological patterns

118. (area unimpacted by trawling) Fulfilled, relative benthic status (RBS) estimate and VMS data covering of the entire

assessment area.

119. (area unimpacted by trawling) Fulfilled, relative benthic status (RBS) estimate and VMS data covering of the entire assessment area.

120. (area unimpacted by trawling) Fulfilled, known probability of including every grid cell.

121. Not fulfilled, sampling design is not model based.

122. (area unimpacted by trawling) Fulfilled, the reference condition is known (no significant reduction in area unimpacted by trawling), a recent estimate of trawling impact will thus provide information about deviation from the reference condition.

123. (area unimpacted by trawling), Fulfilled, seasonality is relevant and taken into account in the sampling.

Biological diversity

Footnotes are given above.

Abiotic factors

124. (temperature) Not fulfilled, the sampling is not design based.

125. (temperature) Not fulfilled, the sampling is not design based.

126. (temperature) Not fulfilled, the sampling is not design based.

127. (temperature) Fulfilled, model-based sampling to measure temperature at two oceanographic sections selected to give a good representation of temperature in the area.

128. (temperature) Adequate, long time series relevant to dynamics in the indicator and overlapping with the reference period.

129. (temperature) Adequate, seasonal variability is relevant and considered in the sampling.

130. (stratification) Fulfilled, Design-based sampling where the entire sampling population has a possibility of being included.

131. (stratification) Fulfilled, Design-based sampling where the entire sampling population has a possibility of being included.

132. (stratification) Not fulfilled, Design-based sampling, with UNKNOWN probability of including each sampling unit.

133. (stratification) Not fulfilled.

134. (stratification) Partially adequate, a long time series relative to relevant dynamics but only to a limited extent (5 years) overlapping with the reference period.

135. (stratification) Inadequate, seasonal variability is relevant but not taken into account in the sampling.

136. (inflow) Not fulfilled.

137. (inflow) Not fulfilled.

138. (inflow) Not fulfilled.

139. (inflow) Fulfilled: Model-based sampling based on a model that is relevant for the indicator and the phenomenon in question.

140. (inflow) Partially adequate, a long time series relative to the relevant dynamics, but not overlapping with the

reference period.

141. (inflow) Seasonal variability is relevant and taken into account in the sampling.

142. (nutrients) The sampling is not design based.

143. (nutrients) The sampling is not design based.

144. (nutrients) The sampling is not design based.

145. (nutrients) Data come from the Torungen-Hirtshals oceanographic section which is positioned to cover three water masses: Coastal water, “Mid component” and “southern component”. This covers the main sources of anthropogenic input of nutrients, and the sampling is therefore considered to be model-based.

146. (nutrients) The time series is long but not covering what could be considered a reference period. The North Sea has been subject to considerable runoff of nutrient for substantially longer than the length of the time series.

147. (nutrients) The Torungen-Hirtshals section is sampled monthly. Here data from the winter months are used, as these give the best signal of nutrient input and amount available for primary production later in the year.

148. (light attenuation) Not fulfilled, the sampling is not design based.

149. (light attenuation) Not fulfilled, the sampling is not design based.

150. (light attenuation) Not fulfilled, the sampling is not design based.

151. (light attenuation) A statistical model is built where year, season and location of sampling (there are > 20000 samples all together) are added as factors. Thus, it is considered that a model-based sampling is applied, see Opdal et al. (2019).

152. (light attenuation) Adequate, as the time series is long relative to relevant dynamics and covers substantial parts of the climate reference period.

153. (light attenuation) A statistical model is built where year, season and location of sampling (there are > 20000 samples all together) are added as factors. The effect of year is seen from this model. Thus, it is considered that seasonality is covered, see Opdal et al. (2019).

154. (pH) Not fulfilled, the sampling is not design based.

155. (pH) Not fulfilled, the sampling is not design based.

156. (pH) Not fulfilled, the sampling is not design based.

157. (pH) Model-based sampling done in the Atlantic Water core present at 3-4 stations along the Torungen-Hiltshals section (Skagerrak) (regional box 58.00-58.40 N, 8.77-9.37 E.).

158. (pH) Inadequate, short time series relative to relevant dynamics as they start only in 2012, thus decades after CO_2 concentration in the atmosphere had started to increase significantly due to anthropogenic emissions.

159. (pH) Adequate, sampling is done in winter when year to year variation can be best detected.

160. (Aragonite) Not fulfilled, the sampling is not design based.

161. (Aragonite) Not fulfilled, the sampling is not design based.

162. (Aragonite) Not fulfilled, the sampling is not design based.

163. (Aragonite) Model-based sampling done in the Atlantic Water core present at 3-4 stations along the Torungen-

Hiltshals section (Skagerrak) (regional box 58.00-58.40 N, 8.77-9.37 E.).

164. (Aragonite) Inadequate, short time series relative to relevant dynamics as they start only in 2012, thus decades after CO2 concentration in the atmosphere had started to increase significantly due to anthropogenic emissions.

165. (Aragonite) Adequate, sampling is done in winter when year to year variation can be best detected.

HAVFORSKNINGSINSTITUTTET

Postboks 1870 Nordnes
5817 Bergen
Tlf: 55 23 85 00
E-post: post@hi.no
www.hi.no