## Material and methods

### Sea surface temperature analysis

SST data was obtained from the Extended Reconstructed Sea Surface Temperature (ERSST, version 5) dataset (https://www1.ncdc.noaa.gov/pub/data/cmb/ersst/v5/ascii/). ERSST is a global monthly sea surface temperature dataset derived from the International Comprehensive Ocean–Atmosphere Dataset (ICOADS). Production of the ERSST is on a 2° × 2° grid with spatial completeness enhanced using statistical methods. This monthly analysis begins in January 1854 continuing to the present (Huang et al. 2017, 2018, 2019). We averaged the SST over the GOM region (the region between latitudes 40.375 N and 45.125 N and longitudes 70.875 W and 65.375 W) to produce a monthly time series SST. This time series was then processed into annual time series.



**Fig.S1 (a) Average SST and (b) average SST in summer (from June to August) of Gulf of Maine from 1982 to 2018.**

### Stock recruitment relationship in OM

Based on recommendations made in the benchmark assessment (NEFSC 2013), the parameters of stock-recruitment model were calculated by the SSB and age-1 Recruitments data from 1982 to 2009. Recruitments after 2009 were not included due to their greater variance.

**Table.S1 The parameters of stock-recruitment relationship for operating models**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| parameters | α | β | *R*max (n) | *S*max (mt) |
| Ms1 | 0.551 | 7.386\*10-6 | 31373.12 | 26048.9 |
| Ms2 | 1.586 | 5.569\*10-5 | 33406.02 | 26184.69 |
| Ms3 | 0.516 | 5.889\*10-6 | 29345.16 | 25329.38 |
| Ms4 | 0.909 | 2.153\*10-5 | 40841.99 | 31530.59 |
| Ms5 | 0.914 | 2.439\*10-5 | 41216.88 | 29111.31 |
| Ms6 | 0.848 | 1.695\*10-5 | 45621.3 | 31258.54 |
| Ms7 | 0.872 | 1.835\*10-5 | 46179.64 | 30782.51 |

α: Linear growth parameter at low stock size

β: Density-dependent parameter

*R*max (n): Maximum recruitment

*S*max (mt): SSB that produces maximum recruitment

### Age-based population dynamic model (Sun et al. 2019)

A basically used VPA-based XSA model based on the data structure of cod was written as follows:

where age.max indicates the maximum age, indicates the number of age a fish of year y, α was the linear growth parameter at low stock size, β was the density-dependent parameter. An error term ε was added to the recruitment relationship to represent the associated uncertainty (recruitment variation represented by historical residuals was added to SRR estimation).

is the total mortality for age group a of the year y. The total mortality was acquired by summing up natural mortality and fishing mortality as following:

where is the age- and year-specific natural mortality, is the year-specific selectivity for each age group determined by the fleet sub-model, is the year-specific fishing mortality at full selectivity. Because we considered only one fleet, the catch for each year was simply obtained by accumulating catch from all age groups:

## Results

### Retrospective error

**Table.S2 Retrospective errors of Atlantic cod stock assessment. The results were averaged for the last** 7**-years and compared among different *M* scenarios. The seven *M* scenario were explained in Table 1 in the main text.**

|  |  |  |
| --- | --- | --- |
| *M* scenario | SSB.err | F.err |
| Ms1 | 0.518 | -0.288 |
| Ms2 | 0.293 | -0.161 |
| Ms3 | 0.523 | -0.291 |
| Ms4 | 0.193 | -0.092 |
| Ms5 | 0.295 | -0.179 |
| Ms6 | 0.543 | -0.291 |
| Ms7 | 0.400 | -0.232 |

### Population dynamics



**Fig.S2 The estimated population dynamics between different M scenarios**. a: Spawning stock biomass, b: Year-specific fishing mortality at full selectivity, c: Estimated trends in age-1 recruitment. Different colors represent different M assumptions

### Relative error

**Table.S3 Age specific relative error (*EEF*) of estimated fishing mortality (F)**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| F | Age1 | Age2 | Age3 | Age4 | Age5 | Age6 | Age7 | Age8 | Age9 |
| Ms1 | 0.16 | 0.11 | 0.05 | -0.04 | -0.06 | 0.05 | 0.18 | 0.35 | 0.35 |
| Ms2 | 0.16 | 0.12 | 0.05 | -0.04 | -0.03 | 0.08 | 0.20 | 0.18 | 0.18 |
| Ms3 | 0.16 | 0.12 | 0.05 | -0.04 | -0.06 | 0.04 | 0.19 | 0.37 | 0.37 |
| Ms4 | 0.28 | 0.10 | 0.06 | -0.04 | -0.02 | 0.09 | 0.24 | 0.22 | 0.22 |
| Ms5 | 0.16 | 0.11 | 0.05 | -0.03 | -0.02 | 0.07 | 0.18 | 0.23 | 0.23 |
| Ms6 | 0.17 | 0.11 | 0.05 | -0.04 | -0.03 | 0.07 | 0.14 | 0.19 | 0.19 |
| Ms7 | 0.16 | 0.11 | 0.05 | -0.04 | -0.03 | 0.07 | 0.14 | 0.19 | 0.19 |

**Table.S4 Age specific relative error (*EEN*) of estimated abundance (N)**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| N | Age1 | Age2 | Age3 | Age4 | Age5 | Age6 | Age7 | Age8 | Age9 |
| Ms1 | -0.01 | -0.01 | -0.02 | -0.03 | -0.03 | 0.01 | 0.00 | -0.12 | -0.27 |
| Ms2 | 0.00 | -0.01 | -0.04 | -0.04 | -0.06 | -0.03 | -0.09 | -0.19 | -0.25 |
| Ms3 | -0.01 | -0.01 | -0.03 | -0.03 | -0.03 | 0.03 | 0.01 | -0.12 | -0.28 |
| Ms4 | -0.02 | -0.03 | -0.04 | -0.06 | -0.07 | -0.03 | -0.04 | -0.12 | -0.27 |
| Ms5 | -0.01 | -0.02 | -0.04 | -0.05 | -0.07 | -0.02 | -0.05 | -0.14 | -0.27 |
| Ms6 | -0.02 | -0.03 | -0.03 | -0.04 | -0.05 | -0.02 | -0.04 | -0.14 | -0.26 |
| Ms7 | -0.02 | -0.03 | -0.04 | -0.04 | -0.05 | -0.02 | -0.04 | -0.13 | -0.26 |

### Stock status

**Table. S5 The estimated stock status for simulation analysis (%)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| M assumptions | PF>FMSY and B>BMSY | PF>FMSY and B<BMSY | PF<FMSY and B>BMSY | PF<FMSY and B<BMSY |
| Ms1 | 0 | 100.00 | 0 | 0 |
| Ms2 | 59.46 | 24.32 | 5.41 | 10.81 |
| Ms3 | 0 | 100.00 | 0 | 0 |
| Ms4 | 72.97 | 10.81 | 5.41 | 10.81 |
| Ms5 | 72.97 | 16.22 | 0 | 10.81 |
| Ms6 | 37.84 | 56.76 | 0 | 5.40 |
| Ms7 | 45.95 | 48.65 | 0 | 5.40 |

PF>FMSY and B>BMSY: overfishing is occurred, stock is not overfished

PF>FMSY and B<BMSY: overfishing and overfished occurred simultaneously

PF<FMSY and B>BMSY: overfishing is not occurred, stock is not overfished

PF<FMSY and B<BMSY: overfishing is not occurred, stock is overfished

## References

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