Celtic sea cod:

ICES, assessment, advice and a thimble of literature

Cod (*Gadus morhua*) in divisions 7.e–k (western English Channel and southern Celtic Seas)

Dr. Jonathan White
Marine Institute, Ireland

Chair:
- ICES Working Group for the Celtic Seas Ecoregion (WGCSE)
- ICES Fisheries Resources Steering Group

Foras na Mara
Marine Institute

ICES
CIEM
Science for sustainable seas

12th June 2024

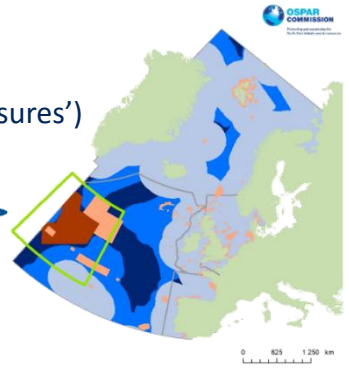
ICES advice in 2023

Fisheries advice:

- **198 stocks**/ 73 % MSY or PA
- ecosystem considerations for forage fish species
- “zero TAC technical” service
- unavoidable bycatch

Ecosystem services and effects advice:

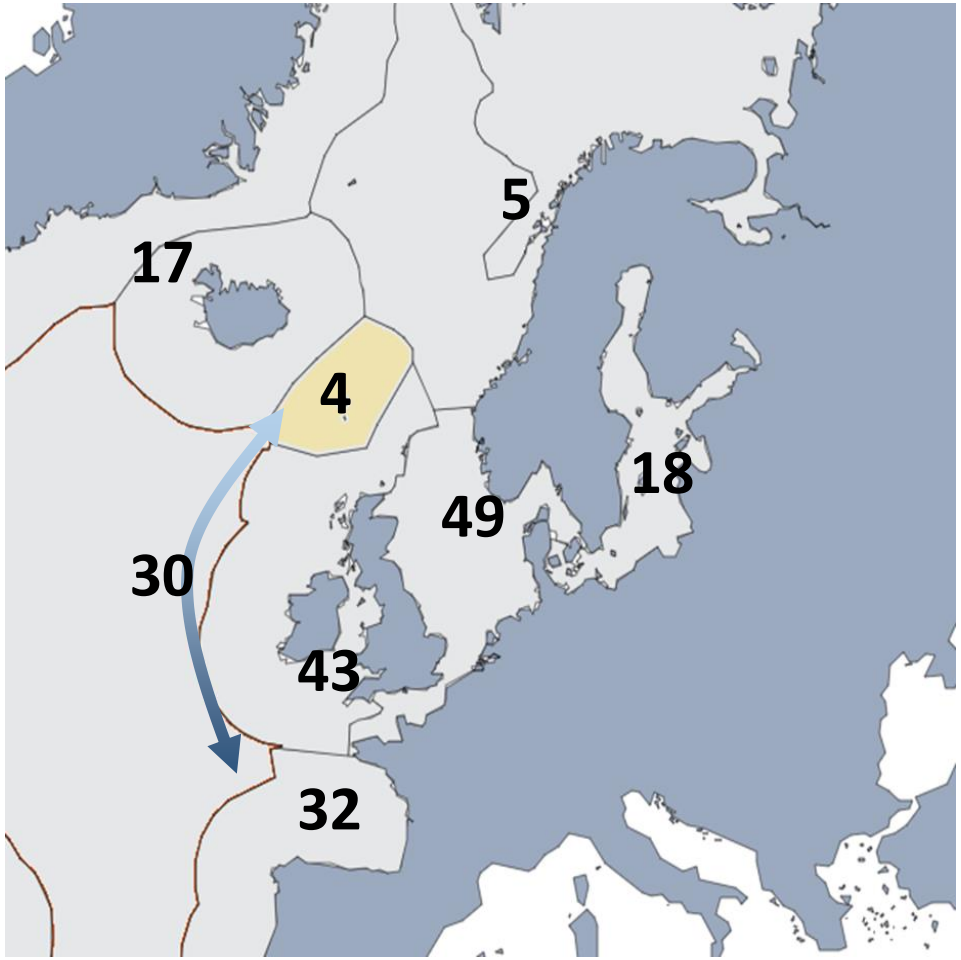
- VME, Bycatch mitigation
- Innovative fishing gears
- MSFD D1/D6
- OECM (‘other effective area-based cons. measures’)
- Bird Bycatch
- Evlanov MPA



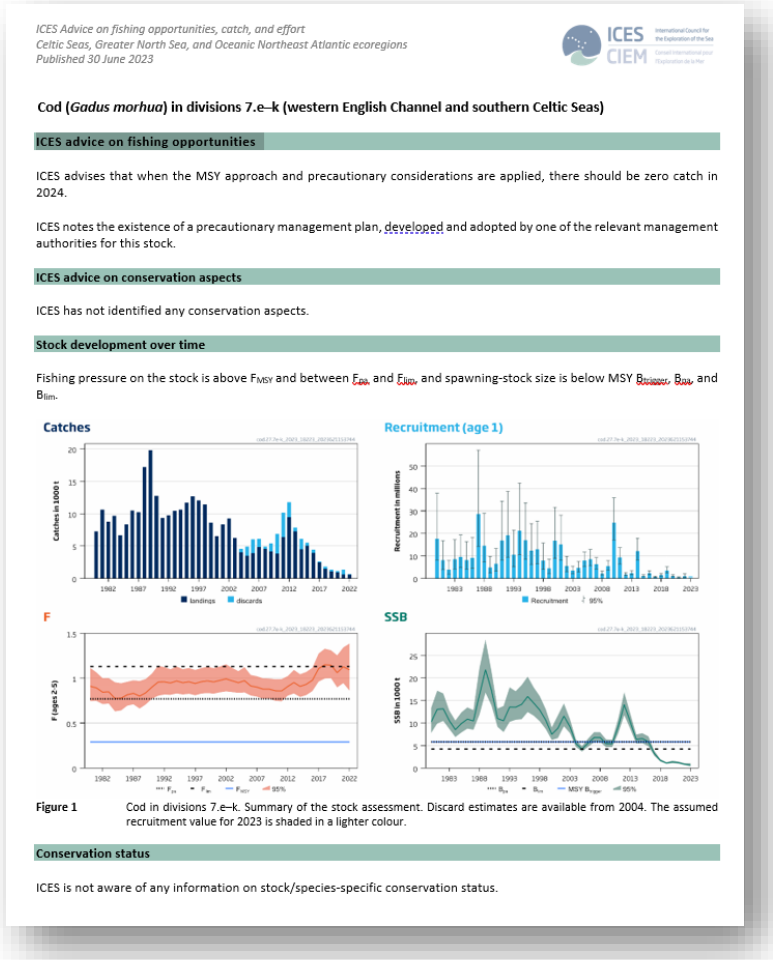
Overviews:

Fisheries, Aquaculture, Ecosystems

- Faroes Ecosystem & Aquaculture Overview
- Updated Greenland Sea Ecosystems Overview



ICES advises that…



ICES Advice on fishing opportunities, catch, and effort
Celtic Seas, Greater North Sea, and Oceanic Northeast Atlantic ecoregions
Published 30 June 2023

Cod (*Gadus morhua*) in divisions 7.e–k (western English Channel and southern Celtic Seas)

ICES advice on fishing opportunities

ICES advises that when the MSY approach and precautionary considerations are applied, there should be zero catch in 2024.

ICES notes the existence of a precautionary management plan, developed and adopted by one of the relevant management authorities for this stock.

ICES advice on conservation aspects

ICES has not identified any conservation aspects.

Stock development over time

Fishing pressure on the stock is above F_{MSY} and between F_{pa} and F_{lim}, and spawning-stock size is below MSY $B_{trigger}$, B_{pa}, and B_{lim}.

Catches

Recruitment (age 1)

F

SSB

Figure 1 Cod in divisions 7.e–k. Summary of the stock assessment. Discard estimates are available from 2004. The assumed recruitment value for 2023 is shaded in a lighter colour.

Conservation status

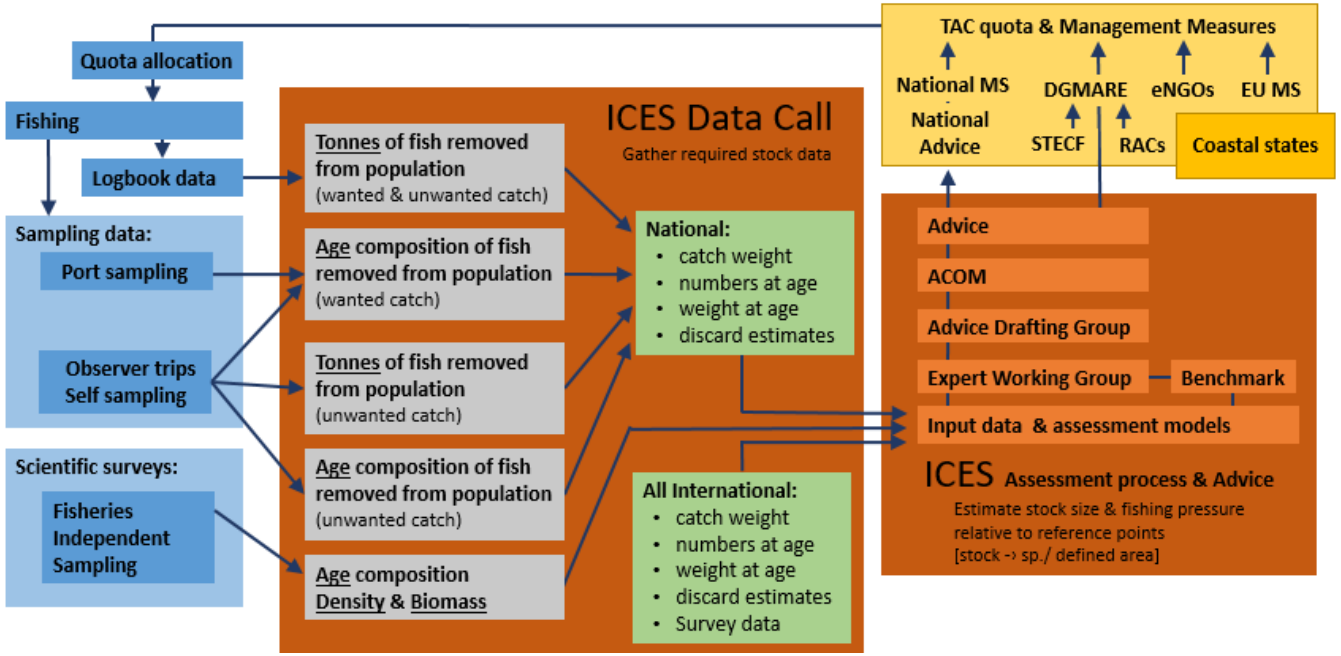
ICES is not aware of any information on stock/species-specific conservation status.

… when the MSY approach and precautionary considerations are applied, there should be zero catch in 2024.

https://www.ices.dk/advice/Pages/Latest-Advice.aspx

Benchmarks, Assessments, Reviews, Advice

Fisheries Stock assessment – Fishing/ Advice cycle

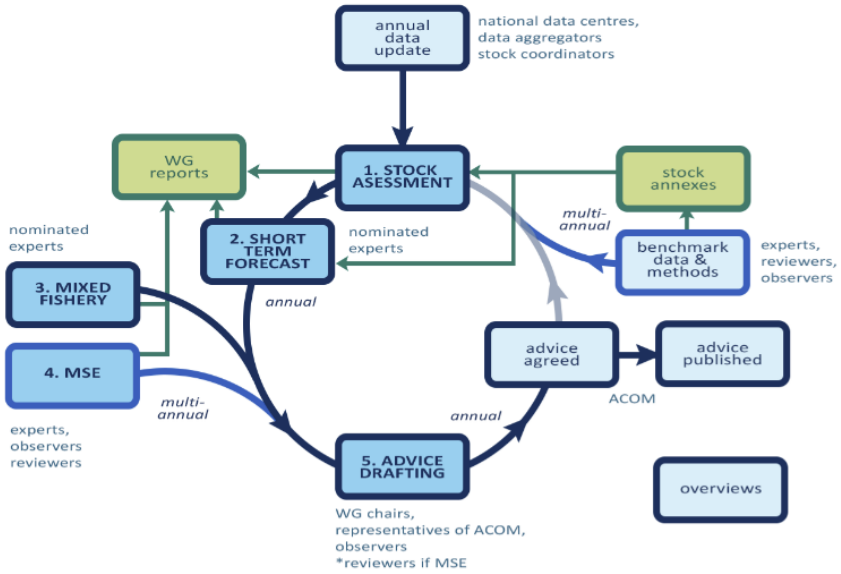


Process flow of ICES advice production

Process flow - production of ICES advice on fishing opportunities WKAFPA https://doi.org/10.17895/ices.pub.24866088

Benchmarks, Assessments, Reviews, Advice

Process flow of ICES advice production



WKAFPA https://doi.org/10.17895/ices.pub.24866088

WKCELTIC: Benchmark Workshop on Celtic Sea Stocks 2019-2020

To evaluate the current data and assessment methodology for several stocks and to propose improvements

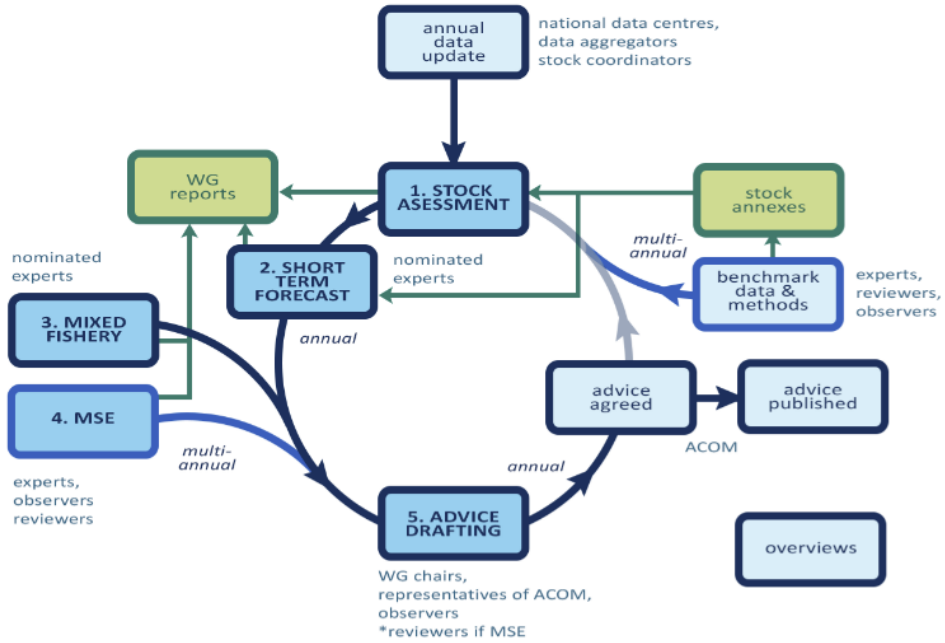
- **Cod 7.e–k** (eastern English Channel and southern Celtic Seas)
- **Whiting 7.b–c and 7.e–k** (southern Celtic Seas and eastern English Channel)
- **Haddock 7.b–k** (southern Celtic Seas and English Channel)

Two Data evaluation workshops (DEWK) – February 2019 & October 2019

- Review historic data: landings, discards, weight, number, size composition, age length keys, métiers/fleets
- Stock identity, migration, life history data
- Standardize data processing

Assessment Benchmark workshops – February 2020

- Updated assessments with revised data
- Comparison of alternative assessment
- Comparison of tuning fleets inclusion on assessment estimates
- Parallel assessment approaches to aid mixed fishery assessments.
- Review environmental drivers, potential for inclusion and ecosystem impacts
- Update reference points

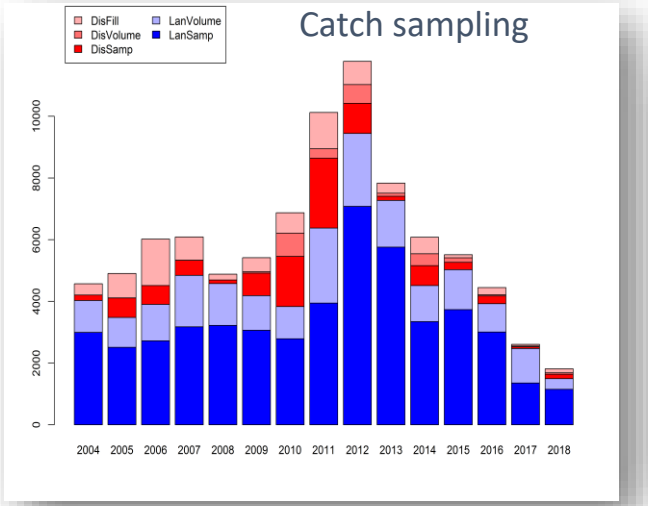


ICES. 2020. Benchmark Workshop on Celtic Sea Stocks (WKCELTIC)
ICES Scientific Reports. 2:97. 166 pp. http://doi.org/10.17895/ices.pub.5983

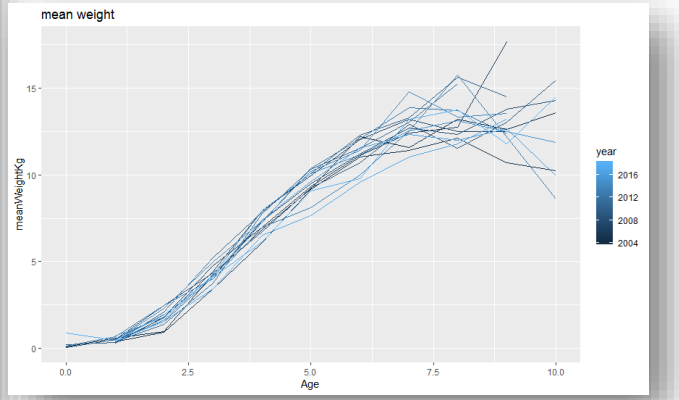
WKCELTIC: Benchmark Workshop on Celtic Sea Stocks 2019-2020

Celtic sea cod – Assessment updates

Catch sampling



Mean weight of the catch per year and age



Survey areas and data

Previous values

Natural mortality

Age	0	1	2	3	4	5	6	7	8	9	10
M	1.12	0.51	0.37	0.30	0.269	0.247	0.233	0.223	0.216	0.210	0.207

Age	0	1	2	3	4	5	6	7	8	9	10
M WKCELTIC 2020	0.967	0.501	0.330	0.264	0.233	0.211	0.211	0.211	0.211	0.211	0.2

Maturity

Age	1	2	3	4	5+
Before 1999	0.00	0.05	1.00	1.00	1.00
Current	0.00	0.39	0.87	0.93	1.00

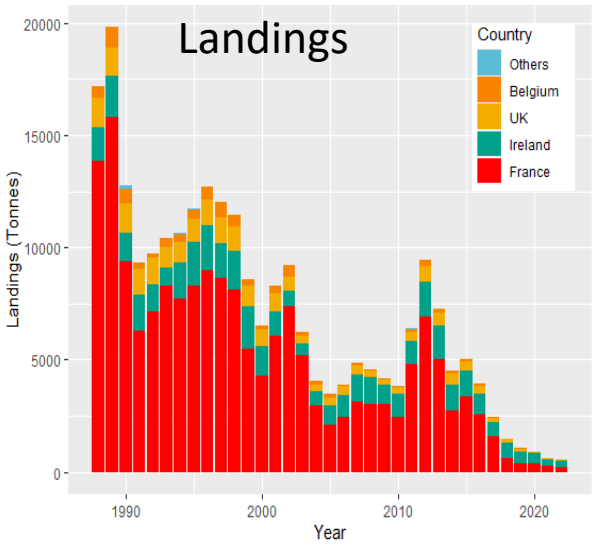
Age	1	2	3	4	5+
WKCELTIC 2020	0.00	0.54	0.93	1.00	1.00

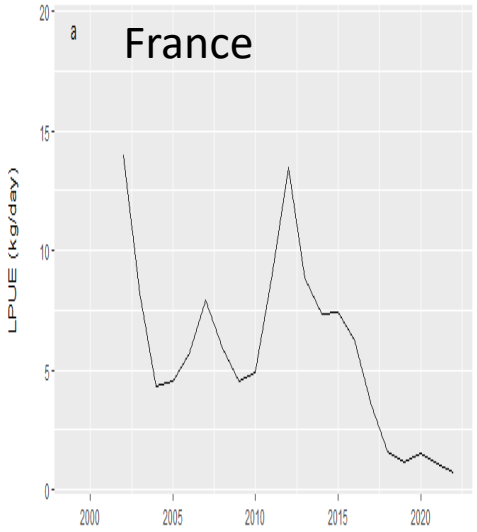
Assessment model:

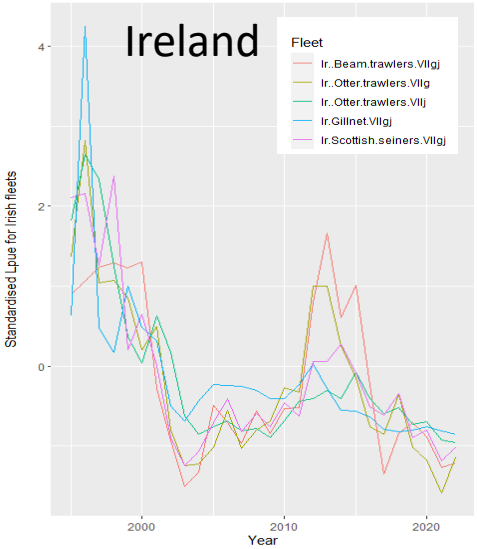
- ASAP (Age Structured Assessment Program)
- SAM (State-Space Stock Assessment Model)

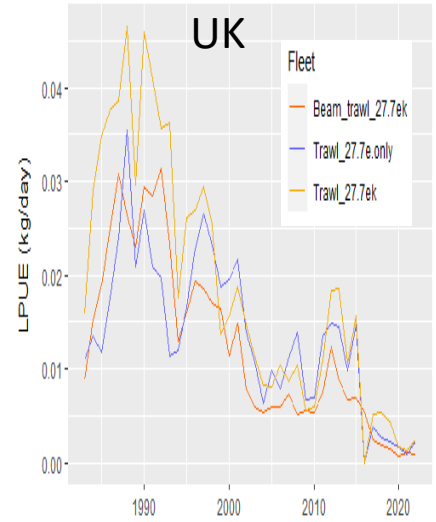
WGCSE 2023 Cod assessment

Fishing

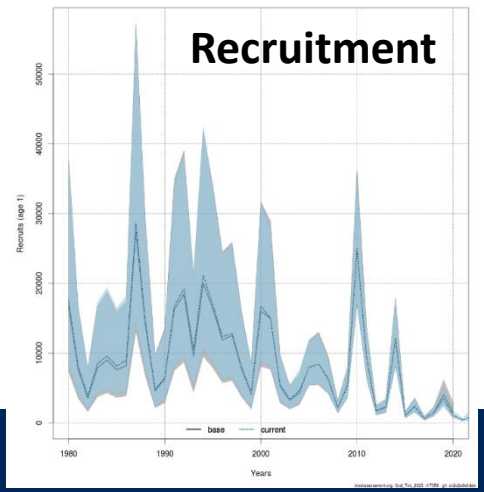


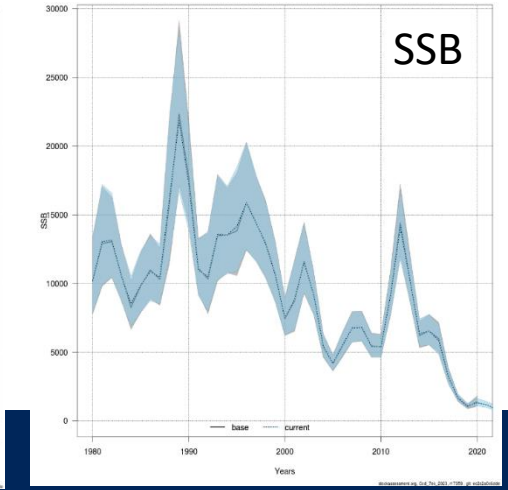


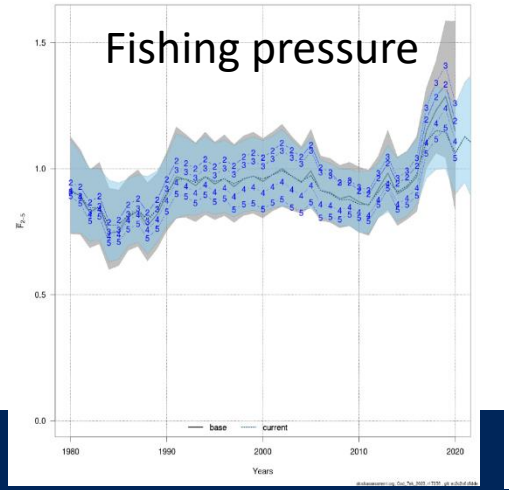


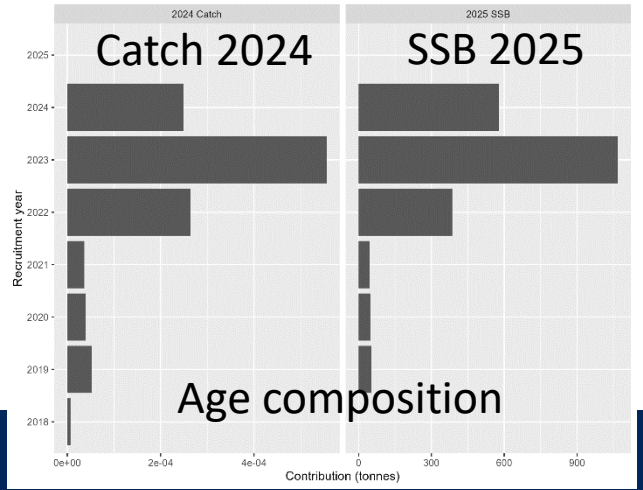


Assessment







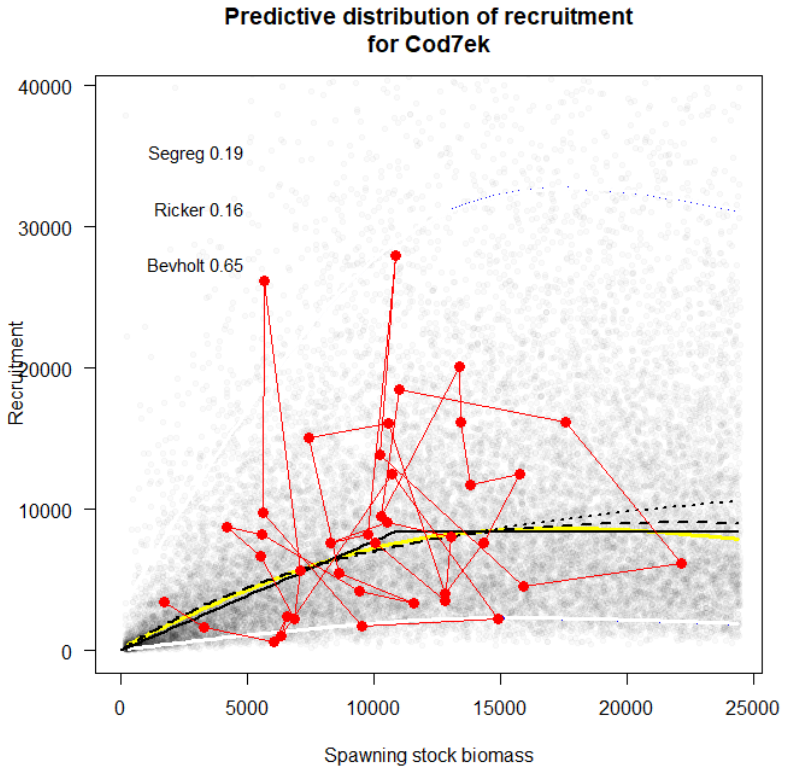


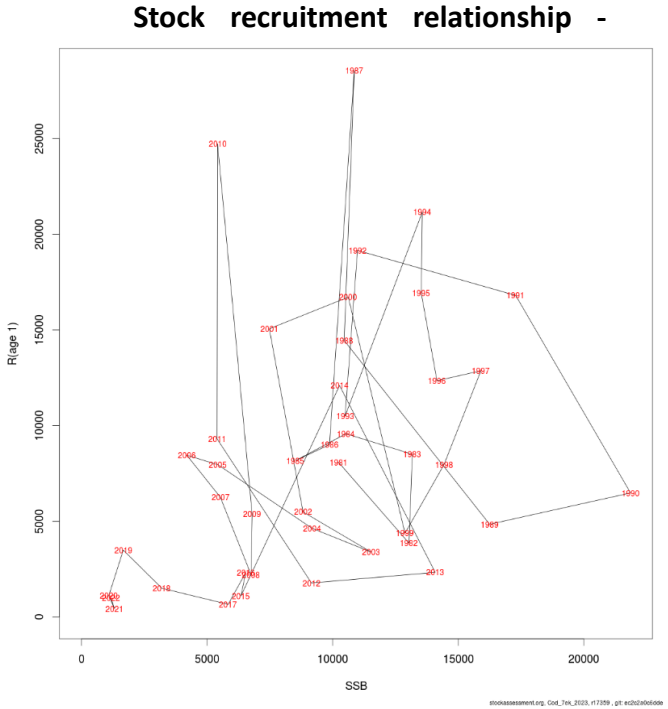
Environment driven:
Stock / Recruitment relationship

The “Recruitment” relative to the “Spawning Stock”

- **Each point represents values of a single year** across the full assessment area and 12 months

- Each point, ***intrinsically***, incorporate the affect & impact of the environment - biotic & abiotic factors on the stock





… what is “Recruitment”…

… fish becoming vulnerable to harvest (e.g., reaching legal size), or fish transitioning to a different life stage

… the process of small, young fish transitioning to an older, larger life stage

https://edis.ifas.ufl.edu/publication/FA222#TOP

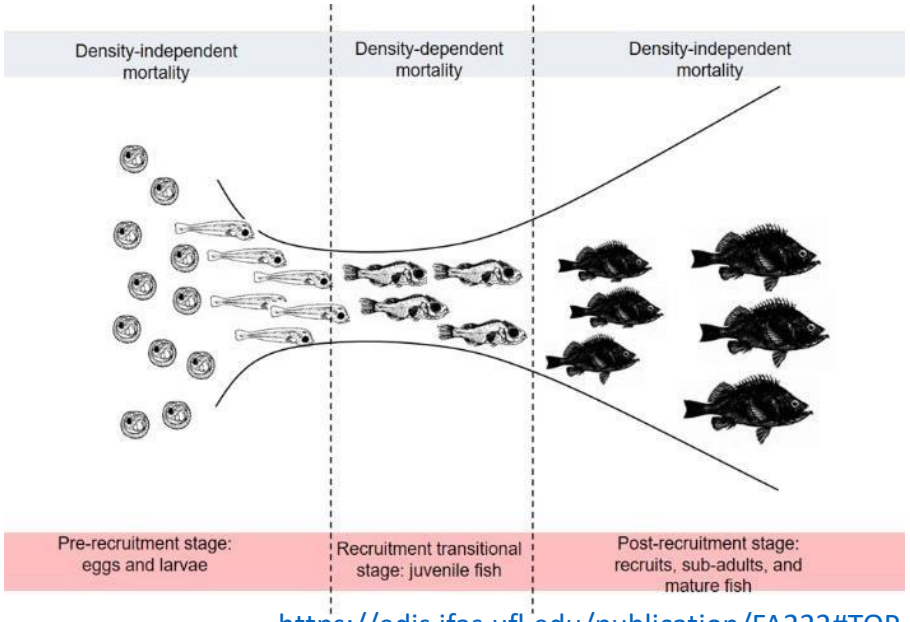
… the addition of new members of a population to the first life stage at which natural mortality stabilizes near adult levels.

https://u.osu.edu/ludsinlab/research/fish-recruitment/

… the addition of new individuals to the fished component of stock.

https://www.fishbase.se

… early life stage when fish become more robust to natural mortality and large enough to catch



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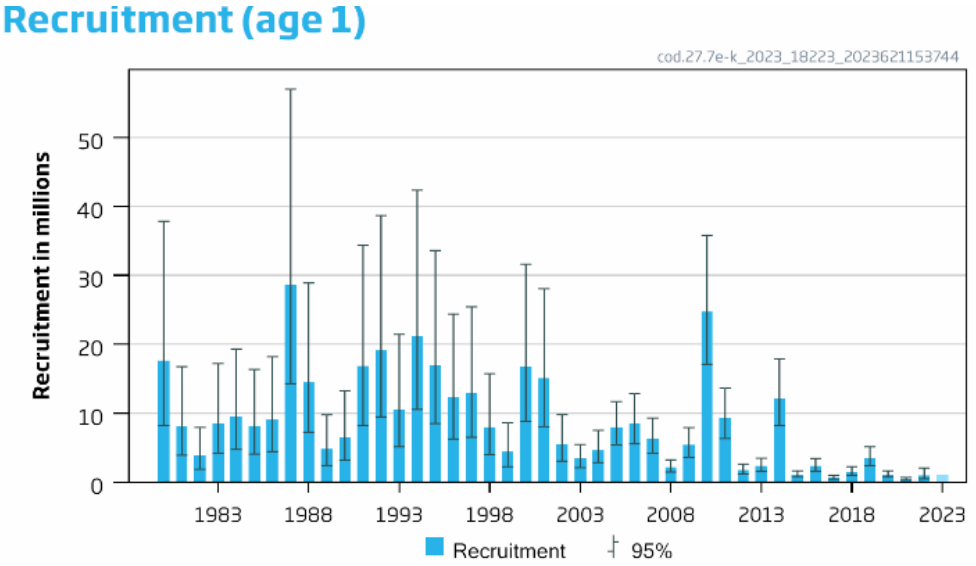
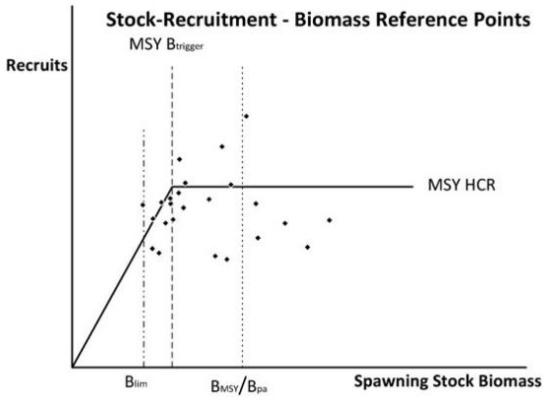
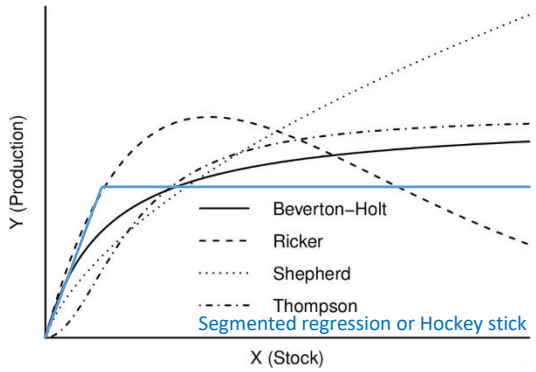


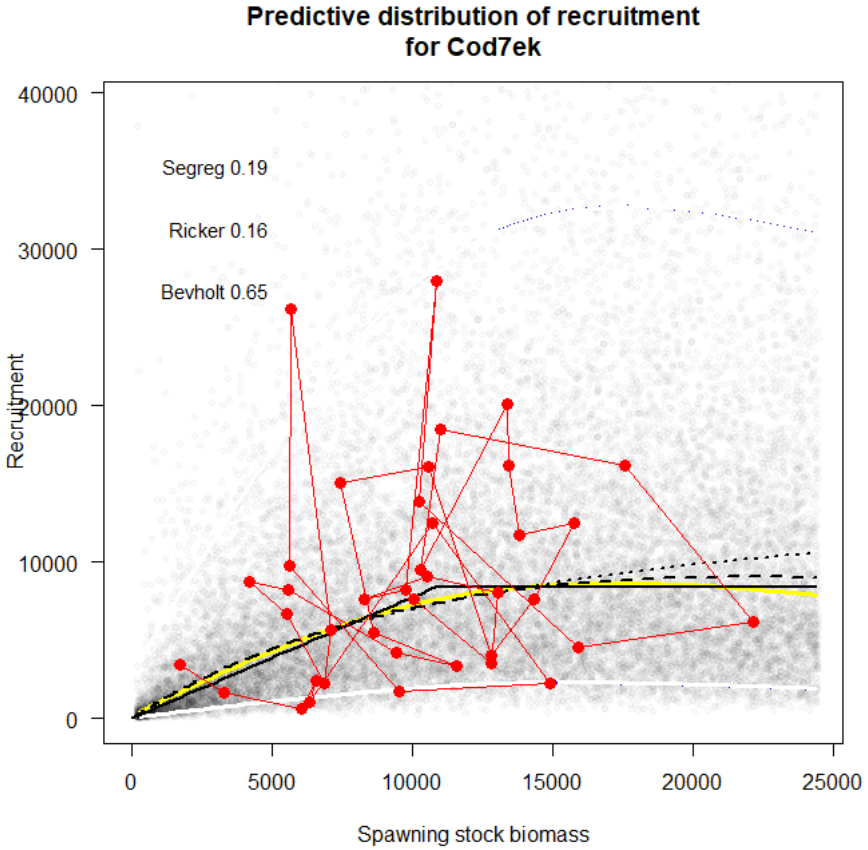
Environment driven: Stock / Recruitment relationship & Reference Points



Lassen, Kelly and Sissenwine, 2014.
10.1093/icesjms/fst146



Baker, 2019
doi.org/10.1101/714956



Stock – Recruitment relationship: Reference points

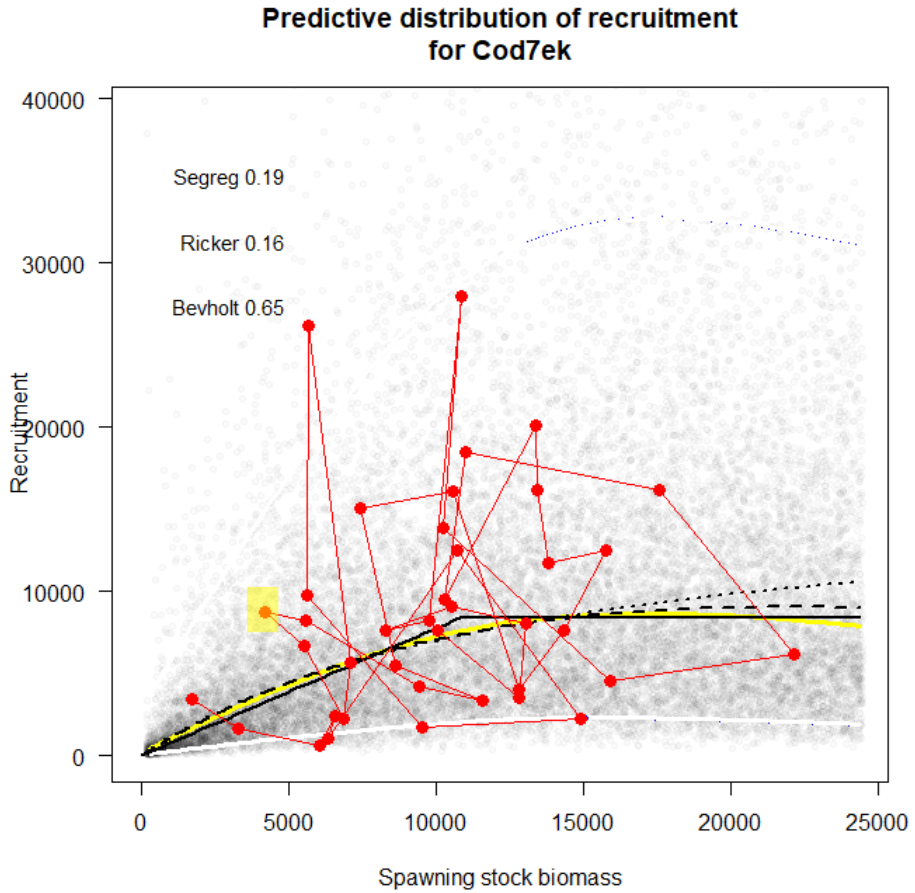
Celtic sea cod:

Set "B_{lim}" to "B_{loss}"

- the lowest observed SSB for which a strong recruitment was later observed in the time-series. B_{lim} is then equal to B_{loss} = 4200 tonnes = Corresponds to SSB in 2006

Framework	Reference point	Value	Technical basis	Source
MSY approach	MSY $B_{trigger}$	5800	B_{pa}; in tonnes	ICES (2020)
	F_{MSY}	0.29	Segmented regression with B_{lim} (EqSim).	ICES (2020)
Precautionary approach	B_{lim}	4200	B_{loss}, lowest observed SSB from which there has been some recovery (2005), rounded value; in tonnes	ICES (2020)
	B_{pa}	5800	B_{lim} × 1.4; in tonnes	ICES (2020)
	F_{lim}	1.13	Segmented regression with B_{lim} (EqSim)	ICES (2020)
	F_{pa}	0.77	F_{P05}; the F that leads to SSB ≥ B_{lim} with 95% probability	ICES (2020)
Management plan (MAP)*	MAP MSY $B_{trigger}$	5800	MSY $B_{trigger}$; in tonnes	EU (2019), ICES (2020)
	MAP B_{lim}	4200	B_{lim}; in tonnes	EU (2019), ICES (2020)
	MAP F_{MSY}	0.29	F_{MSY}	EU (2019), ICES (2020)
	MAP range F_{lower}	0.17	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY	EU (2019), ICES (2020)
	MAP range F_{upper}	0.41	Consistent with ranges resulting in no more than 5% reduction in long-term yield compared with MSY	EU (2019), ICES (2020)

* EU multiannual plan (MAP) for the Western Waters (EU, 2019).



Cod (*Gadus morhua*) in divisions 7.e–k (western English Channel and southern Celtic Seas)

Linking biotic and abiotic factors with stock status:

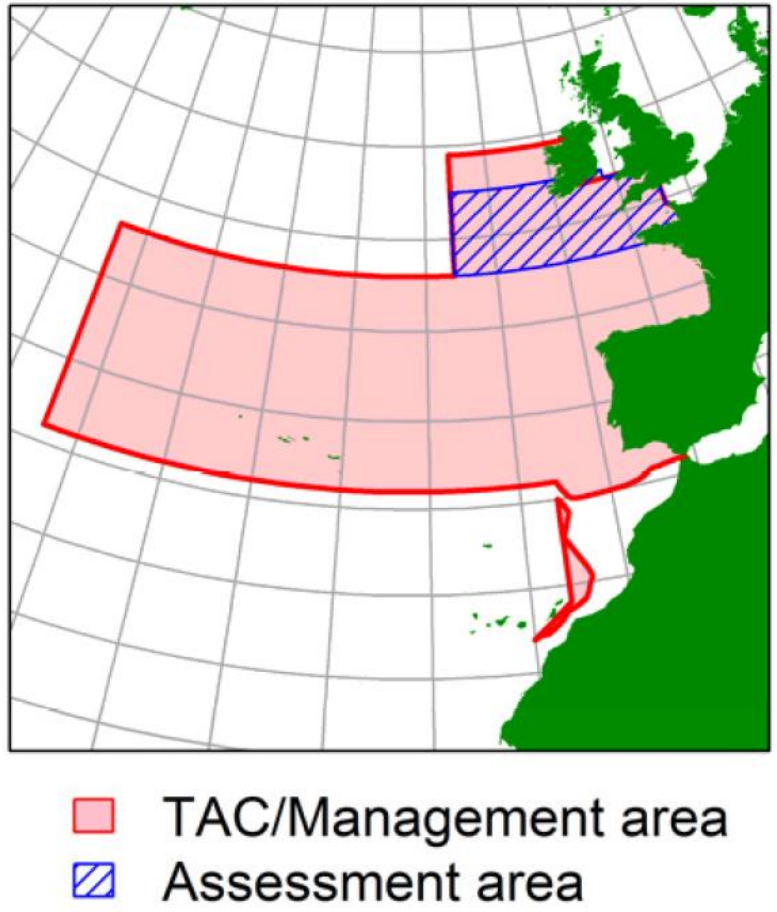
- Spatial extent
- Temporal extent

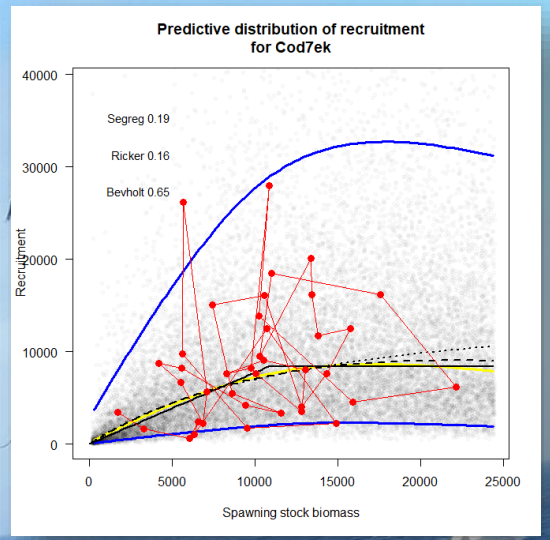
Biotic:

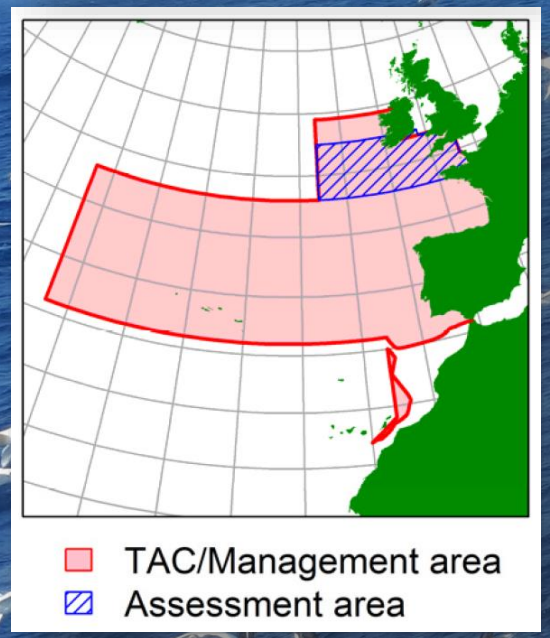
- Predation
- Food availability
- Planktonic assemblages
- Natural mortality (viral/ bacterial loadings)
- Growth
- Maturity
- Reproduction potential

Abiotic:

- Temperature regimes
- Ocean fronts
- Currents
- NAO / AMO
- Storm events
- Embayment effects
- pH
- Salinity
- Run off

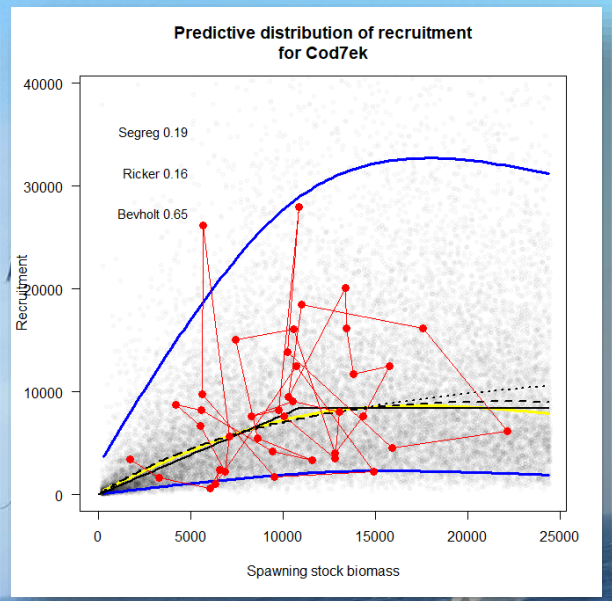


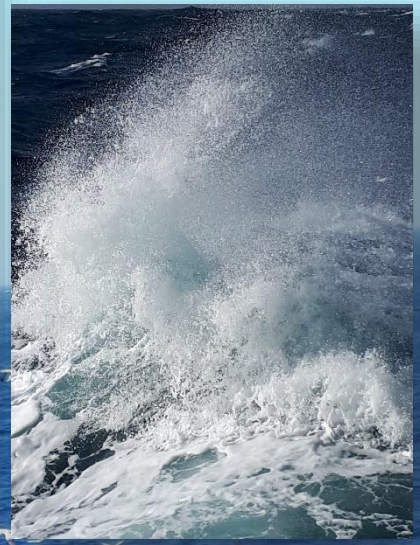


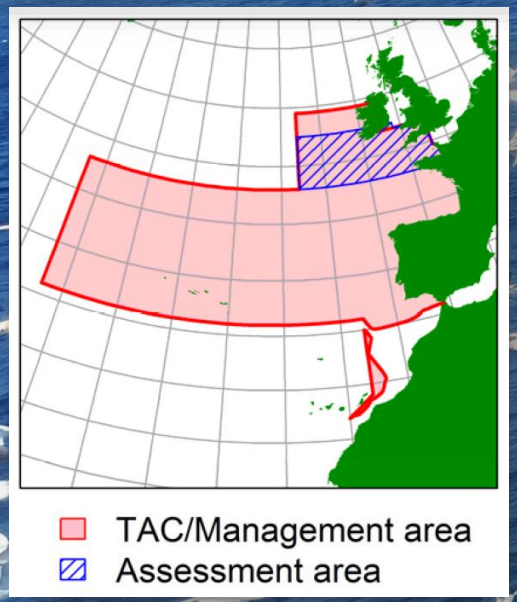


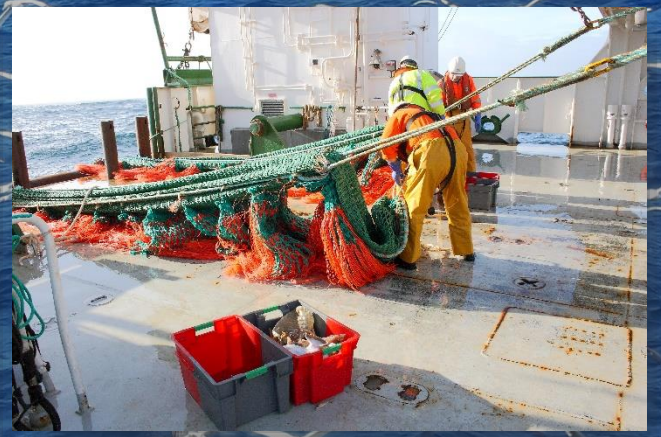
It's a big sea

- Oceanographic modelling can provide biotic & abiotic data
- Fishing data points are limited


Predictive distribution of recruitment
for Cod7ek
Segreg 0.19
Ricker 0.16
Bevholt 0.65
Recruitment
Spawning stock biomass
40000
30000
20000
10000
0
0
5000
10000
15000
20000
25000

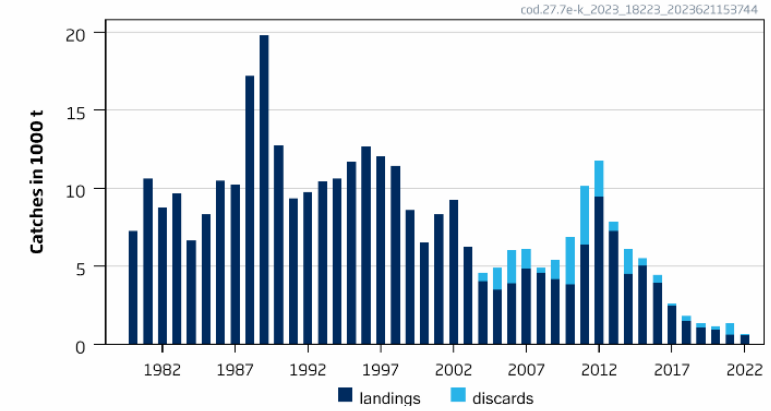



TAC/Management area
Assessment area

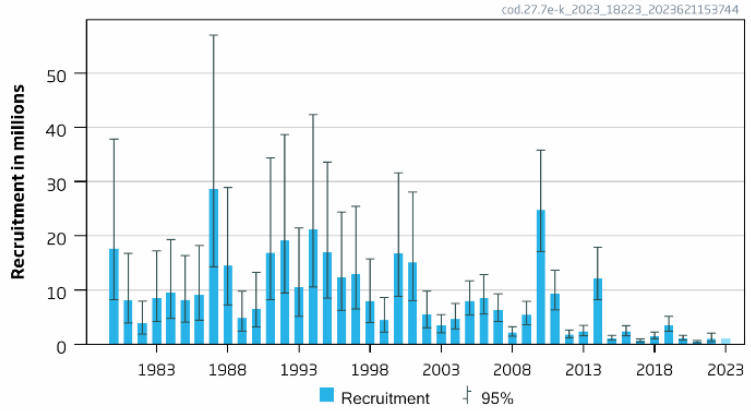


Stock – Recruitment Observations and Reference points

Catches



Recruitment (age 1)



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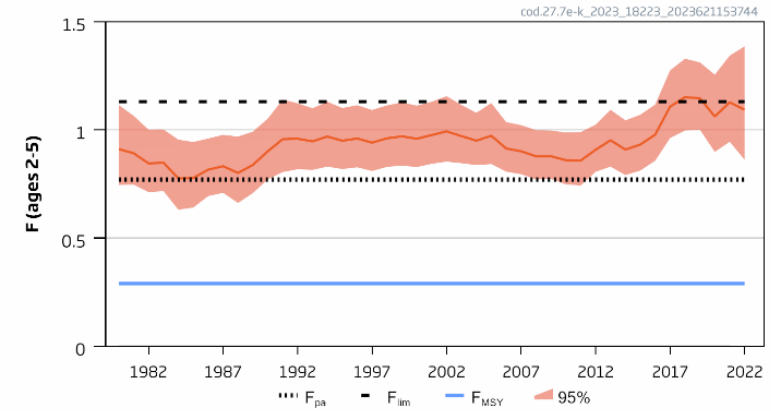
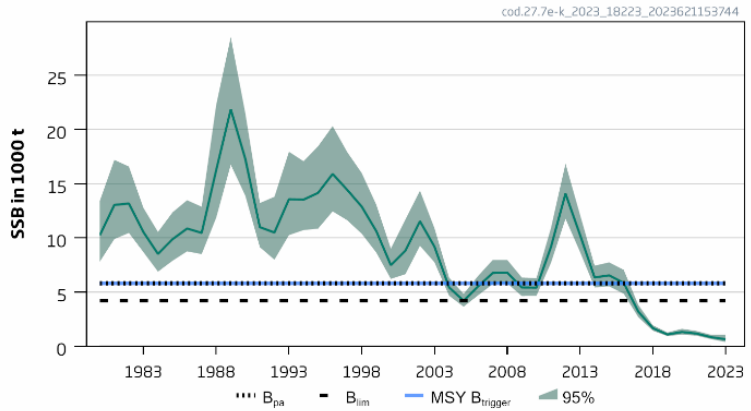


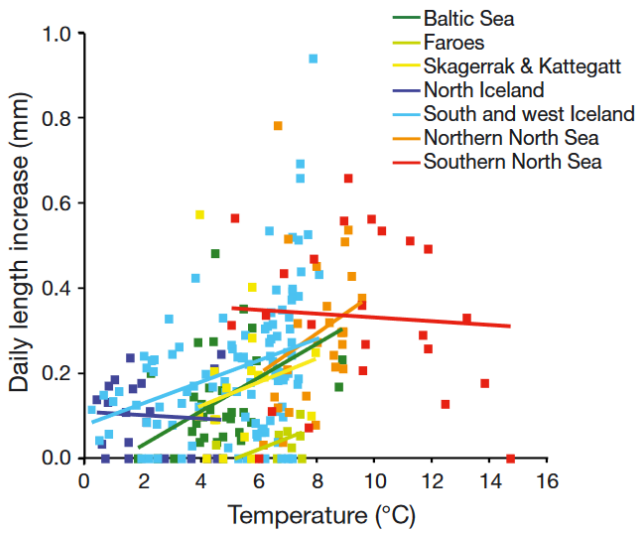
SSB



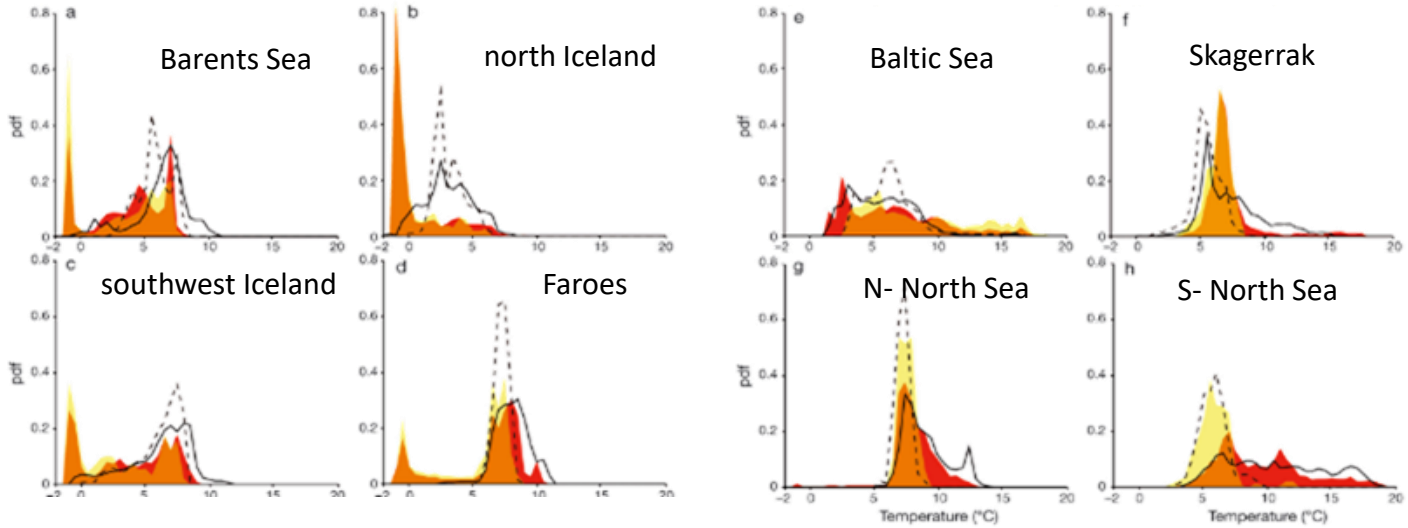
- ***Intrinsically & implicitly,*** assessments incorporate impact of the environment, biotic & biotic factors:
  - Predation
  - Food availability
  - Growth/maturity/rep
  - Temperature
  - Ocean fronts
  - Currents

“Thermal niche” of cod

Righton *et al.*, (2010). **Thermal niche of Atlantic cod *Gadus morhua*: limits, tolerance and optima.** MARINE ECOLOGY PROGRESS SERIES. Vol. 420: 1–13, 2010. doi: 10.3354/meps08889



Cod growth rates in relation to temperature



Thermal habitat availability and thermal habitat occupancy of cod - probability densities.
Habitat **availability shown by the shaded** areas, habitat **occupation by lines**.

- Spawning season - Yellow shading, *dashed lines*
- Full year - Red shading, **solid line**
- Overlapped habitat availability Orange

- Cod occupy water from near freezing (-1.5°C) to almost 20°C
- Individuals endure medium-term (days to months) exposure to the upper and lower extremes.
- During spawning, cod exhibited a narrower thermal experience than for the full year

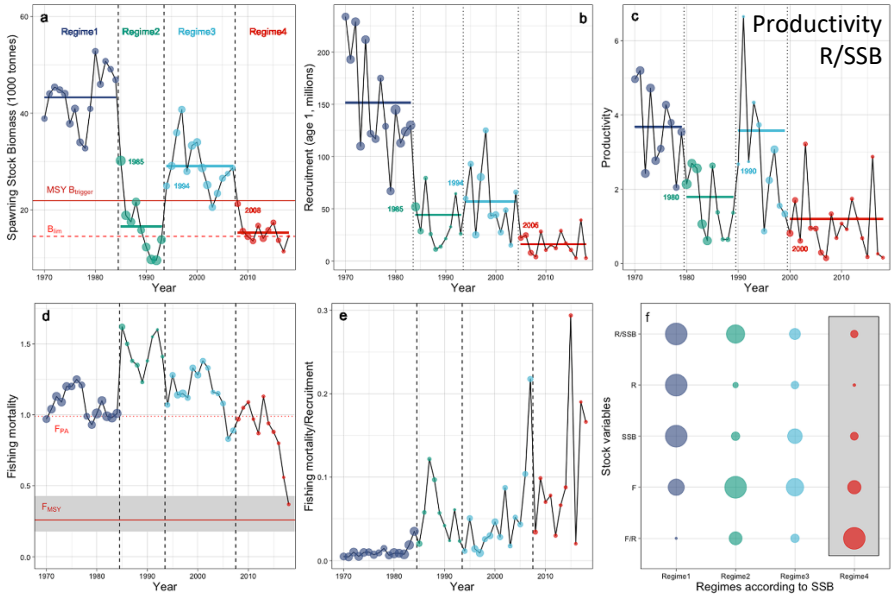
“… suggest that adult cod will be able to tolerate warming seas, but that climate change will affect cod populations at earlier life-history stages as well as exerting effects on cod prey species.”

“Regime shifts” and “Tipping points”

Western Baltic cod

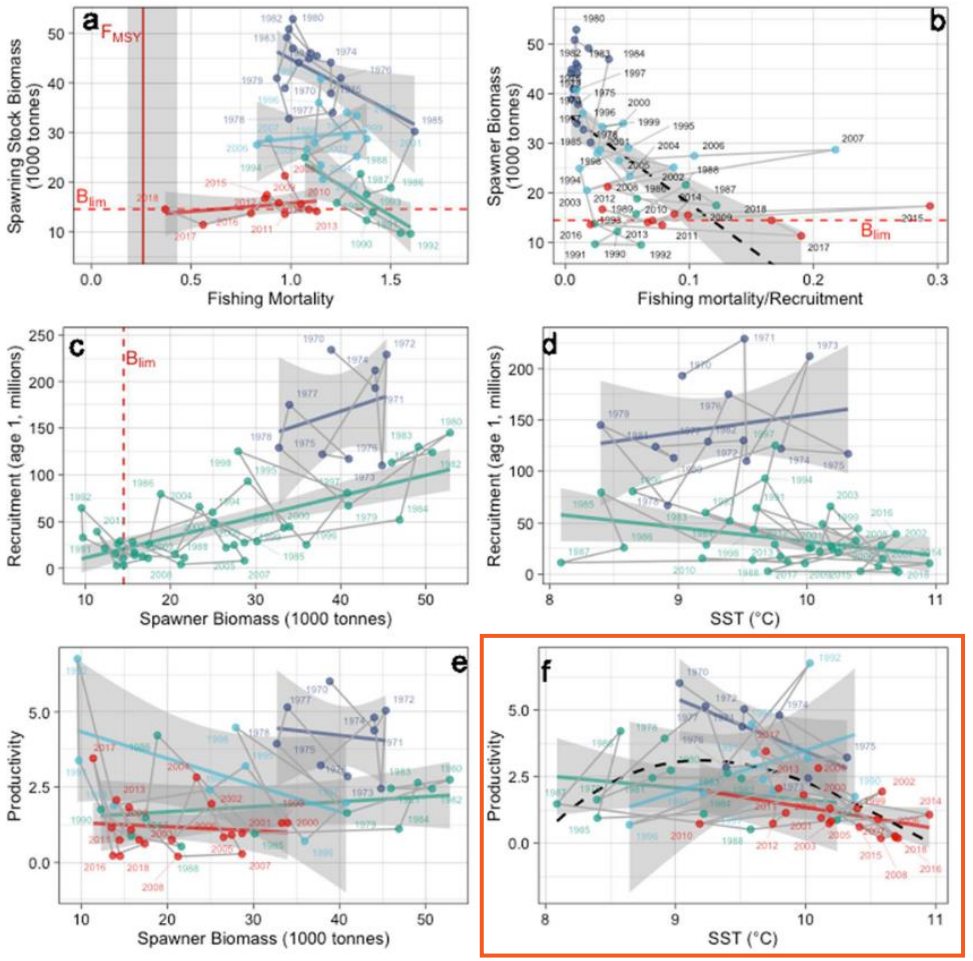
Möllmann, C., Cormon, X., Funk, S. et al. (2021) **Tipping point realized in cod fishery**. Sci Rep 11, 14259 https://doi.org/10.1038/s41598-021-93843-z

Regime identification



… ignorance of non-linear resource dynamics caused the demise of an economically and culturally important social-ecological system which calls for better adaptation of fisheries systems to climate change.

… during the early 2000s Western Baltic cod realized a tipping point to a low productive state, caused by recruitment overfishing and stabilized by ongoing climate change.



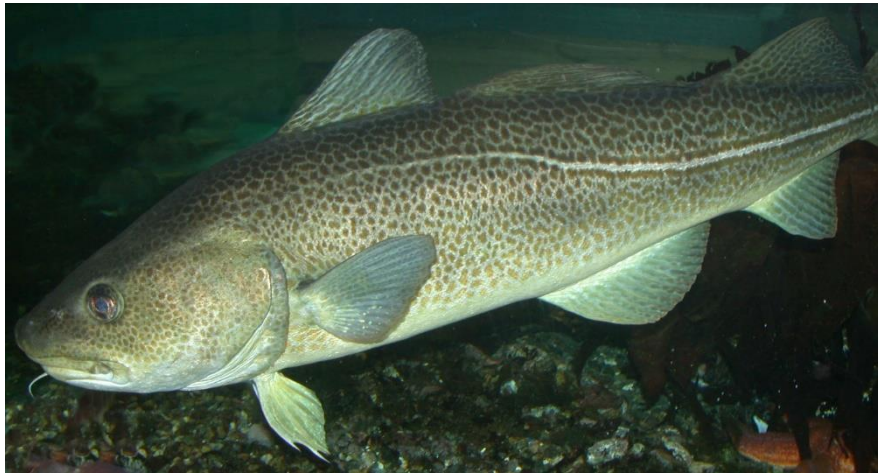
Breakpoints in stock functioning.

Effect of SST on productivity; black dashed line - spline model. Coloured points & lines indicate regime-dependent linear models from breakpoint analysis

Climate change on fish around the UK

Wright, Pinnegar and Fox (2020) **Impacts of climate change on fish, relevant to the coastal and marine environment around the UK**. MCCIP Science Review 2020, 354–381

- **Distinguishing between climate-induced effects on fish distribution and other drivers is a key challenge**
- Synchrony between winter–spring hatching fish larvae (e.g. cod, sole, sandeel) and plankton prey appears to be changing, with consequences for recruitment…
- Temperature changes affecting fish growth and maturation age
- Rising temperatures decrease oxygen solubility and increase metabolic costs… considerable debate if this limits maximum size fish species can attain
- Fin-fish larvae may be sensitive to expected changes in acidification… species have shown a variety of responses in experiments. For example, the use of End-of-century CO_2 concentration under IPCC RCP 8.5
  Resulted in doubling of daily mortality rates in Atlantic cod larvae,
  but only had a minor effect on European seabass and herring larvae



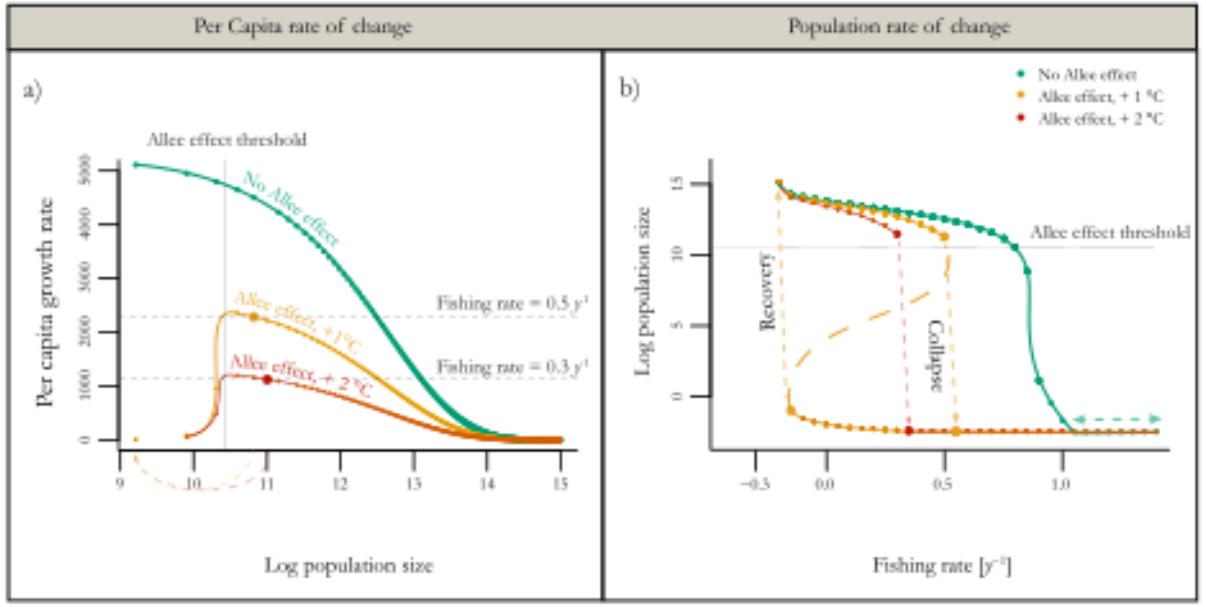
“Allee effects”, fisheries management, changing climate

Winter, A.-M., Richter, A., and Eikeset, A. M. (2020). **Implications of Allee effects for fisheries management in a changing climate: evidence from Atlantic cod**. Ecol. Appl., 30, e01994, https://doi.org/10.1002/eap.1994, 2020.

Allee effect - **At low abundances**, per capita population growth rate can be positively linked with abundance, such that **an abundance decline reduces population productivity**.

We find that:

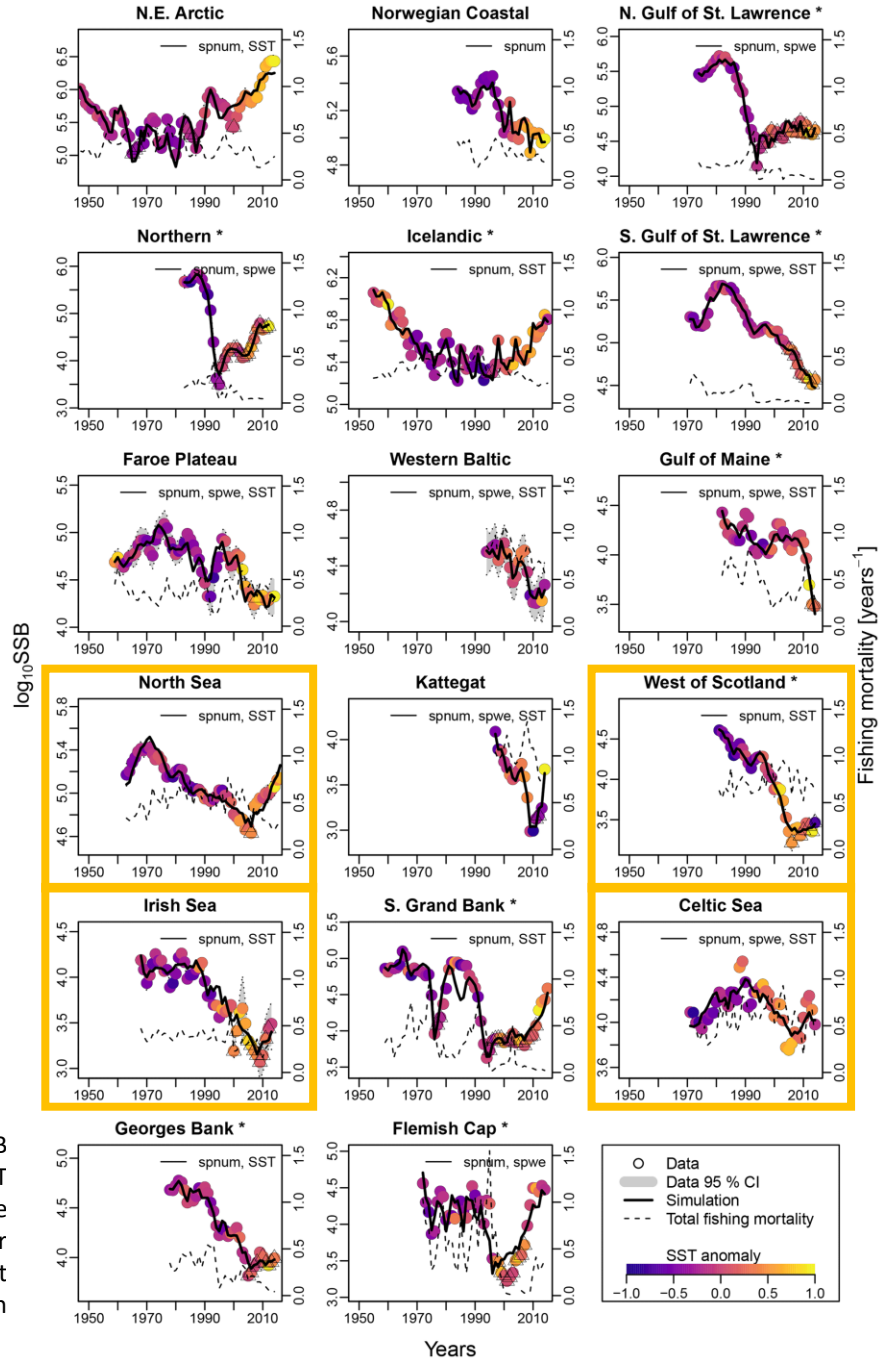
- **in presence of the Allee effect, a fishing moratorium is only sufficient for recovery when sea surface temperature rise remains within 2°C and fishing is restricted within 10 yrs**.
- **If sea surface temperature rises beyond 2°C, even immediate banning of fishing is not sufficient to guarantee recovery.**
- **If fishing is not fully banned and a residual fishing pressure remains, the probability of recovery is further decreased, also in the absence of an Allee effect.**



Spawner weight, ocean temperature, Allee effect dynamics

Winter, A.-M., Vasilyeva, N., and Vladimirov, A. (2023) **Spawner weight and ocean temperature drive Allee effect dynamics in Atlantic cod, *Gadus morhua*: inherent and emergent density regulation**, Biogeosciences, 20, 3683–3716, https://doi.org/10.5194/bg-20-3683-2023

- Used time series of 17 Atlantic cod stocks to fit population equations that consider abundance of spawners, body weight and sea water temperature as independent components of recruitment.
- “Relative change between max and min recruitment per capita at low abundance was increased when recruitment production was suppressed by unfavorable changes in water temperature and/or in spawner weight.”
- “The latter can be a concomitant of heavy fishing or a result of temperature-related altered body growth.”
- **“…anthropogenic stress can increase the risk of Allee effects in stocks where ocean temperature and/or spawner weight had been beneficial in the past but are likely to unmask and strengthen an inherent Allee effect under future conditions.**



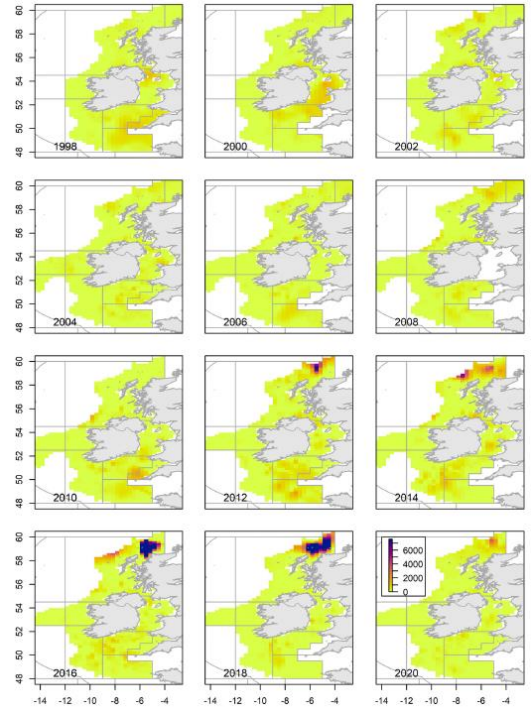
Dot = stock-assessment data for SSB
Colour = matching year’s average SST
--- = Fishing pressure
spnum = best model needs no other effects except spawner number
spwe = best model required spawner weight effect
SST = best model required SST effect in recruitment production function

Cod distribution, Celtic seas, Variable trends

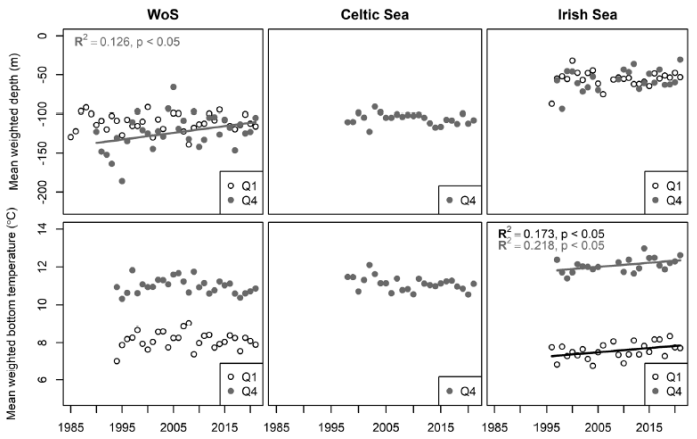
Ellis, *et al.*, 2024. **Variable trends in the distribution of Atlantic cod (*Gadus morhua*) in the Celtic seas.** Journal of Fish Biology. https://doi.org/10.1111/jfb.15715

- Trawl surveys: Irish Sea, Celtic Sea, and West of Scotland, 1985 to 2021
- Mapped cod densities, analyzed trends in mean weighted depth and bottom temperature

- **West of Scotland stock shifted north and east** spilling into the North Sea
- **Irish Sea and Celtic Sea stocks shifted west, neither shifting northwards or into deeper waters**
- **No clear trends** in the average occupied depth
- Each stock showed **decreasing trends in equivalent area**
- **No apparent relationship between temperature and cod distribution**, though bottom temperature varied little from 1993 to 2021



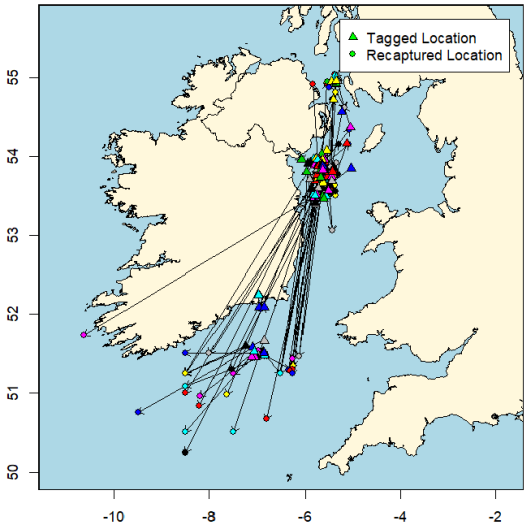
Interpolated quarter 4 cod density



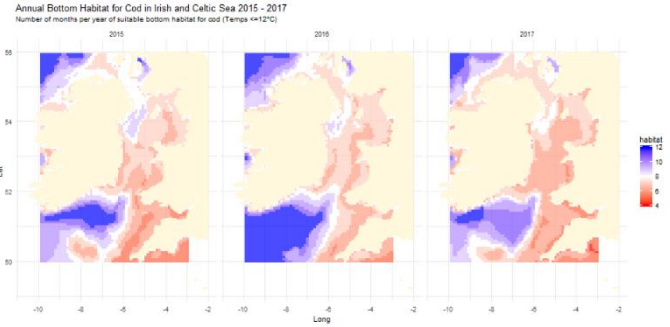
weighted depth in meters (top) & bottom temperature (bottom)

Irish Sea Cod tagging & mortality

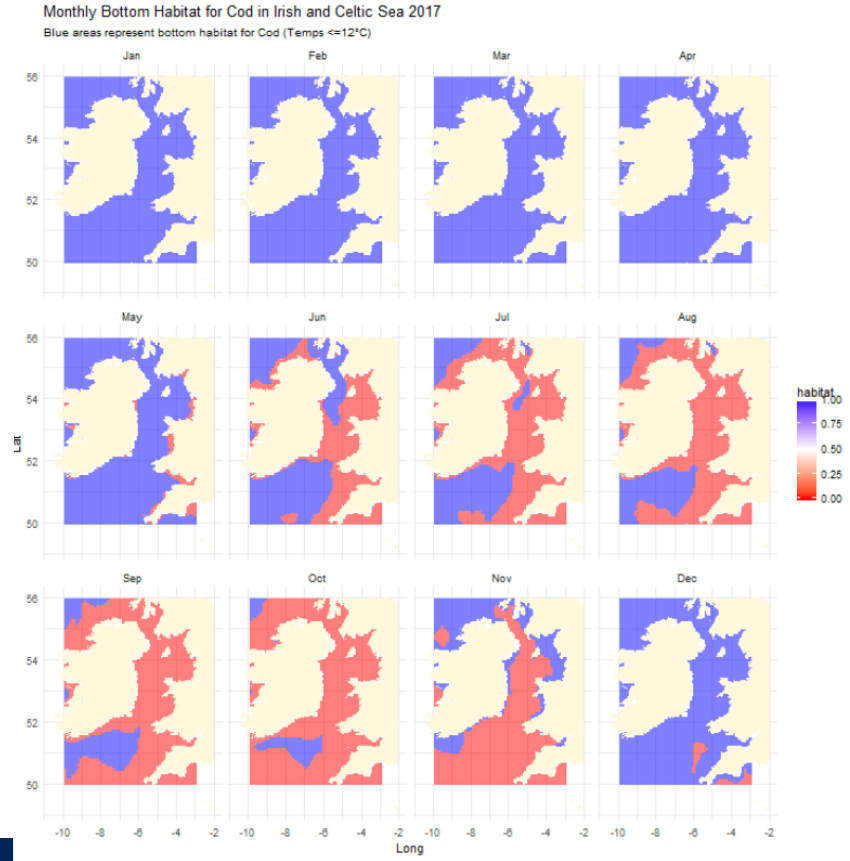
Lundy et al, 2022. **Tagging study to determine mortality sources on cod in the Irish Sea**
European Maritime and Fisheries Fund (EMFF)
https://op.europa.eu/en/publication-detail/-/publication/c8a63ce2-1f6c-11ed-8fa0-01aa75ed71a1



- **Spatial pattern of optimal habitat overlapped with the observed recapture results**
- Analysis **supports the hypothesis that this environmental driver would have strongest effect in late quarter 3 and early quarter 4**



Annual thermal habitat 2015-2017:
sum of months with <=12°C



Monthly thermal habitat bottom temperature 2017
Blue <=12°C, Red >12°C.

ICES Irish Sea "F_{ECO}" reference point

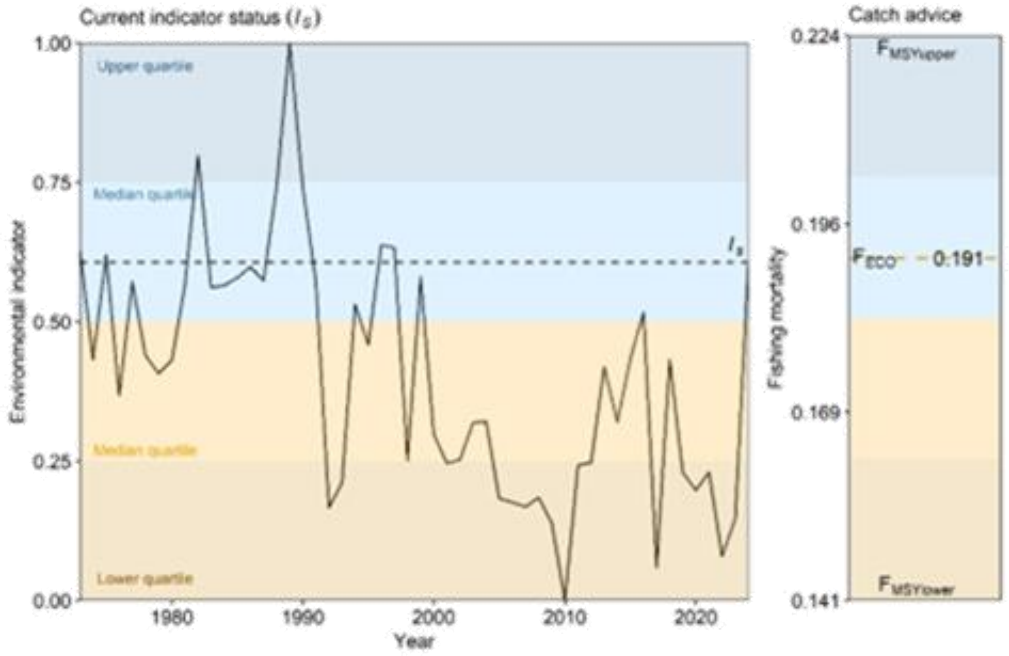
Cod (*Gadus morhua*) in Division 7.a (Irish Sea)

ICES (2023). Cod (*Gadus morhua*) in Division 7.a (Irish Sea). ICES Advice: Recurrent Advice. Report. https://doi.org/10.17895/ices.advice.21840786.v1

ICES (2020). Workshop on an Ecosystem Based Approach to Fishery Management for the Irish Sea (WKIrish6; outputs from 2019 meeting). ICES Scientific Reports. 2:4. 32 pp. http://doi.org/10.17895/ices.pub.5551

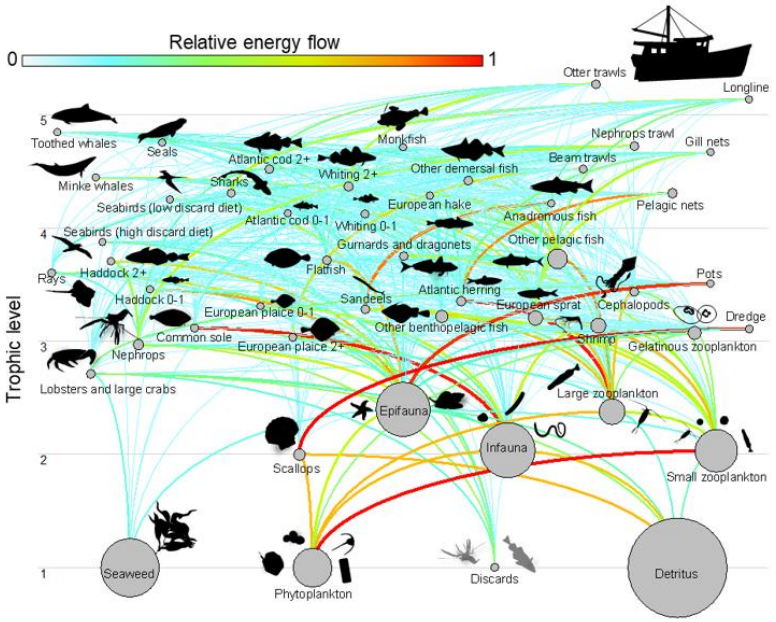
F_{eco} :

- a dynamic reference point
- falls in the pre-defined F_{MSY} range
- should provide better yield and lower risk where followed consistently in the long term by including an ecosystem driver of stock productivity.



Left: SST: inverted; scaled; 3yr lag) - informs the status indicator (*Is*)
Right: *Is* determines placement of F_{ECO} within FMSY ranges.

Bio/ecological
Marine ecosystem (biotic)

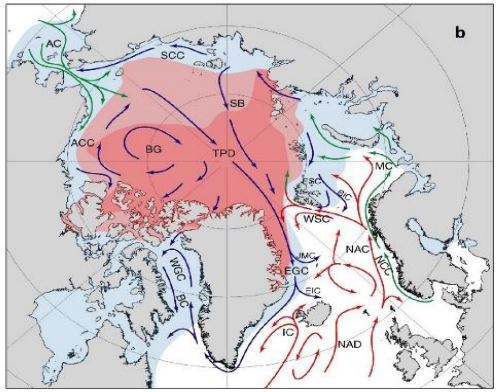


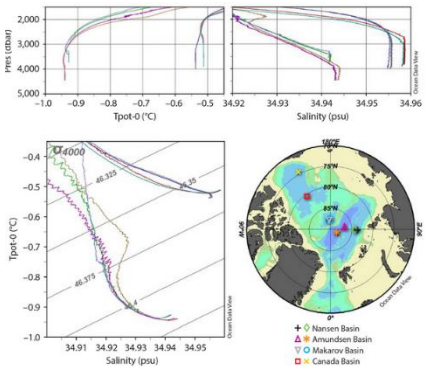
Energy flow and biomass diagram for the Irish Sea Ecopath foodweb model. Relative size of functional group nodes denote biomass. Size of fleet nodes denote size of catch.

ICES. 2020. (WKIrish6).
ICES Scientific Reports. 2:4. 32 pp.
http://doi.org/10.17895/ices.pub.5551

Bentley *et al.* 2019. Combining scientific and fishers' knowledge to co-create indicators of food web structure and function. – ICES Journal of Marine Science, doi:10.1093/icesjms/fsz121

Physical
Marine oceanography (abiotic)

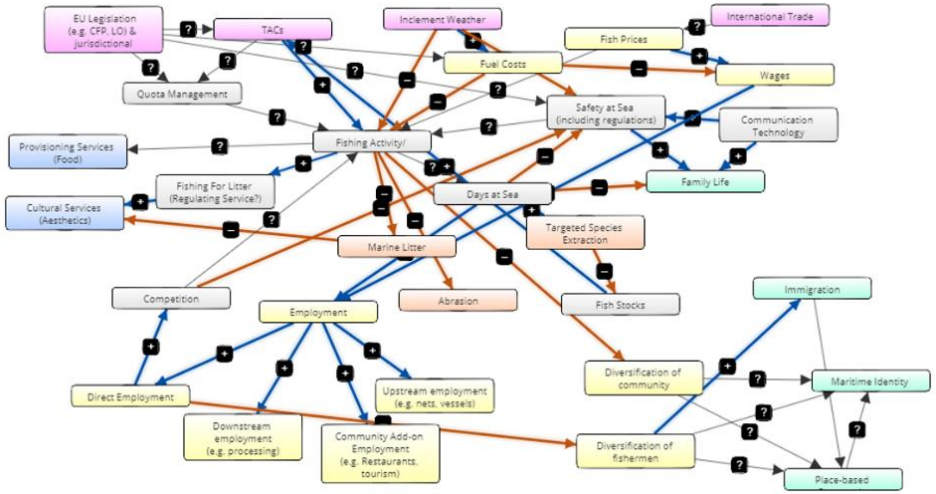




Circulation & Stratification: From the Bottom Up

Rudels, B., and E. Carmack. 2022. Arctic ocean water mass structure and circulation. *Oceanography* 35(3–4):52–65, https://doi.org/10.5670/oceanog.2022.116.

Human
Social Marine system (society)



Conceptual map / Mental Model: top risks and sectors identified from *Options for Delivering Ecosystem based Marine Management Assessment*

ICES. 2019. Report of the Workshop on an Ecosystem-based Approach to Fishery Management for the Irish Sea (WKIrish5), 5–9 November 2018, Dublin, Ireland. ICES CM 2018/ACOM:66. 55 pp. https://doi.org/10.17895/ices.pub.19291121

ICES WKCLIMAD

Workshop on pathways to climate-aware advice

ICES (2023). **Workshop on pathways to climate-related advice (WKCLIMAD).** ICES Scientific Reports. Report. https://doi.org/10.17895/ices.pub.22196560.v1

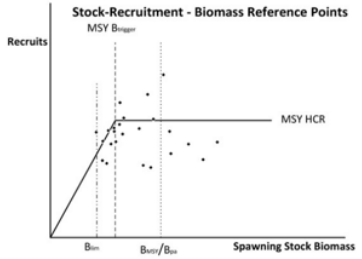
How can the short, medium, and long-term influences of climate change on aquaculture, fisheries, and ecosystems be accounted for in ICES Advice.

- A **wealth of data, tools and methods exists**, **it is important to consider how these are utilised**
- Need to **identify and rank climate impacts & associated risks**; match adaptation measures with policy objectives
- **Balance between actionable advice and reporting of uncertainty**
- Climate-informed advice should include assessment of current conditions in relation to the desired state.

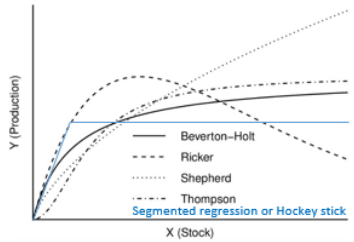
- To provide credible climate-informed advice, the evidence base needs to be strengthened:
  - future scenarios of management options and ecosystem state
  - risk, vulnerability and resilience analysis of species, ecosystems and human communities
  - spatial planning information and models
  - trade-offs among potential actions, and incentives for best practice sharing including technological developments
  - carbon accounting across the system
  - monitoring and early-warning systems

Hard linkage of environment to recruitment & population growth remains a Holy Grail of fisheries science

Questions?



Lassen, Kelly and Sissenwine, 2014.
10.1093/icesjms/fst146



Baker, 2019
doi.org/10.1101/714956