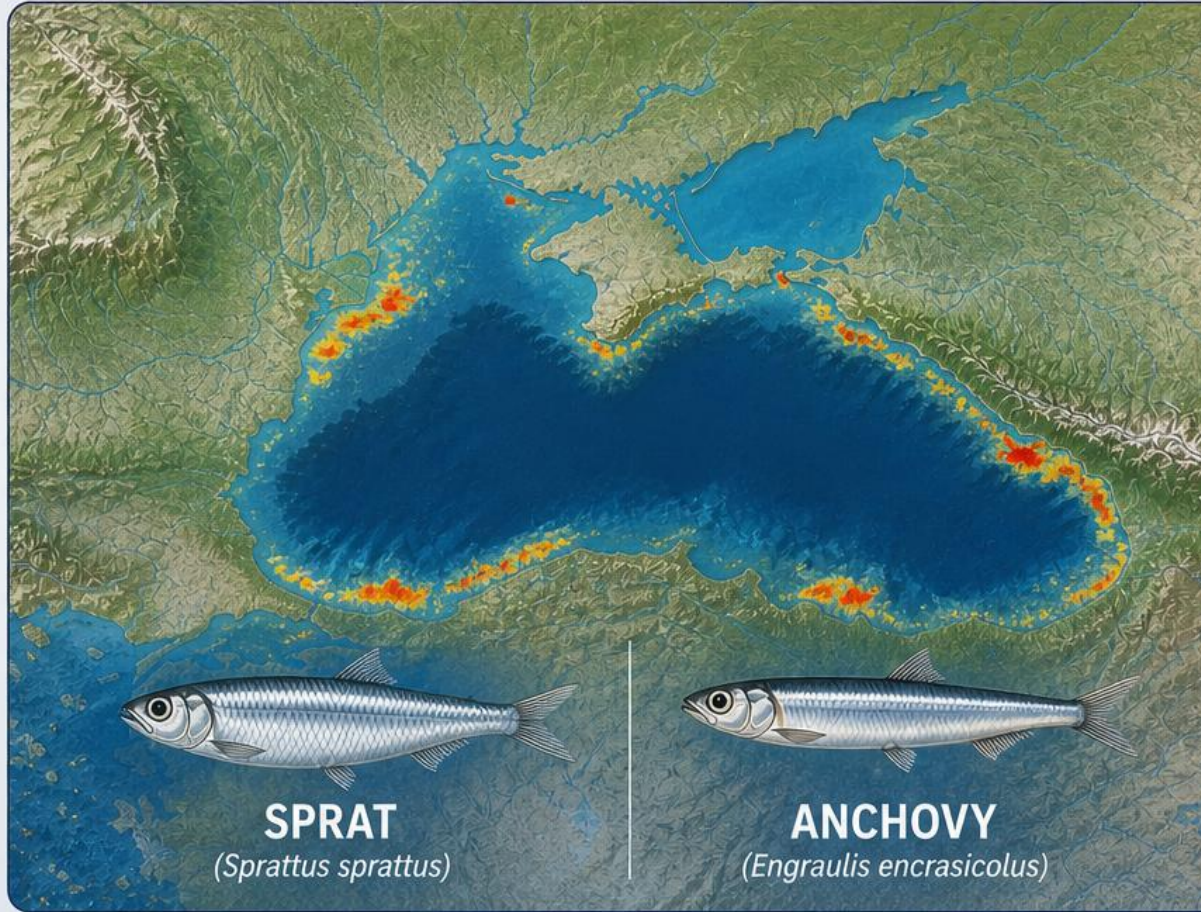
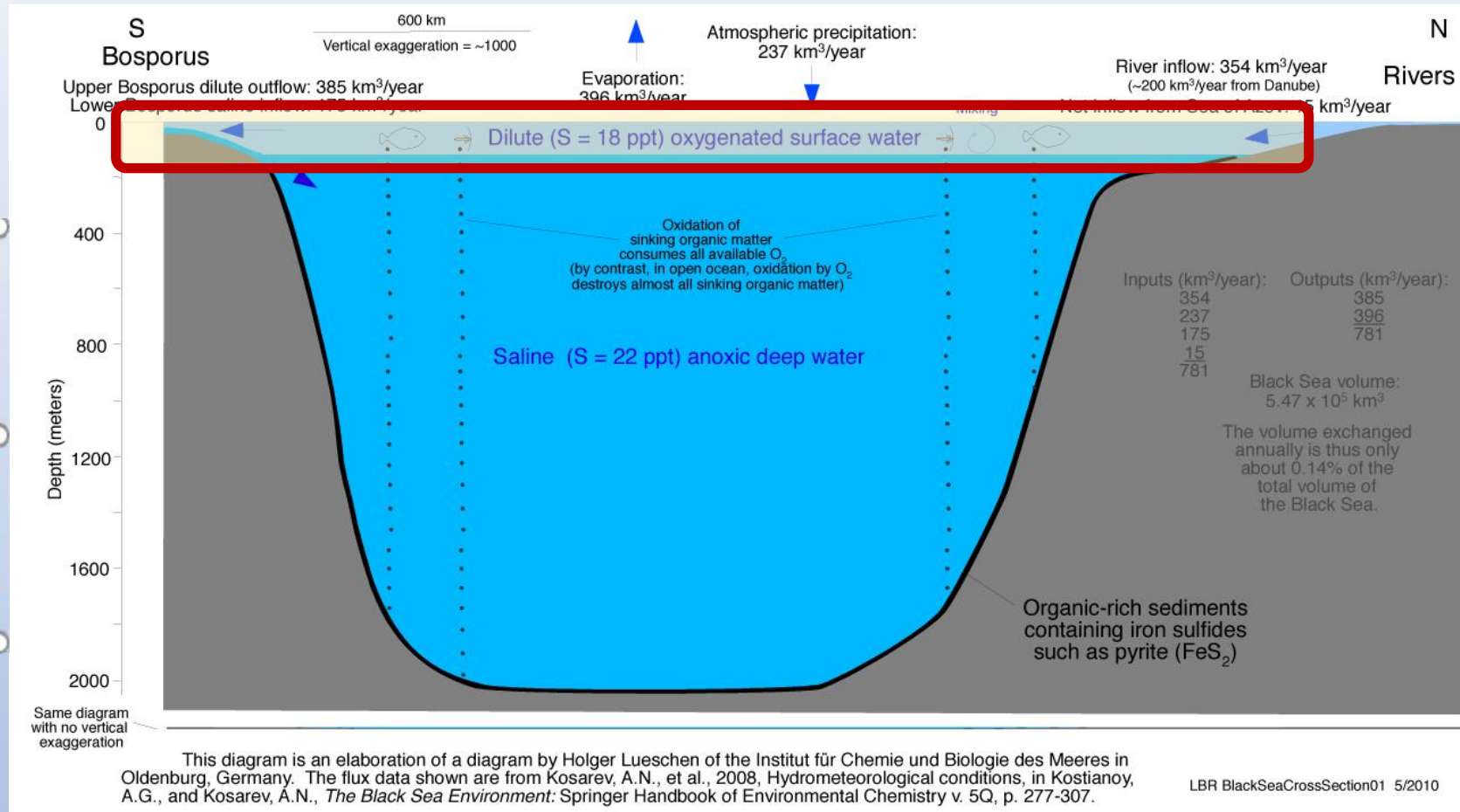
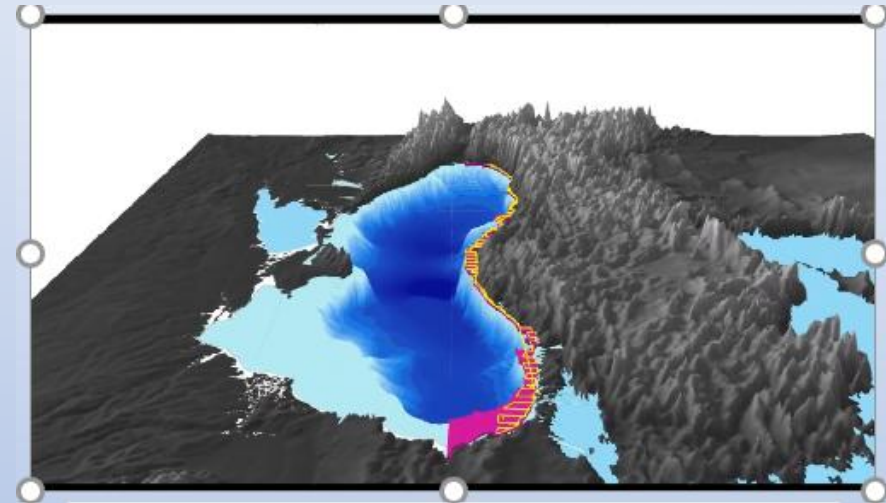


# Black Sea small pelagic dynamics: Two key stocks



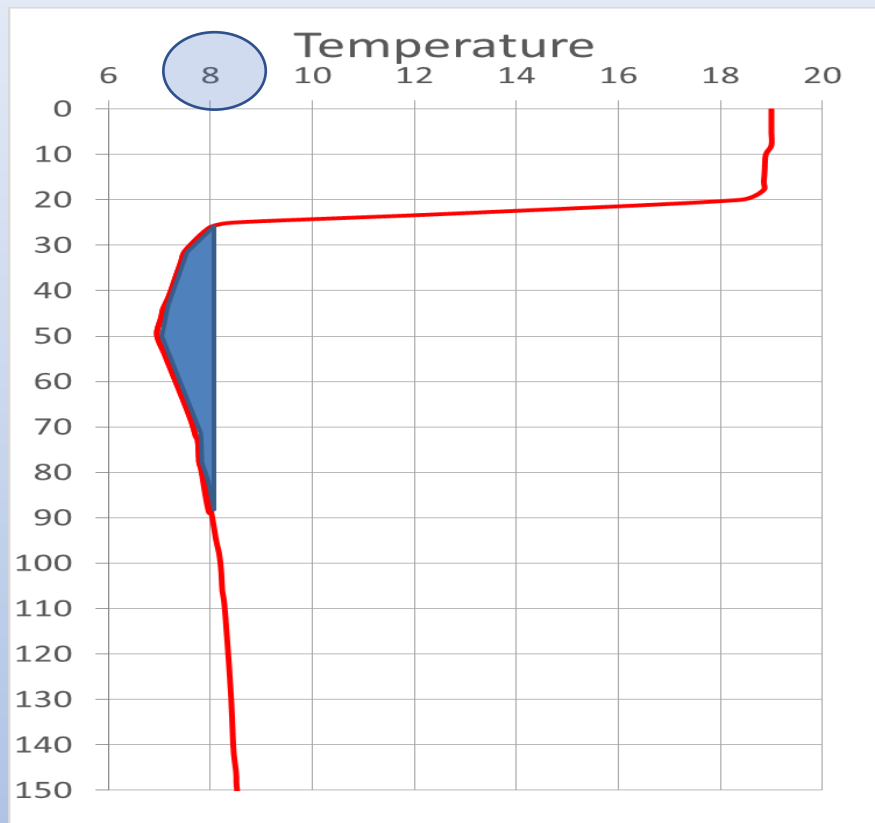
**Ali Cemal Gucu**

Middle East Technical University - Turkiye

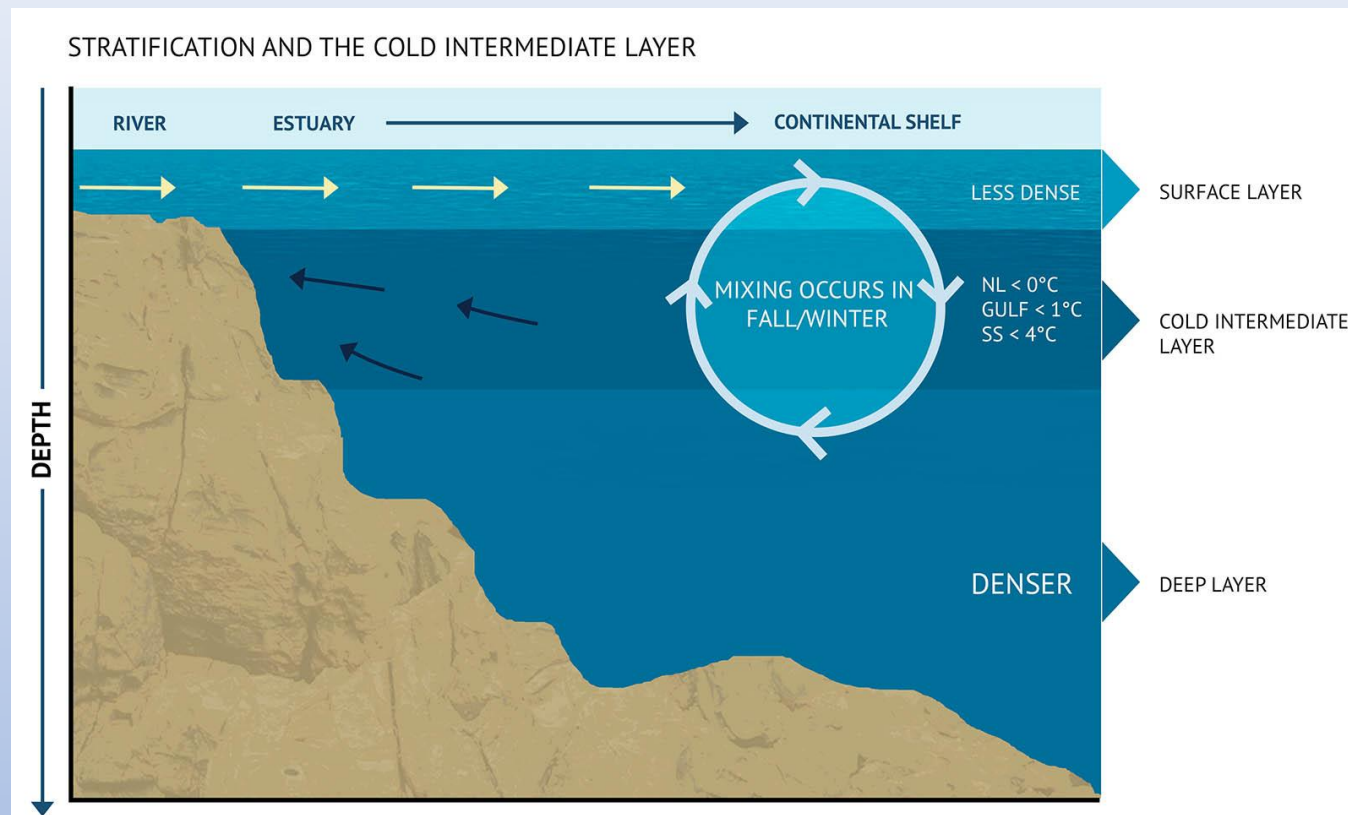




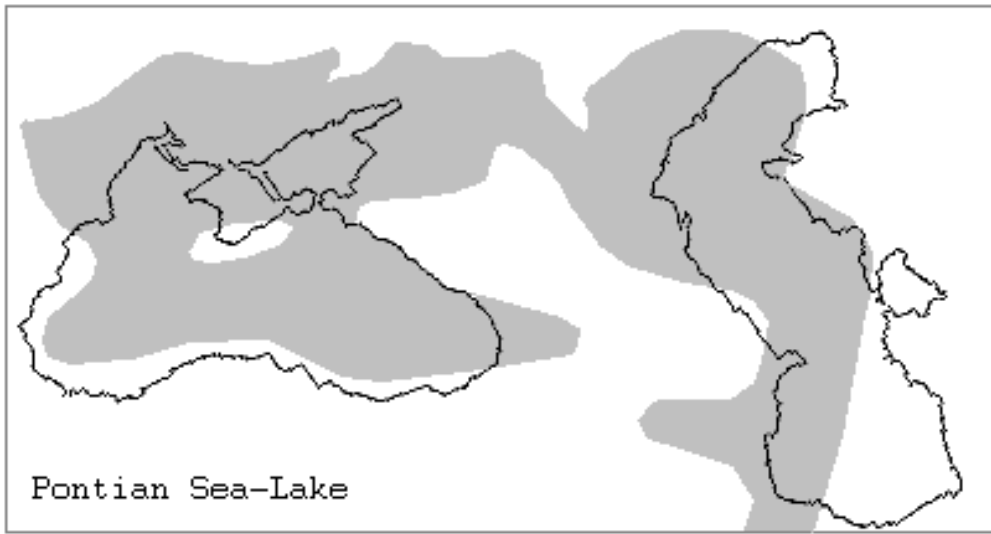
# Cold Intermediate Layer, CIL



<http://dx.doi.org/10.12770/6fe2500a-bc95-494c-9697-65ee84ab44c9>



<https://www.dfo-mpo.gc.ca/oceans/publications/soto-rceo/2018/atlantic-ecosystems-ecosystemes-atlantiques/index-eng.html>



## Host biota originated from 5 different origin)

1. **Autochthonous Ponto-Caspian species**: Oldest of the Black Sea. Inhabit waters under fresh water influence (ROFI)

2. **Thermophobic Boreal-Atlantic species**: Cold water species. Observed in deep waters

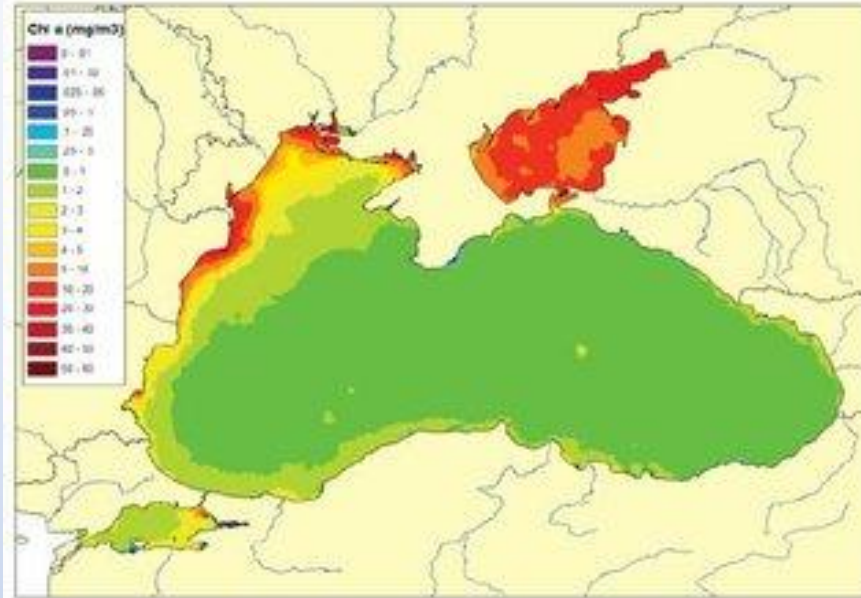
3. **Mediterranean species**: Largest group in the Black Sea and their number keep increasing (Mediterraneanization). Consists 80% of the biomass. Prefers warm and saline waters (occupies the surface layer).

4. **Fresh water species**: Observed in the river mouths

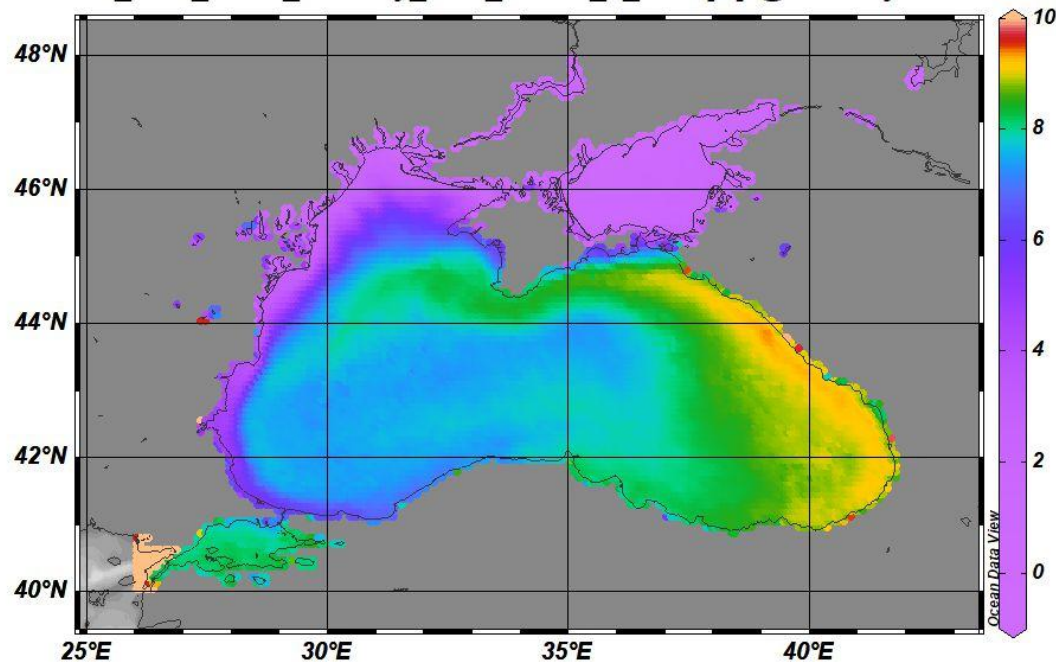
5. **Exotic species**: Transported to the BS though various vectors



Surface chlorophyll distributions in summer (left) and in winter (right)

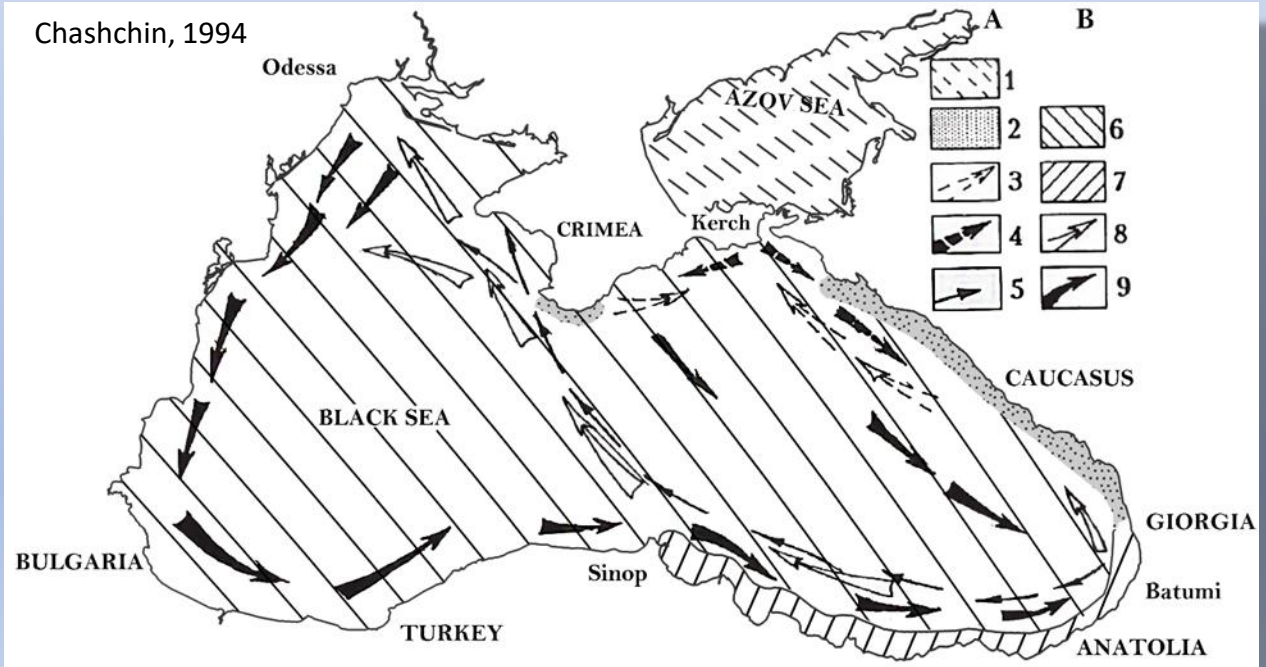
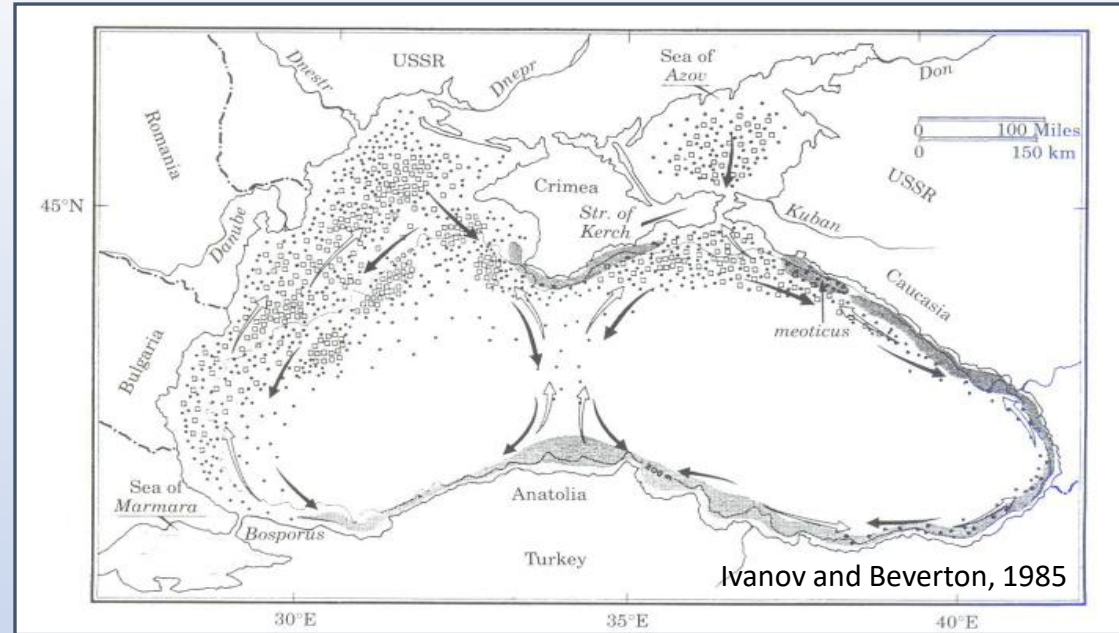


MODISA\_L3m\_SST4\_Monthly\_9km\_R2019\_0\_sst4 [C] @ Dummy=first



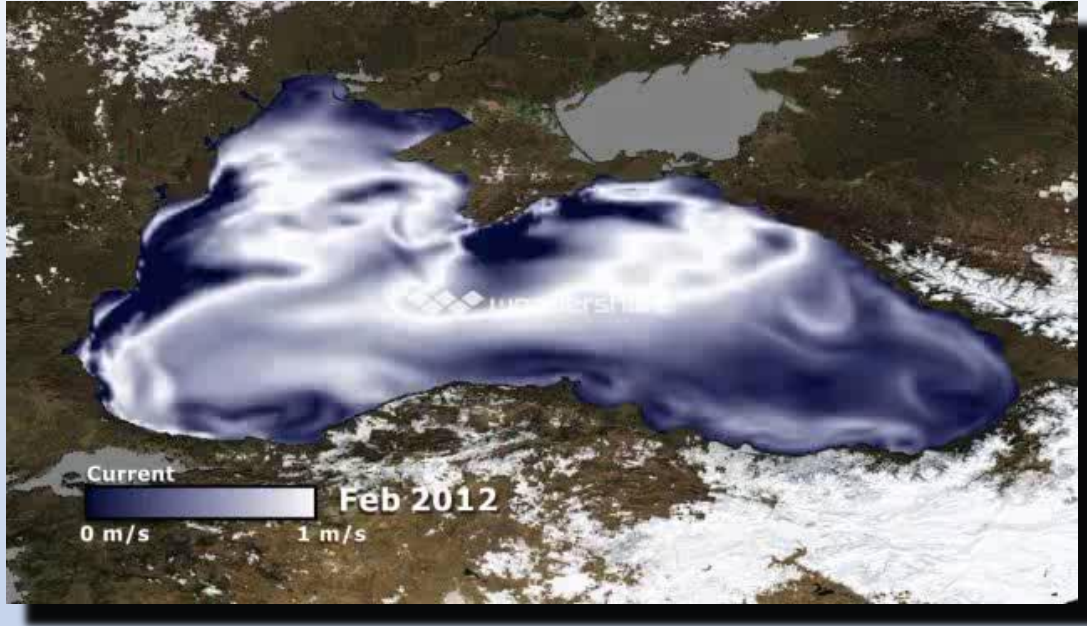


European anchovy (*Engraulis encrasicolus*)



Main biological activities are in the north, fishery is in the south

# Mesoscale eddies – RIM current



Importance for the BS anchovy

- Facilitate migration
- Provides retention areas (spawning, nursery and overwintering)

Adults @15-17C

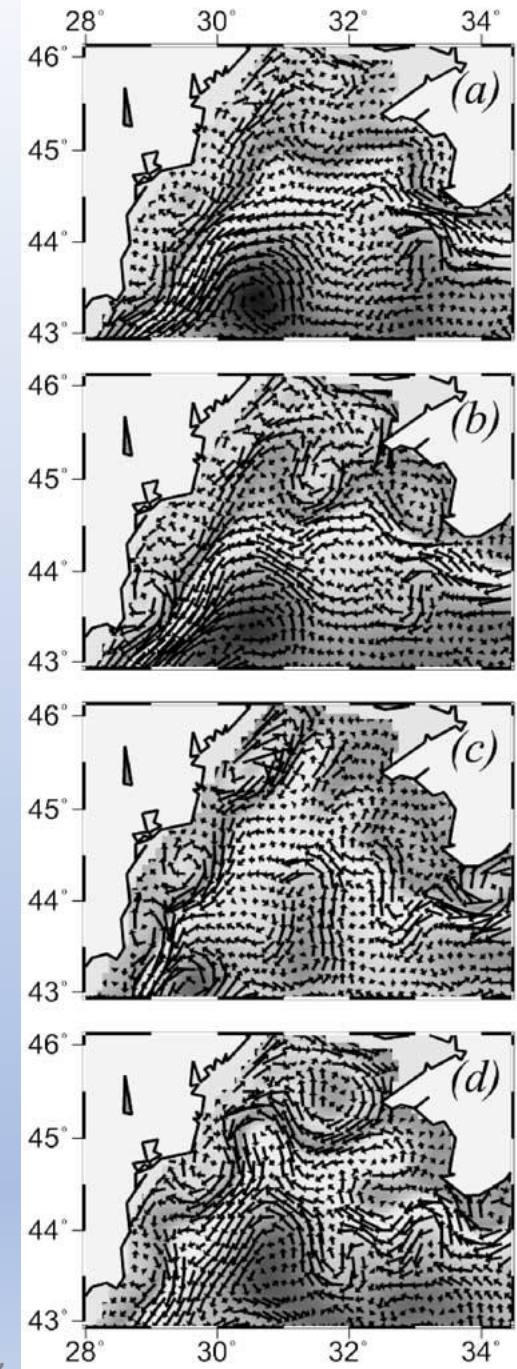
YoY @ 12-13 C 1-1.5 month delay

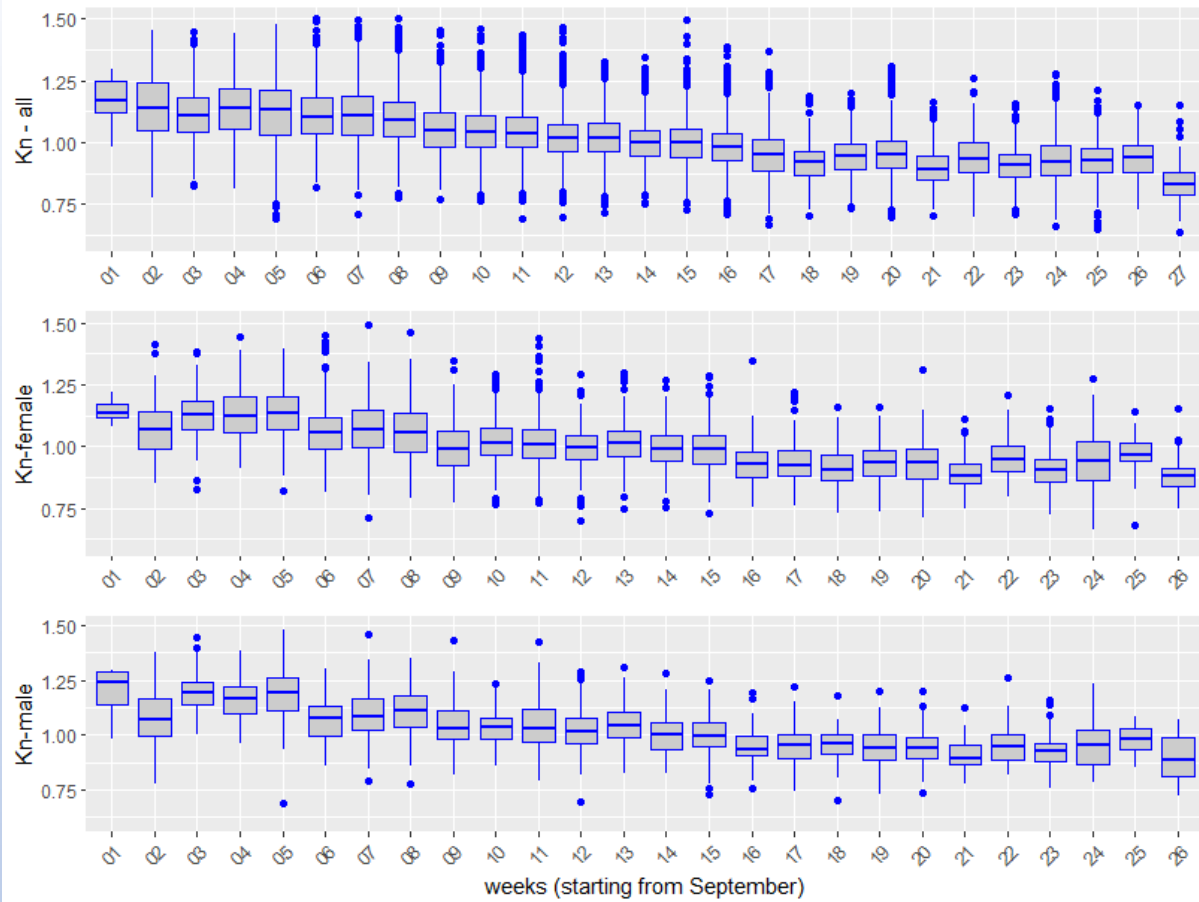
**Ocean triad (Bakun 1998):**

**1-Nutrient enrichment,**

**2-Concentration of food**

**3-Retention of larvae,**

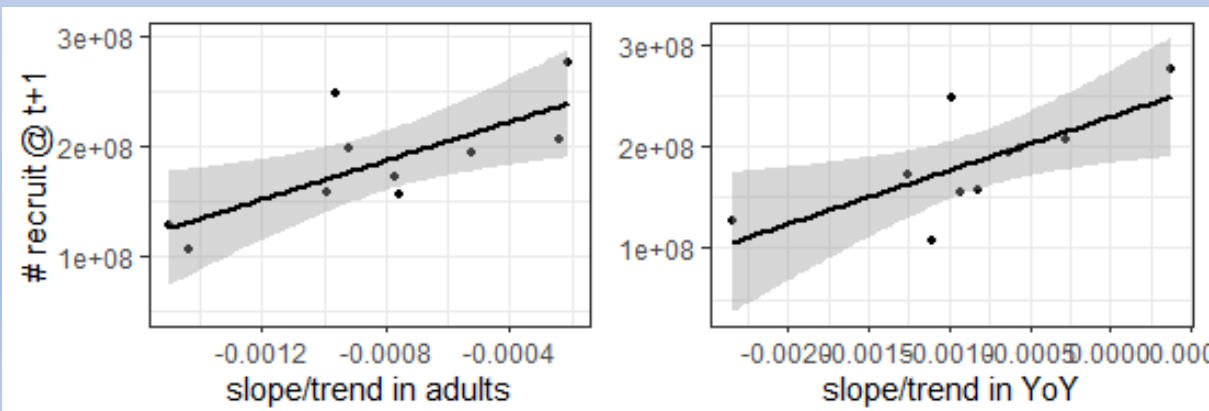




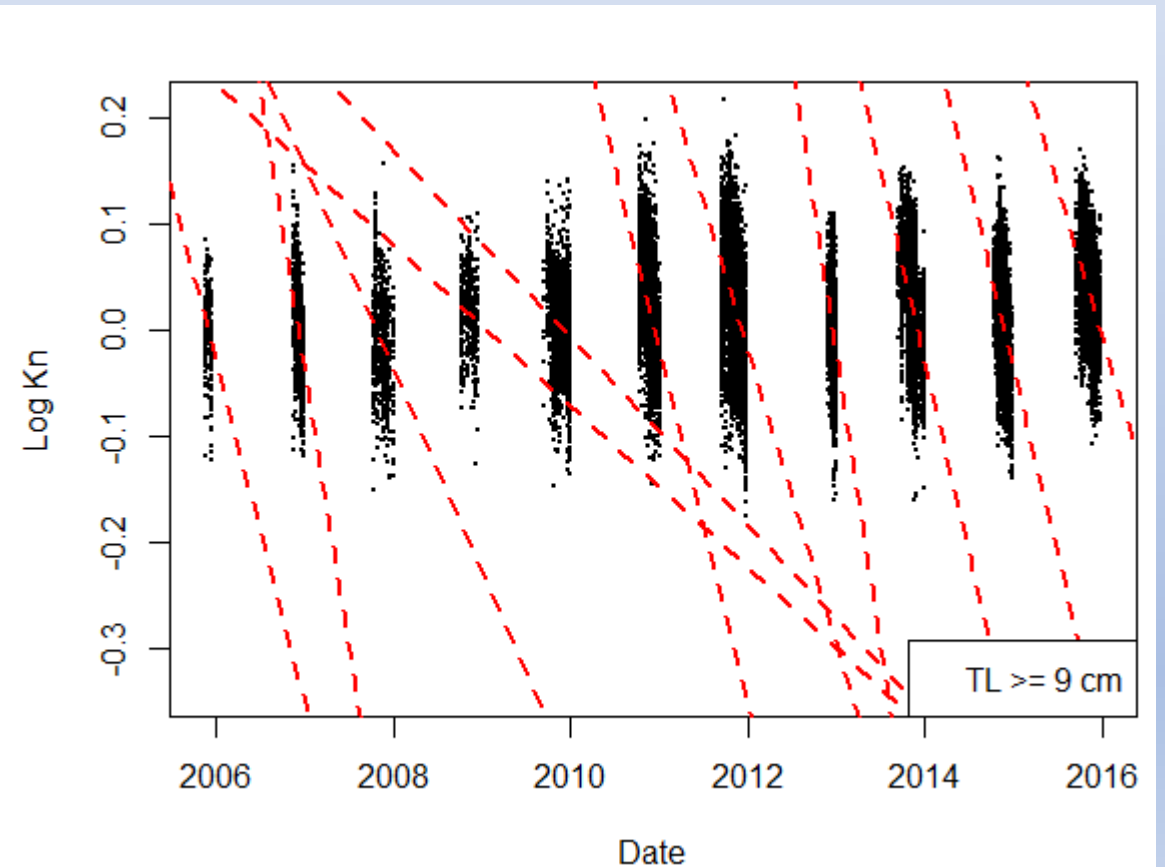
No feeding during overwintering → ~30% weight loss

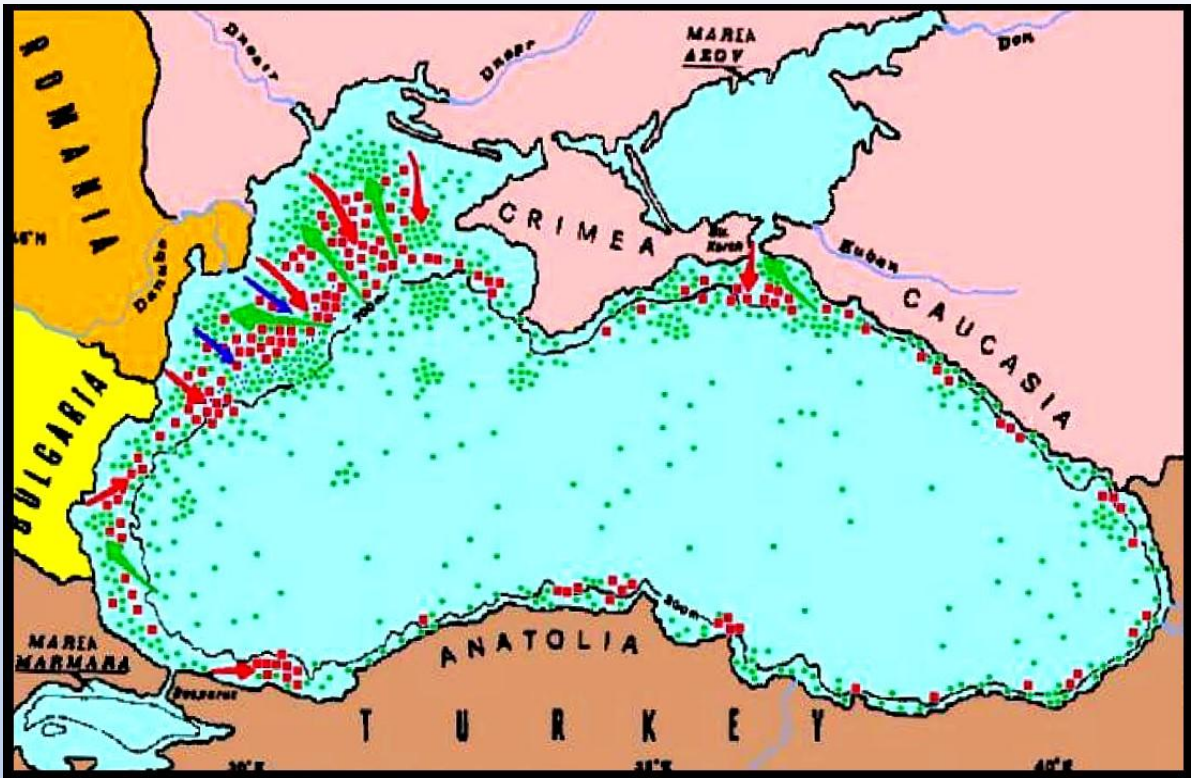
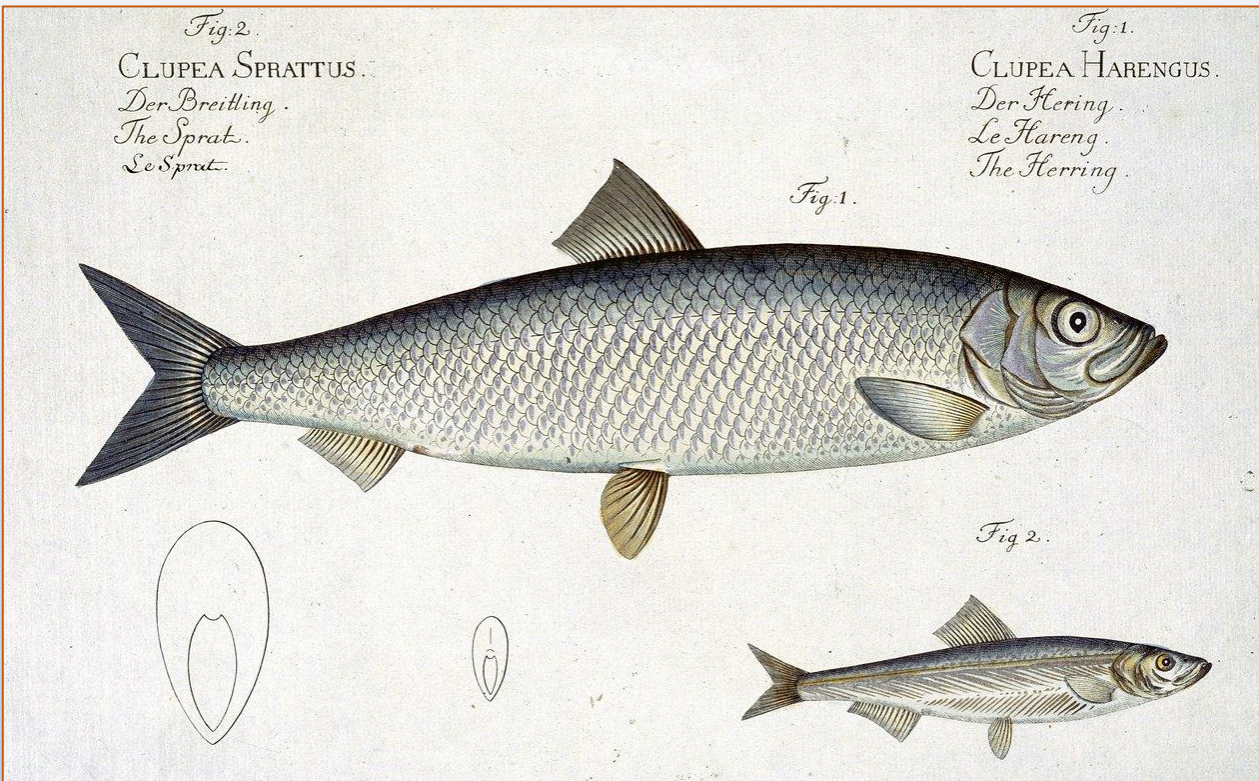
High EKE (strong Rim Current) improves fish condition

Condition → Recruitment success (t+1)



Gücü et al., 2018. Fisheries Research 205 (21-31)

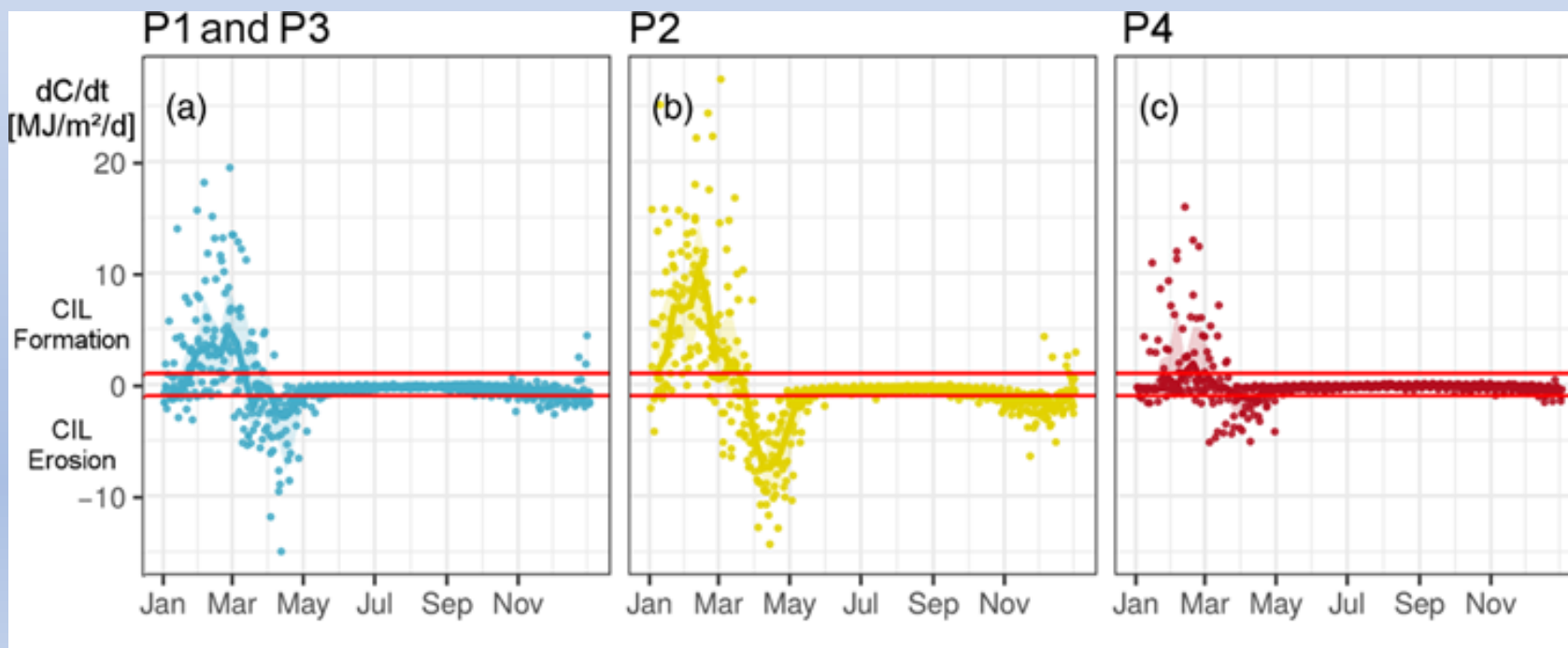
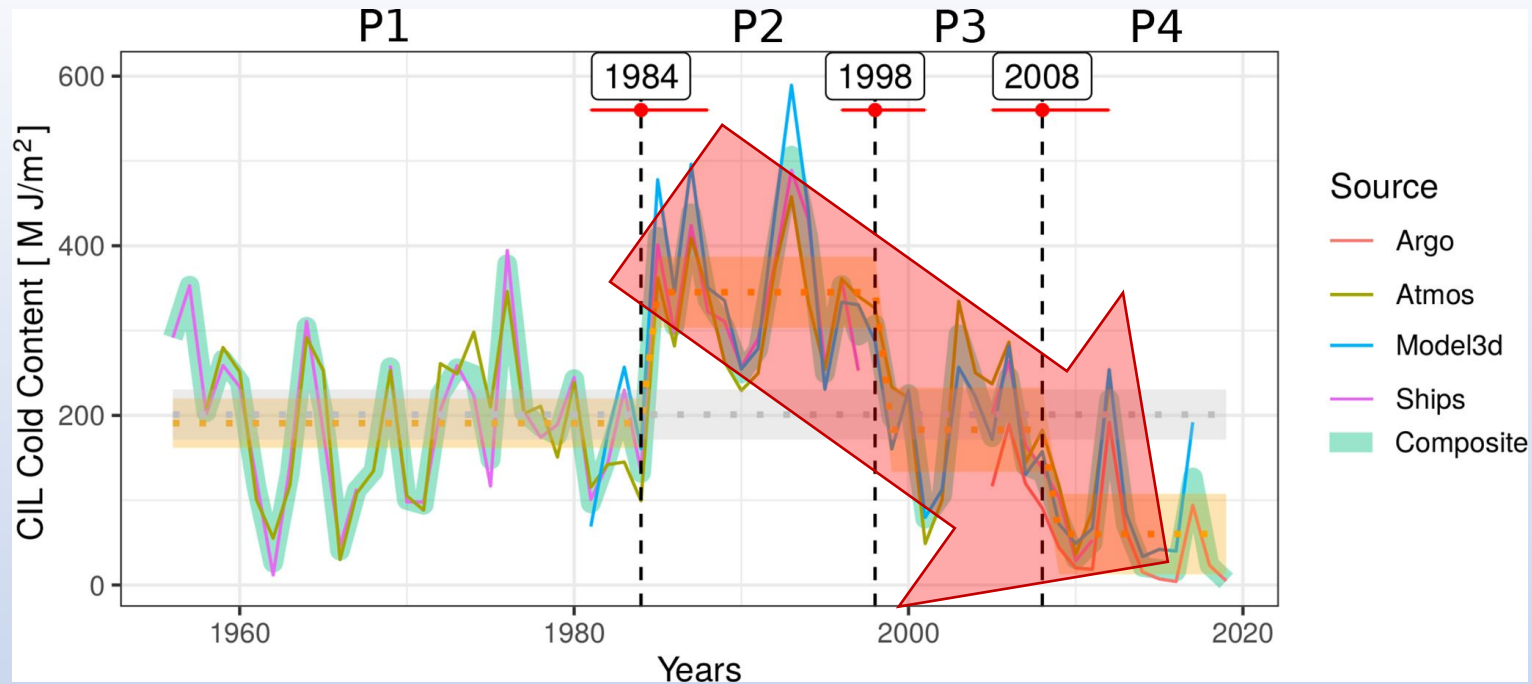
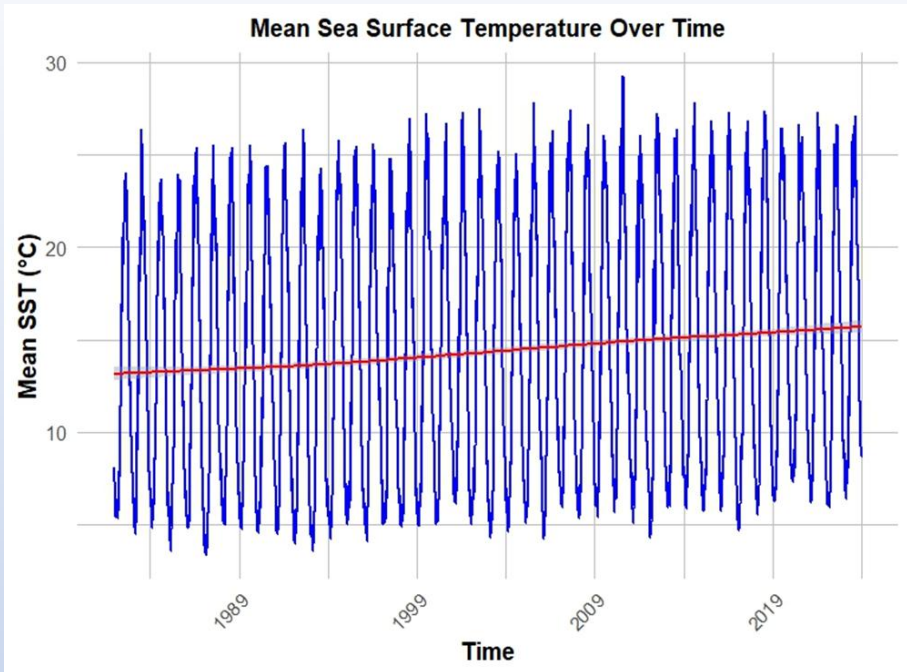




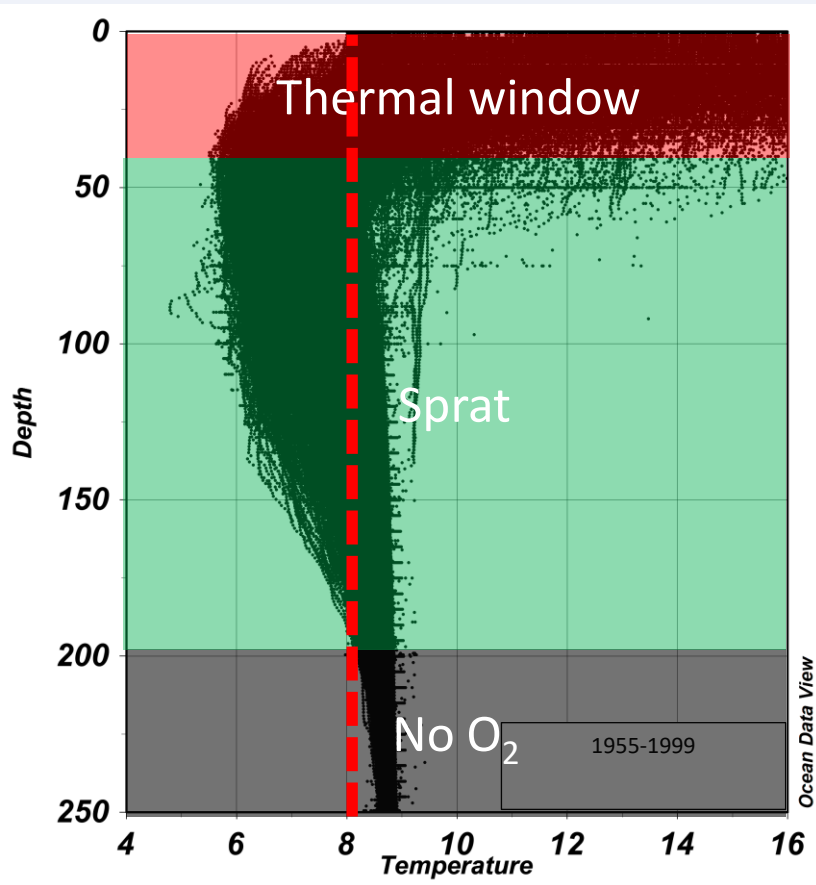
Ivanov and Beverton (1980)

# European Sprat (*Sprattus sprattus*)

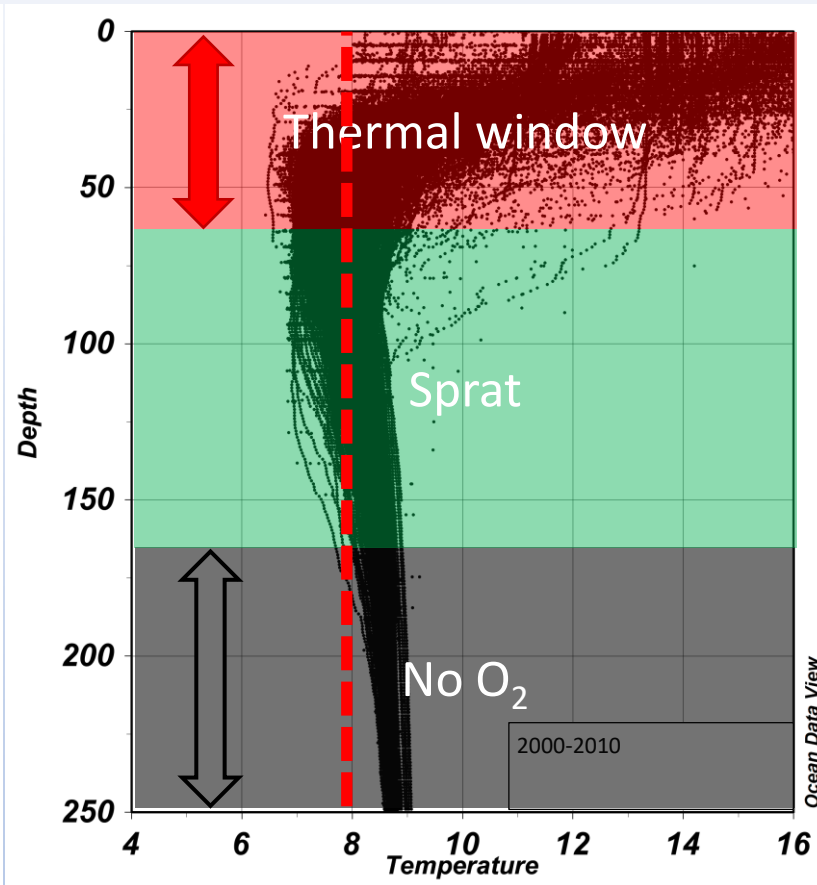
Spawning grounds and spawning movements (red);  
 feeding grounds and feeding movements (green);  
 overwintering migration (blue) of the sprat in the Black  
 Sea (Ivanov and Beverton, 1985).



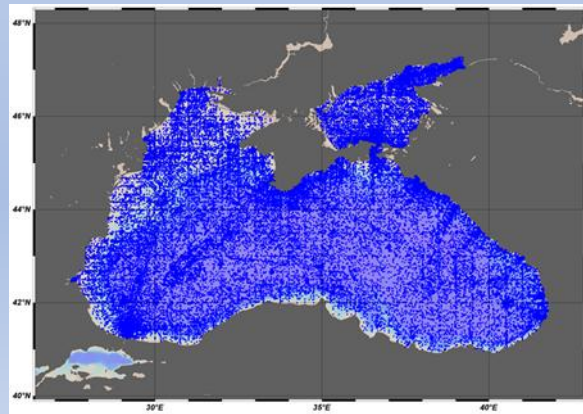
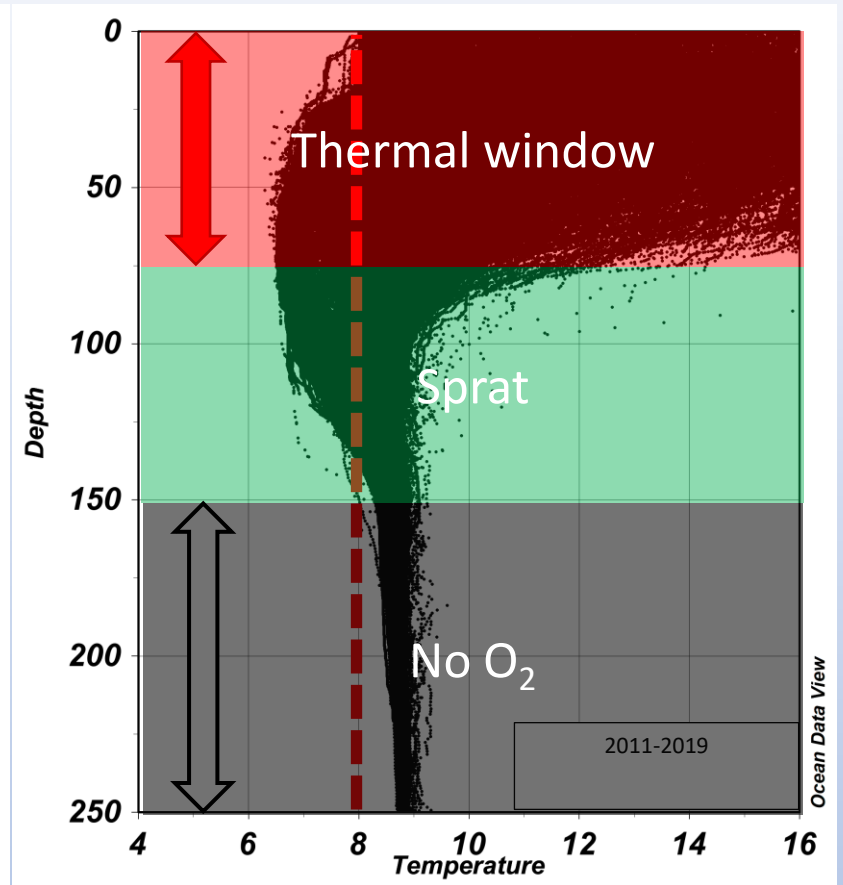
1955-1999



2000-2010



2011-2019





## 1. Data collection (CPC data call)

(Catch, effort, biological data, surveys, metadata)

## 2. Data management & quality control

(Standardisation, validation, gaps identification)

## 3. Stock assessment (Modelling)

(Estimation of  $F$ ,  $SSB$ , Recruitment and other indicators)

## 4. Stock Recruitment Relationship

(SRR analysis and interpretation, if possible)

## 5. Biological Reference Points

(Derivation of BRPs:  $F_{MSY}$  proxy,  $B_{trigger}$ ,  $B_{lim}$ ,  $MSY$ , etc.)

## 6. Stock status determination

(Comparison with BRPs: overfishing? overfished?)

## 7. Management Strategy Evaluation (MSE) / Scenario analysis

(Test HCR options, robustness, risks, trade-offs)

## 8. Formulation of scientific advice

(Catch/ $F$  targets or ranges, risk & uncertainty, management options)

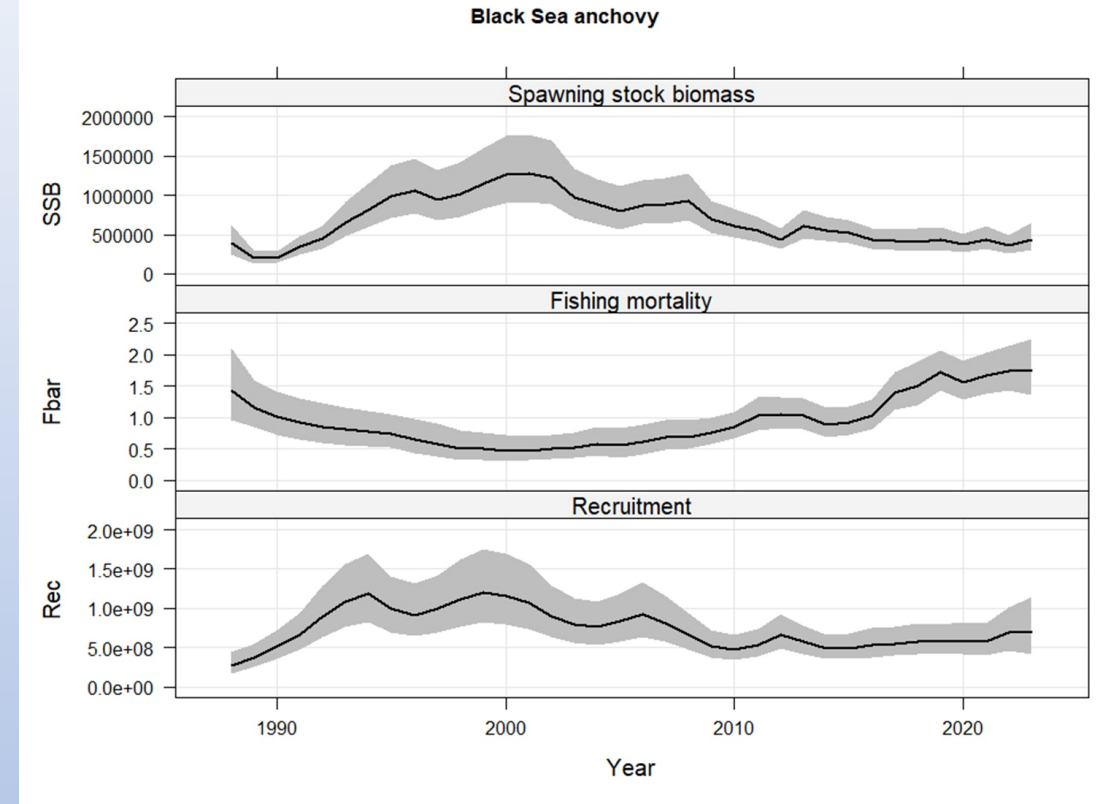
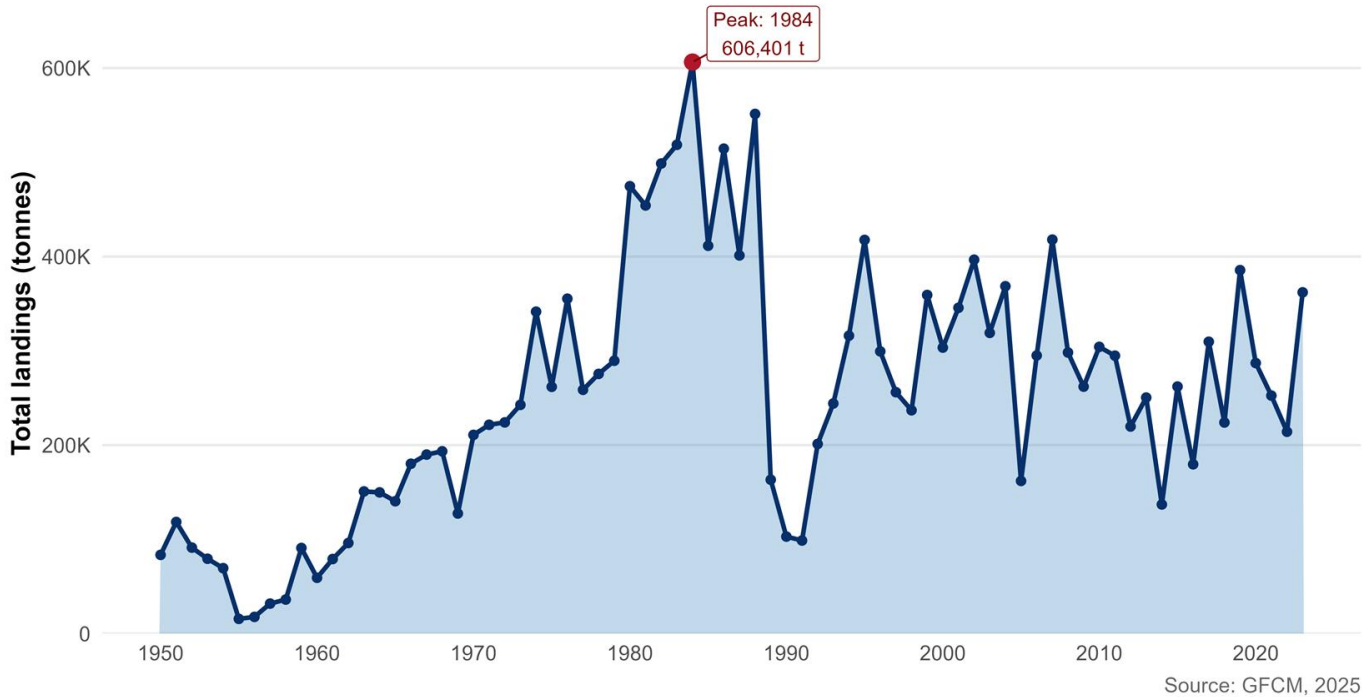
## 9. Scientific advice to the Commission

(WGBS/ACBS provides advice for management decision)

Given the limited reliability of  $MSY$ -based reference points due to high recruitment variability, uncertain stock–recruitment relationships, and a fishing pattern dominated by early age classes, a **precautionary exploitation rate approach** was adopted.

## Total Black Sea Anchovy Landings

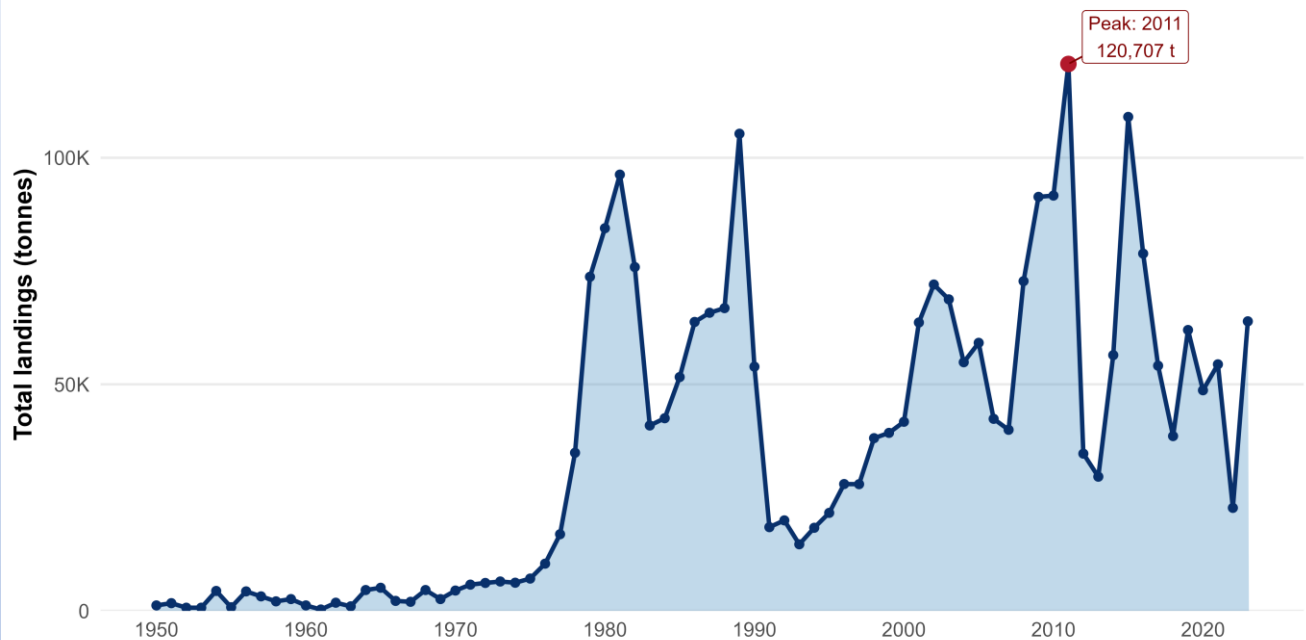
Reported total landings for the Black Sea



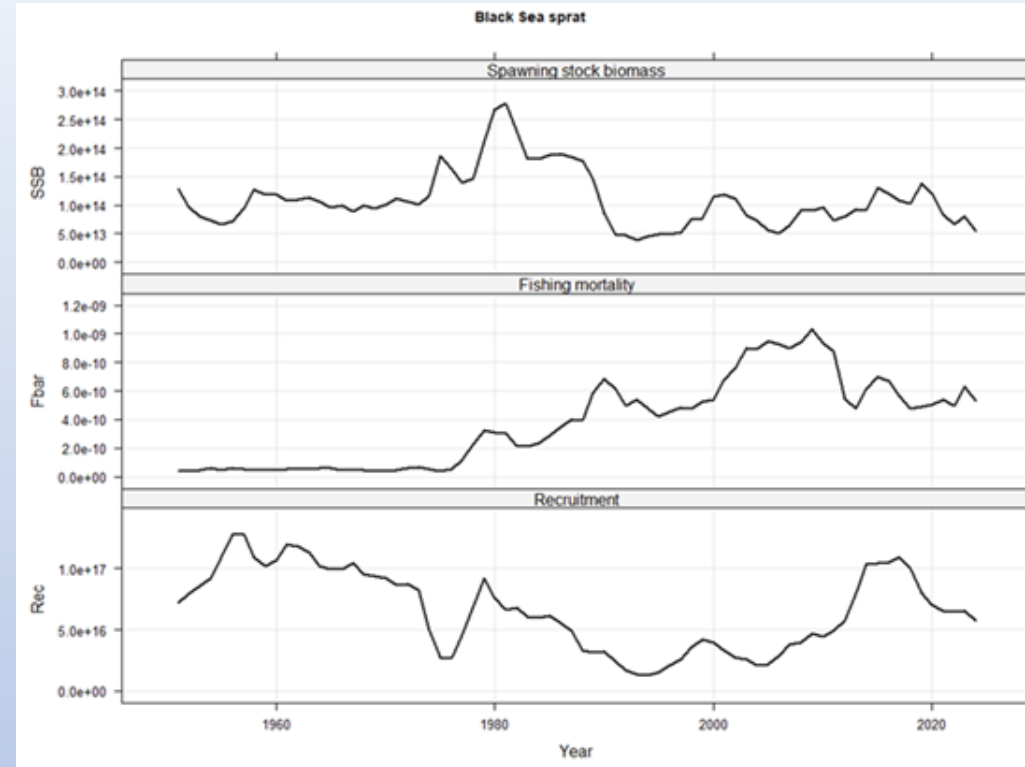
GSA	RefY	Species	Methodology used	Stock status	Scientific advice
29	2024	Anchovy	SAM	Possibly overfished	Reduce fishing mortality

## Total Black Sea Sprat Landings

Reported total landings for the Black Sea



Source: GFCM, 2025



GSA	RefY	Species	Methodology used	Current levels	Reference points	Quantitative status	Stock status	Scientific advice
29	2024	Anchovy	SAM	$F_{curr}$ (2022-2024) = 0.41	$F_{msy} = 0.63$	$F_{cur}/F_{msy} = 0.65$	Sustainable exploitation	Do not increase fishing mortality

# Anchovy management: Input-control driven system

## Main measures

- Closed season
- Spatial closures (key areas)
- Ban on daytime fishing

## Adaptive seasonal rule

- Continuous monitoring of catch size composition
- Juvenile fraction threshold: 15%
- Fishery closes when threshold is exceeded



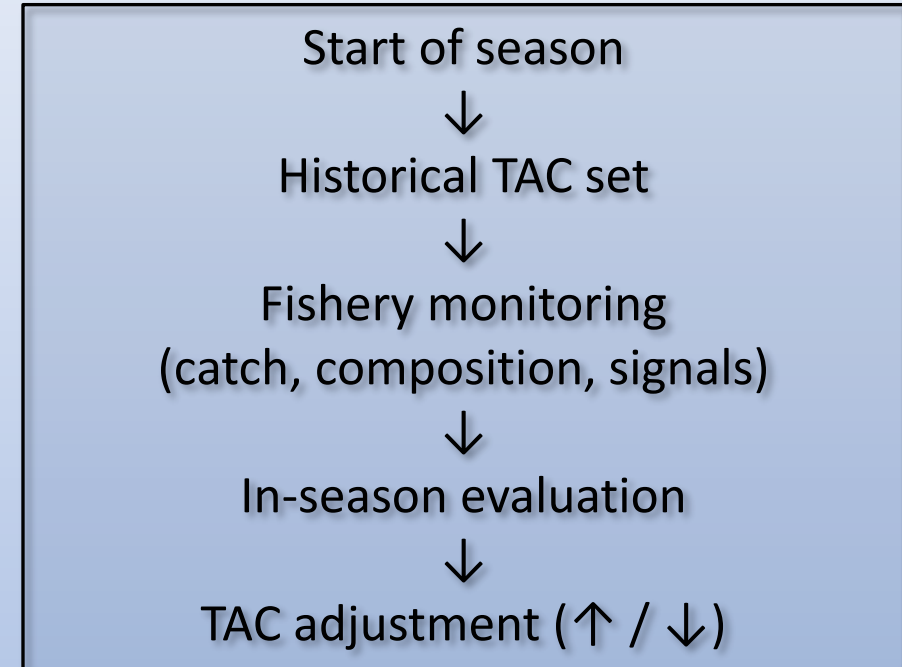
# Anchovy management: Adaptive TAC system

## TAC-based management

- Total Allowable Catch (TAC) is implemented
- Initial TAC based on **historical reference levels**

## In-season adjustment

- Continuous monitoring of fishery performance
- TAC is **revised during the season**
  - Increased if conditions are favorable
  - Reduced if signals indicate weak recruitment



# Sprat management: National system

(No quota sharing among countries)

## **TAC countries**

- Historically assigned TAC set years ago
- Never fully utilized

## **Other countries**

- No fishery or input control
- Spatial & seasonal closures
- Mesh size & vessel limits



At the request  
of Black Sea  
Fisheries Managers

# Climate impact on Sprat (*Sprattus sprattus*) in the Black Sea

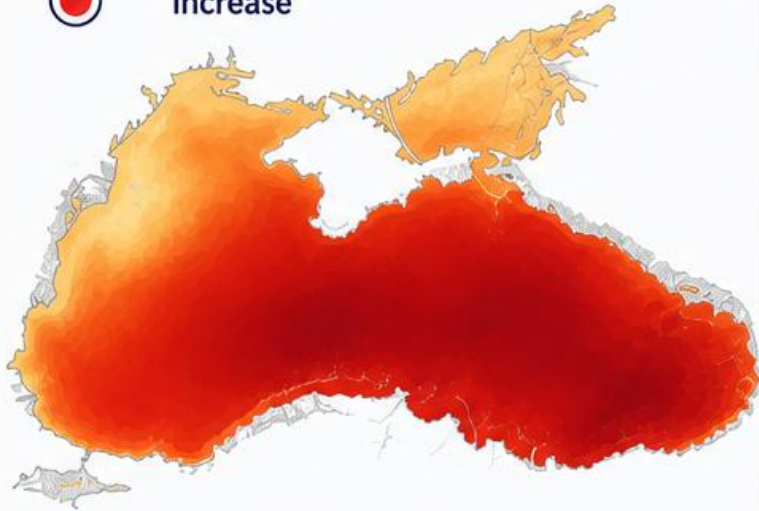
*A warming Black Sea is shrinking the cold-water habitat of sprat*

## 1. The Black Sea is warming

Surface sea temperature increase  
(1982–2023)



~ **+1.2°C**  
increase



Temperature change (°C)



## 2. Cold-water habitat is contracting

Area suitable for sprat  
(modeled cold-water habitat\*)

- Historical (1980s–1990s)
- Recent (2010s–2020s)



~ **30–40%**

reduction in suitable habitat area  
over the last decades

\* Cold-water habitat defined as surface temperature  $\leq 15^\circ\text{C}$   
during the key season (spring–summer).

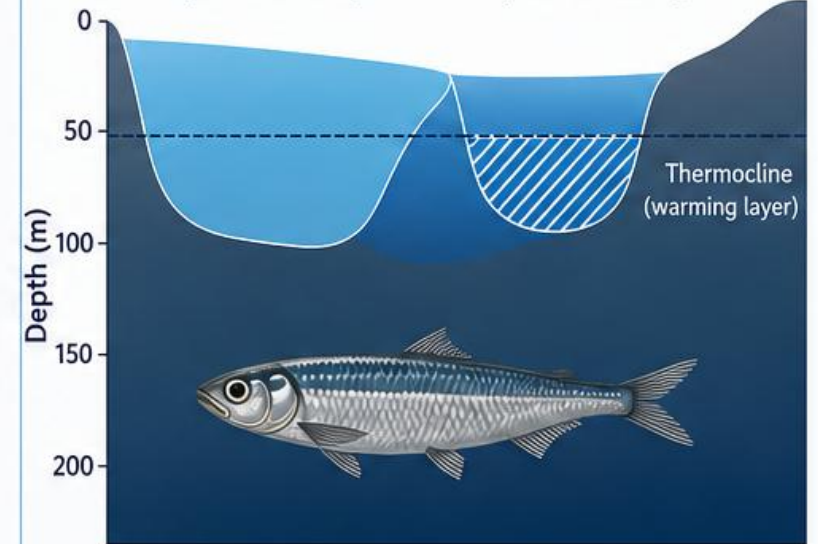
## 3. Living space for sprat is shrinking

Northward and deeper shift  
of suitable habitat

South  $\longrightarrow$  North

Past  
(1980s–1990s)

Recent  
(2010s–2020s)



Sprat prefers cold surface waters ( $\leq 15^\circ\text{C}$ ).  
Warming reduces and pushes its habitat  
northward and deeper.

# A Clockwise, Time-Lagged Cycle in the SSB–Recruitment Space

- We consistently observe a **clockwise, loop-like pattern** in the SSB–recruitment space. *This is not a classical stock–recruitment curve, but a **time-lagged cycle**.*



Strong recruitment years seem to be **triggered by environmental conditions** rather than spawning biomass.

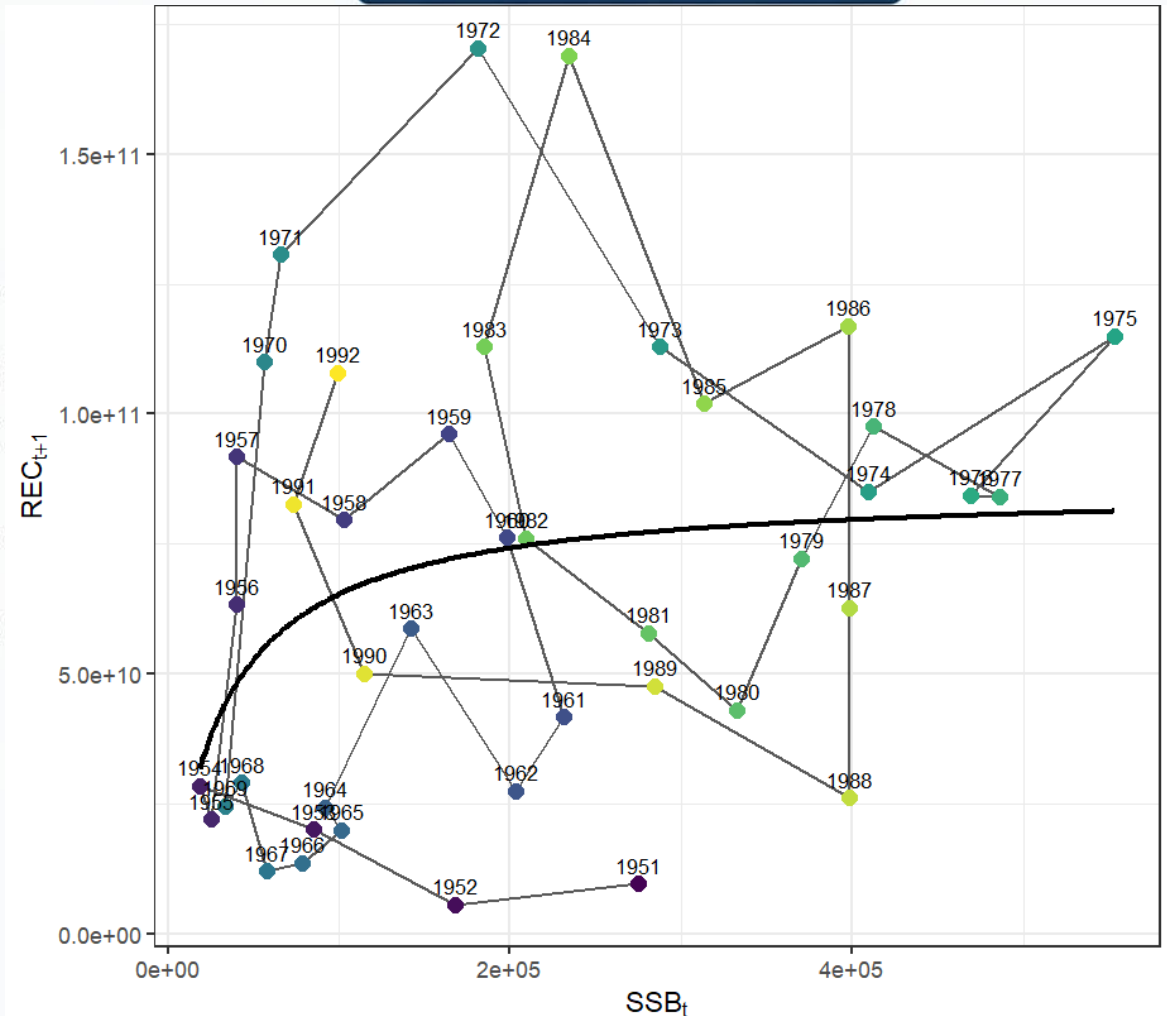


Because the species is short-lived, these strong year classes only translate into higher SSB **after about one year**.

The repeating sequence we observe:

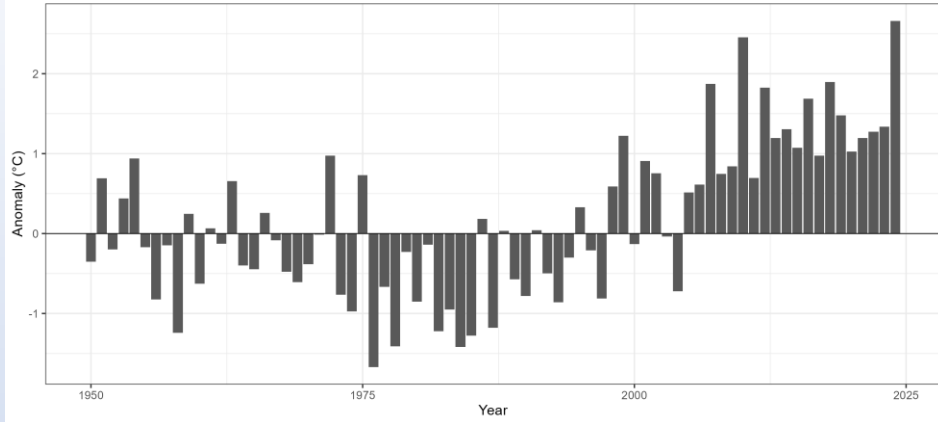
- 1 Recruitment increases first (environmental trigger)
- 2 SSB follows with a delay (~1 year)
- 3 Recruitment drops again (while SSB still high)
- 4 SSB declines afterwards

SSB–Recruitment Phase Space

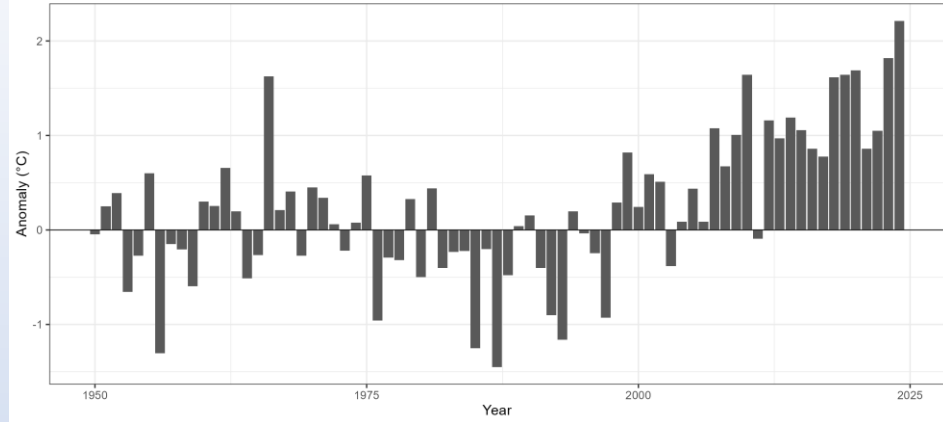


Time 1 → 2 → 3 → 4 → 1 ...

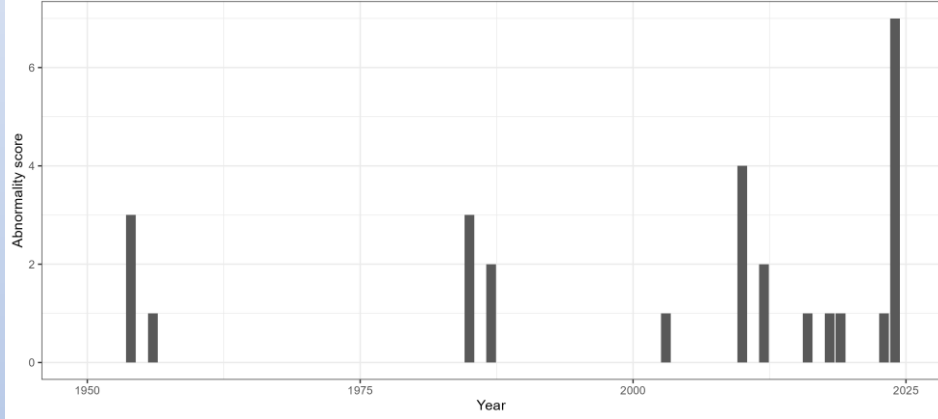
JJA summer 2m air temperature anomaly  
Climatology: 1981-2010



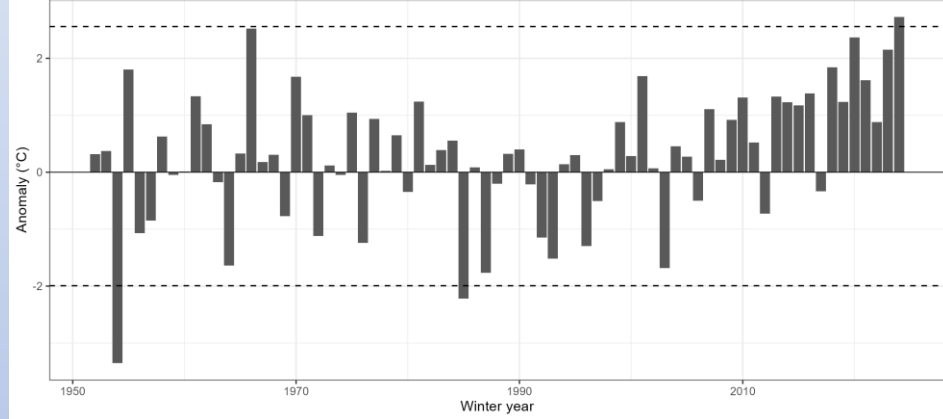
Annual mean 2m air temperature anomaly  
Climatology: 1981-2010



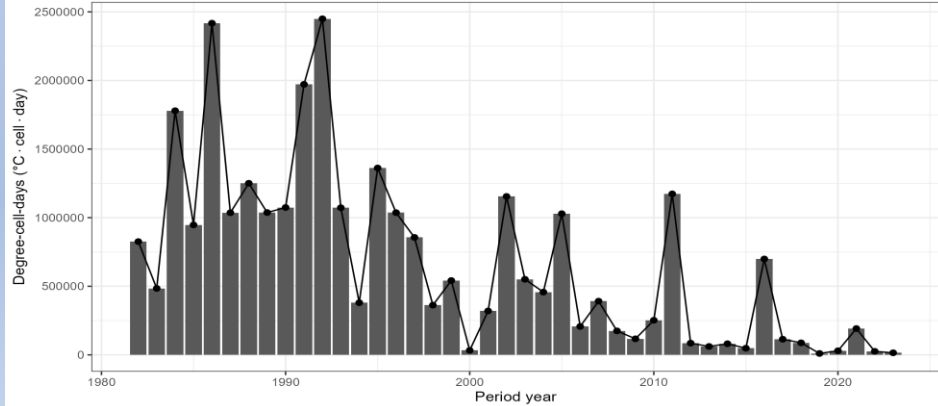
Multi-index abnormality score  
Number of indicators exceeding  $|z| \geq 2$



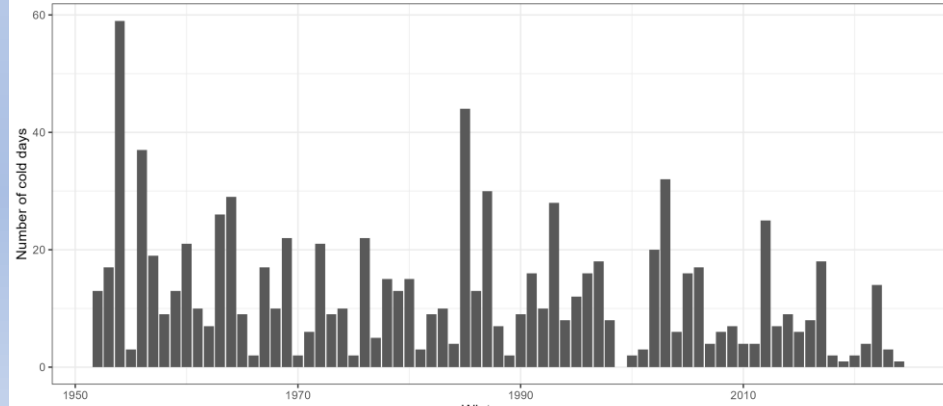
DJFM winter 2m air temperature anomaly  
Dashed lines show approx.  $\pm 2$  SD



SST-based CIL degree-cell index  
 $\Sigma \max(8 - SST\_cell\_day, 0)$ ; Sep-Aug periods



Number of cold days in DJFM  
Cold day = below climatological 10th percentile for that day-of-year



## CIL and CIL-forcing indicators tested so far

### 1. Direct SST-based CIL indicators

- **SST\_CIL\_cell\_days** (number of grid-cell days with SST < 8.35°C.)
- **SST\_CIL\_degree\_cell\_days** (Sums how far each grid cell is below 8°C:  $\text{sum}(\max(8.35 - \text{SST\_cell\_day}, 0))$ )
- **SST\_CIL\_area\_days** (Sums the area with SST < 8.35°C across days.)
- **SST\_CIL\_degree\_area\_days** (Area-weighted version of the degree-based indicator:  $\text{sum}(\text{area\_cell} \times \max(8.35 - \text{SST\_cell\_day}, 0))$ )
- **SST\_CIL\_degree\_area\_normalised\_days** (Normalised area-weighted intensity:  $\text{SST\_CIL\_degree\_area\_days} / \text{total\_area}$ )

### 2. Meteo-derived CIL-forcing indicators

- **CFI\_cell\_days** (Counts grid-cell days where the rolling mean 2 m air temperature is below the calibrated Meteo threshold.)
- **CFI\_degree\_cell\_days** (Sums how far each grid cell is below the calibrated Meteo threshold:  $\text{sum}(\max(\text{threshold} - \text{Tair\_roll\_cell\_day}, 0))$ )
- **CFI\_area\_days** (Sums the area where rolling Meteo temperature is below the calibrated threshold.)
- **CFI\_degree\_area\_days** (Area-weighted atmospheric forcing index:  $\text{sum}(\text{area\_cell} \times \max(\text{threshold} - \text{Tair\_roll\_cell\_day}, 0))$ )
- **CFI\_degree\_area\_normalised\_days** (Normalised version of CFI\_degree\_area\_days.)

### 3. Early Meteo-based deficit indicator

- **t2m\_3mo deficit CFI** (Based on a 3-month right-aligned moving average:  $\text{t2m\_3mo}(t) = \text{mean}(\text{t2m}_t, \text{t2m}_{t-1}, \text{t2m}_{t-2})$ ;  
CFI definition:  $\text{sum}(\max(\text{threshold} - \text{t2m\_3mo}, 0))$ )

### 4. Non-CIL temperature control indicators

- **METEO\_NDJFMA\_mean\_t2m** (Mean 2 m air temperature over November-April).
- **METEO\_DJF\_mean\_t2m** (Mean 2 m air temperature over December-February).
- **METEO\_Annual\_mean\_t2m** (Mean annual 2 m air temperature).

### 5. Calibration approaches used

- **SST-Meteo rolling-window test** (Tested different rolling windows for 2 m air temperature).
- **56-day rolling Meteo** (Used as a literature-supported lag window)
- **GAM calibration** (Modelled the relationship between SST and rolling Meteo temperature)
- **Segmented regression idea** (Considered for detecting slope changes in the SST-Meteo relationship).

## Climate-tuned Beverton–Holt Stock–Recruitment

$$R_{t+1} = \frac{\alpha SSB_t}{1 + \beta SSB_t}$$

- **Base** (classical Beverton-Holt stock-recruitment ) **model**
  - Recruitment is predicted only from spawning stock biomass.
  - $REC = f(SSB)$
- The climate indicator was added in three alternative ways:
  - **Alpha-tuned model**
    - Climate modifies the productivity parameter.
    - Interpretation: for the same SSB, favourable or unfavourable climate can produce more or fewer recruits.
  - **Beta-tuned model**
    - Climate modifies the density-dependence parameter.
    - Interpretation: climate changes how strongly recruitment levels off at higher SSB.
  - **Alpha + beta tuned model**
    - Climate modifies both productivity and density dependence.
    - Interpretation: the whole shape of the stock-recruitment curve can change with climate.
- Model performance was evaluated using:
  - AICc
  - LOOCV prediction skill
  - log-scale RMSE and MAE
  - observed-predicted correlation

# Best-performing CIL indicator in BH-SRR tuning

- **Base model:** M0\_BH (classical Beverton-Holt)
- **Best CIL indicator:** SST\_CIL\_cell\_days
- **Best tuned model:** M1\_alpha\_CFI
- Alpha tuning gave the strongest improvement over the base BH model.
- **Interpretation:** the spatial-temporal extent of SST < 8°C conditions carried the strongest recruitment signal.

	M0_BH	M1_alpha_CFI
LOOCV RMSE_log	0.346	0.293
LOOCV MAE_log	0.280	0.248
LOOCV correlation	0.529	0.696

## Improvement over M0

- **LOOCV RMSE: 15.2%**
- **LOOCV MAE: 11.4%**

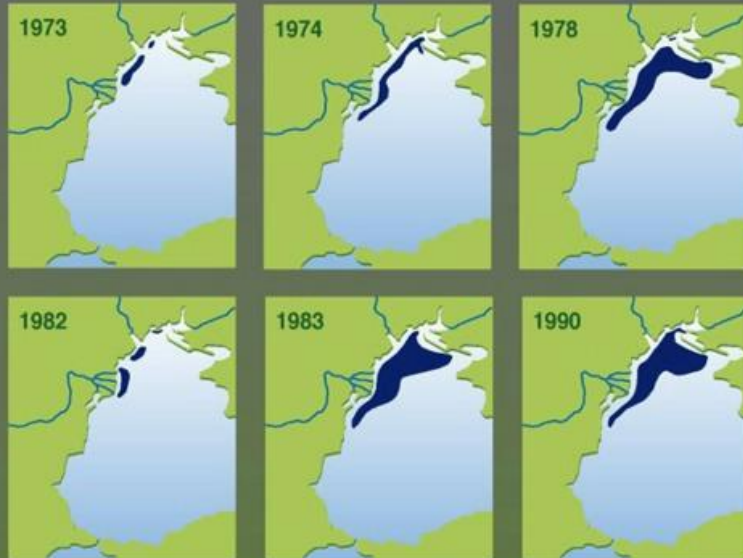
The SST-based CIL cell-days index improved the Beverton-Holt model most strongly, suggesting that recruitment responded mainly to the extent and duration of SST < 8°C conditions.

Catchment is 6 times of surface

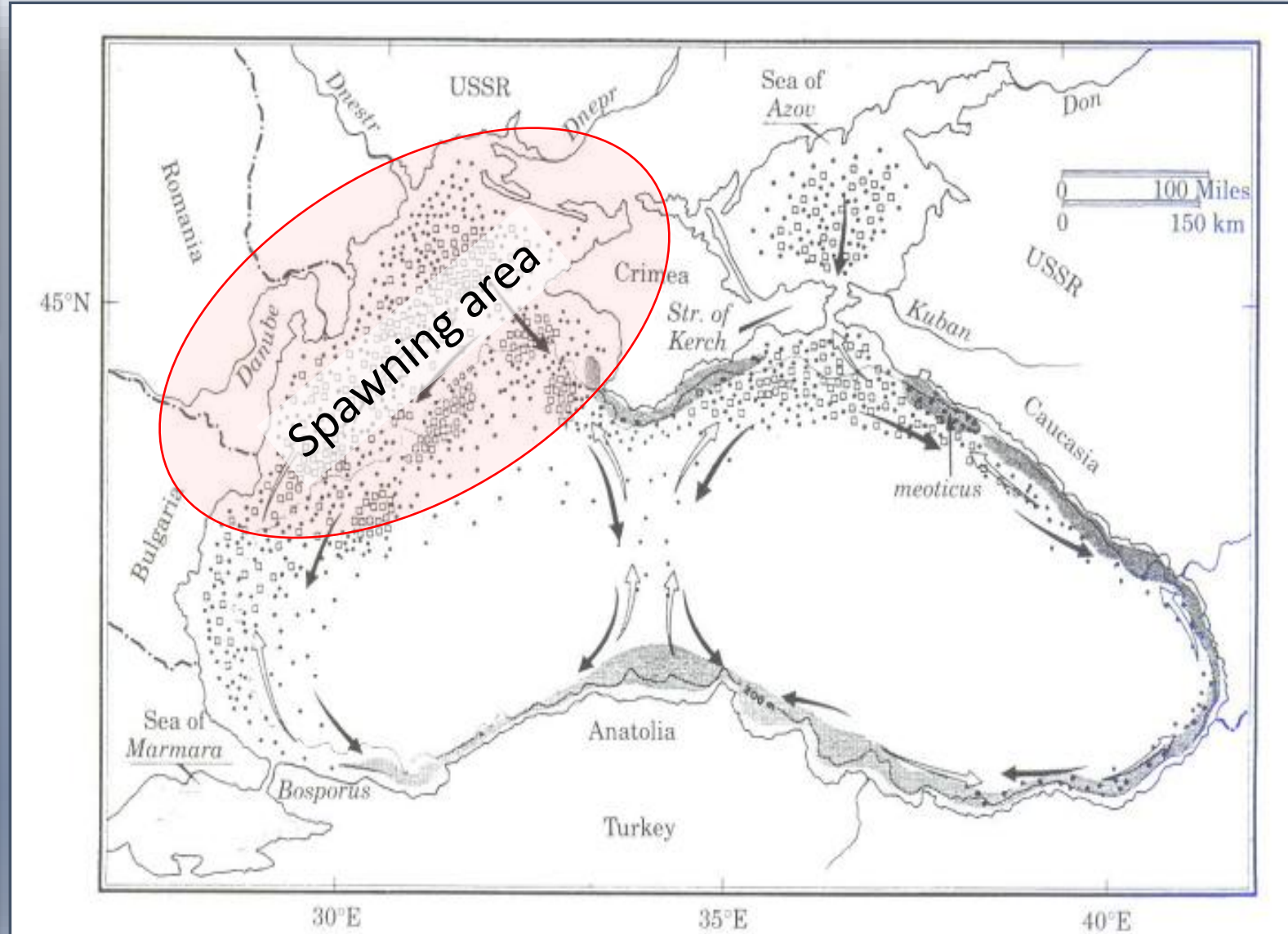


## Green revolution

Expansion of hypoxia and anoxia zones in the northwest of the Black Sea



Note: Eutrophication was so strong that it caused temporary hypoxia events on the sea bottom that resulted to the mass mortality of benthic animals in the relatively shallow northeastern Black Sea.  
Source: Y. Zaitsev and V. Mamaev, *Marine biological diversity in the Black Sea. A study of change and decline*. United Nations Publications, New York, 1997.



# Conclusion



CIL-related conditions improved recruitment prediction, but the effect was moderate.



This suggests that CIL is one contributing factor, not the only driver.

Recruitment of sprat and anchovy may also be affected by:



1 Eutrophication in spawning and nursery areas



2 Episodic hypoxia and anoxia



3 Changes in suitable early-life habitat



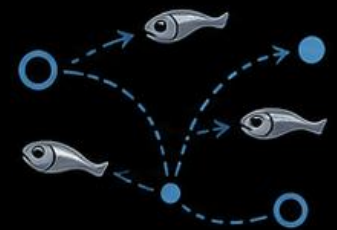
4

Climate-driven changes in the strength and pathway of the Rim Current



5

Larval transport, retention, and connectivity



Therefore, recruitment variability likely reflects the combined effect of physical, biogeochemical, and biological processes.

## **Acknowledgements**

Support from the FAO and General Fisheries Commission for the Mediterranean and the Black Sea is gratefully acknowledged.

The members of the GFCM Network of Experts on Fisheries and Climate Change are also thanked for their valuable contributions, with special thanks to **Gizem Akkuş Lök** and **Merve Kurt**.