Modelling Marine Ecosystems
The Baltic Sea Example

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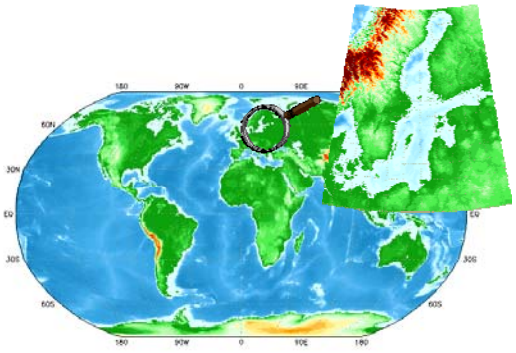
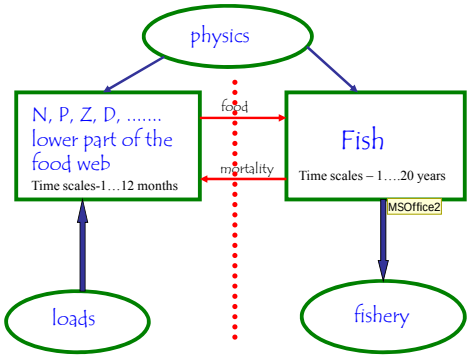
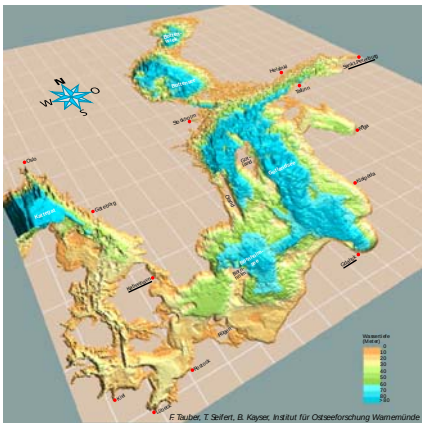
1. Introduction
2. Modelling
3. Eutrophication
4. HABs in the Baltic
5. Fish and foodwed models



The area of the Baltic is only one per mill of the world ocean

The coupled system

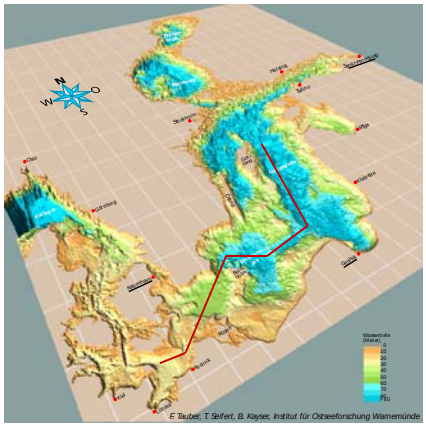




The Baltic Sea

P-E>0
(60km³/year)
River discharge
480 km³/year

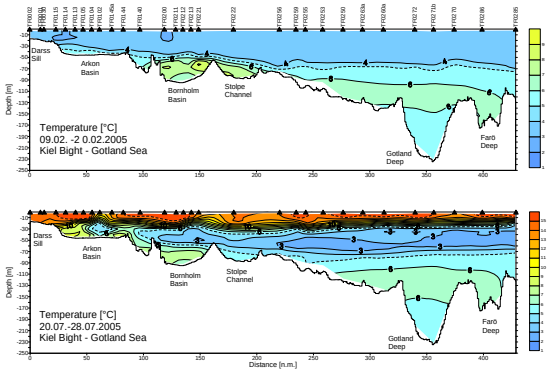
Mean depth = 50 m
Sill depth = 18 m
Vol.= 21 700 km³



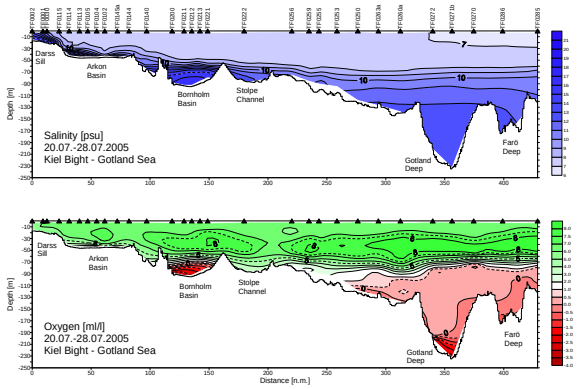
The Baltic Sea

Monitoring
along the 'Talweg'

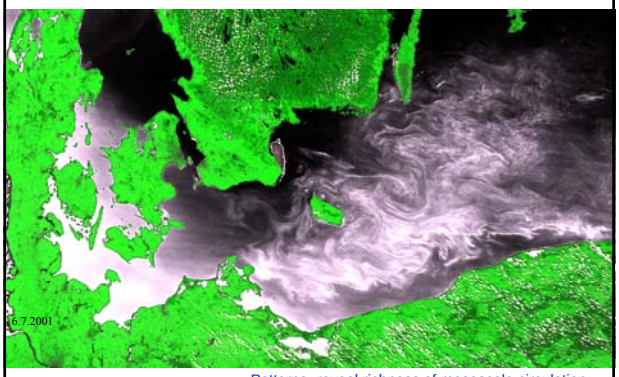
Temperaturverteilung im Winter und im Sommer



Salzgehalt und Sauerstoffverteilungen



Surface accumulation of blue-green algea



Patterns -reveal richness of mesoscale circulation

MODIS NASA (Δx=250m)

(courteously, H. Siegel, T.Ohde)

Features and scales relevant for the ecosystem:

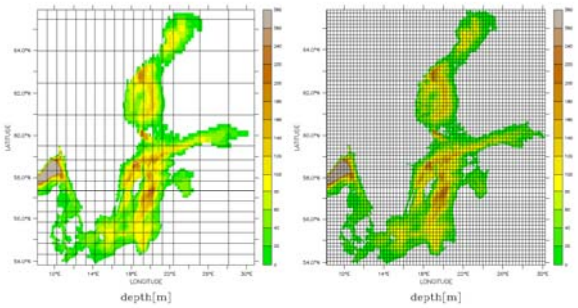
Halocline sets the *long term* physical conditions

Thermocline sets the *yearly cycle*

Mesoscale Processes
(coastal jets, upwelling, river plumes, eddies)
shaping spatial patterns and set the ***variability***
(hours to days) of the chemical biological quantities.

Climate impact → warmer surface layer, ice cover shrinks, changed inflow patterns

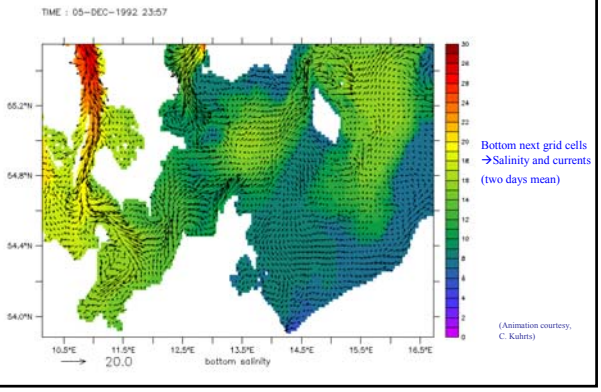
Circulation model



Model set up 3 n.m.
169 x 153 horizontal cells
77 levels
timestep: 12 min (MOM4) 4 min (MOM3)

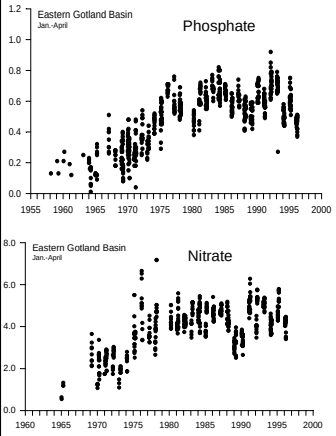
Model set up 1 n.m.
660 x 720 horizontal cells
77 levels
timestep: ~ 4 min (MOM4)

Major salt water inflow in January 1993



Bottom next grid cells
→Salinity and currents
(two days mean)

(Animation courtesy, C. Kuhrts)



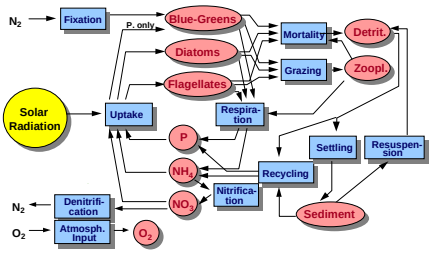
Eutrophication

Increase of Nutrients 1970 – 1990

winter values near the surface-in the central Baltic

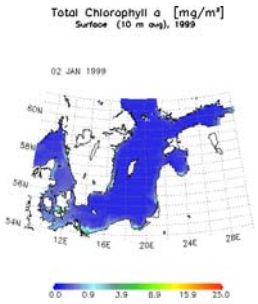
3D coupled model of the Baltic (MOM3)

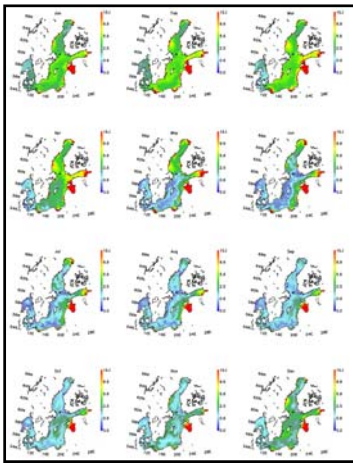
Bio-chemical model for the Baltic Sea



T.Neumann JMS, 2000

Animation (courtesy, Neumann/Kremp)

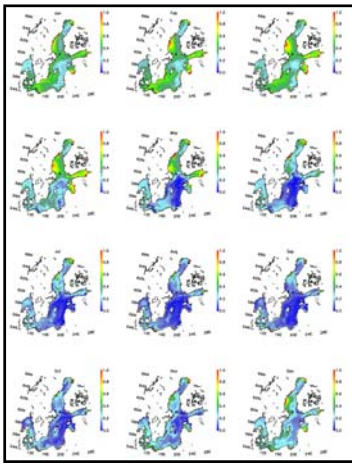




yearly cycle

NO_3 +NH_4

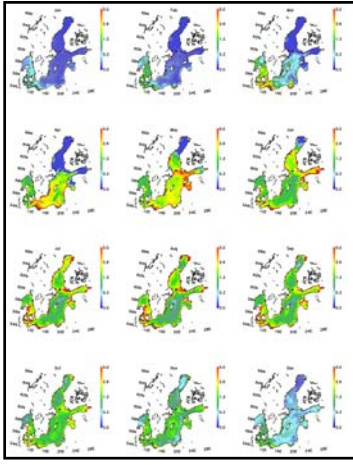
monthly means
near surface
(model year 1984)



yearly cycle

PO_4

monthly means
near surface
(model year 1984)

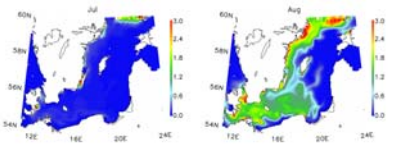


yearly cycle

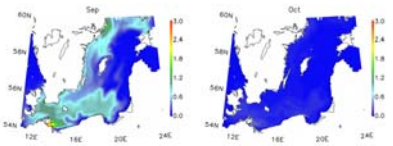
Total Chlorophyll

monthly means
near surface
(model year 1984)

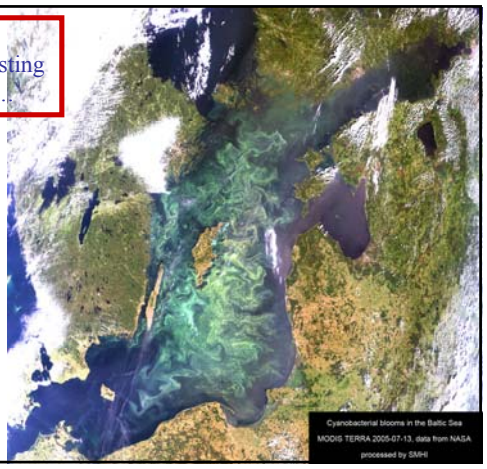
HABs in the Baltic



Model near surface cyanobacteria
monthly means
(model year 1984)



Blue Greens
Looks interesting
from space….



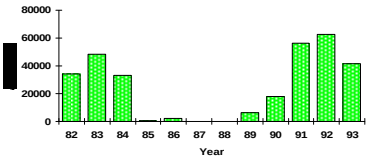
HABs in
the Baltic

..... a nuisance,
if we take a close look

nach Kahru et al. Ambio, 1994

Kahru, M., U. Horstmann, O. Rud, Satellite detection of increased cyanobacteria blooms in the Baltic Sea: Natural fluctuation or ecosystem change? Ambio, 23 (8): 469-472, 1994.

Total area covered by cyanobacterial accumulations



Aera of the Baltic ~ 415 000km²

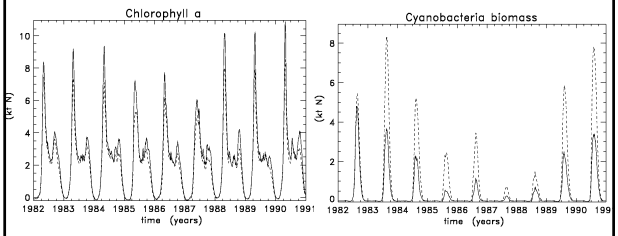
Experiment:

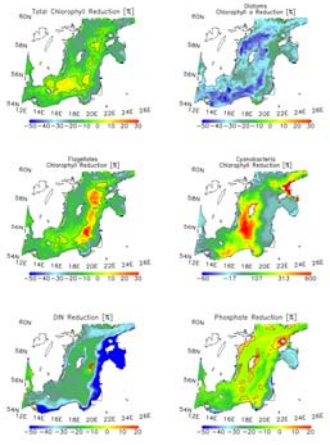
T.Neumann, W.Fennel and C.Kremp
Global Biogeochemical Cycles,
2002, **16**, 7-1 – 7-19

Response of the system to reduced (halved) nitrogen and phosphorus loads

1980-82 -Initialisation,
simulation from 1982 -91

average over upper 50m of the Baltic Proper, solid – baseline run
dashed – reduction run





Halved loads for 1982-1991

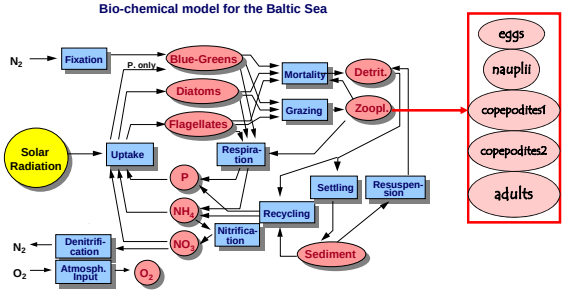
Reductions- minus Reference run
Reference run
(in percent)

Annual mean for 1991
Averaged over upper 50m

T.Neumann, W.Fennel and C.Kremp
Global Biogeochemical Cycles,
2002, **16**, 7-1 – 7-19

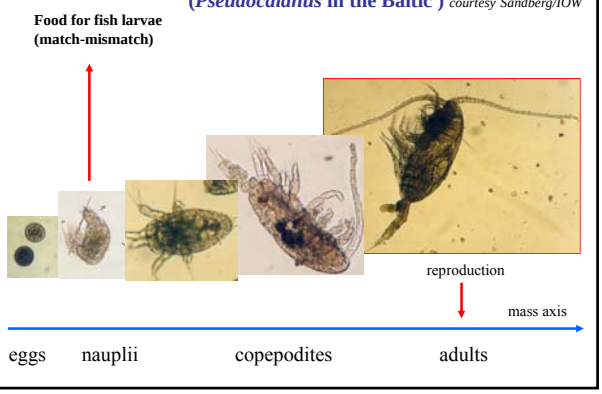
Option: Replace the bulk-zooplankton by a stage resolving model !

Bio-chemical model for the Baltic Sea



(Neumann, JMS, 2000;Fennel, JPR, 2001, Fennel&Neumann, ICES Jour Mar Sci., 2003)

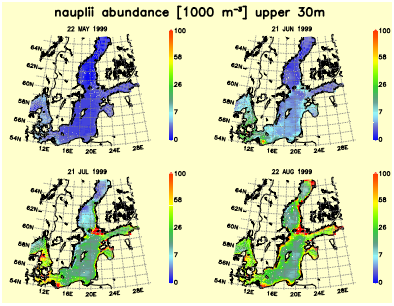
Sketch of the life cycle of copepodes (*Pseudocalanus* in the Baltic) *courtesy Sandberg/IOW*



Horizontal Nauplii Distributions

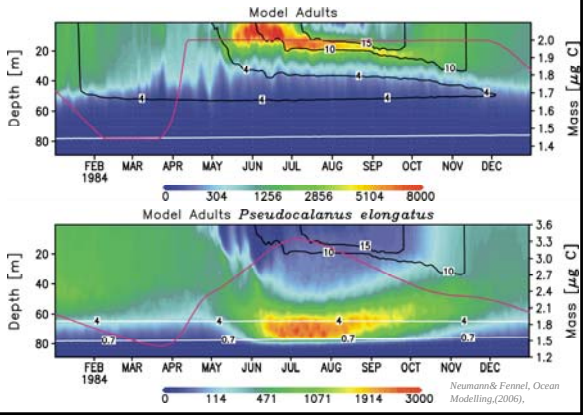
- increase in response to the spring bloom,
- peak abundances in coastal areas,
- mesoscale patterns

Prey fields for fish larvae (Match-Mismatch Hypothesis)



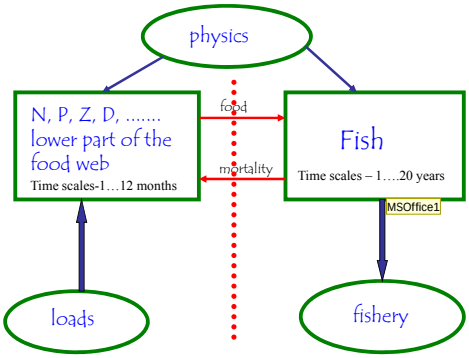
Courtesy T.Neumann

Modeling behaviour

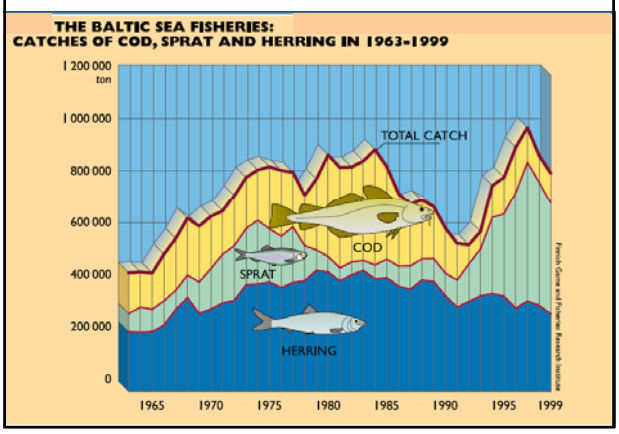


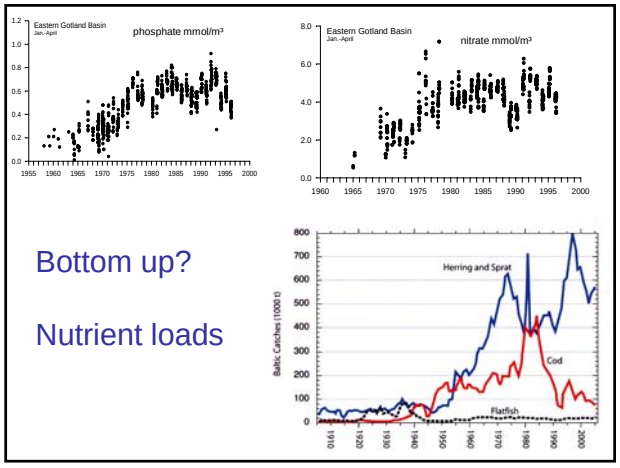
Neumann& Fennel, Ocean Modelling,(2006),

The coupled system



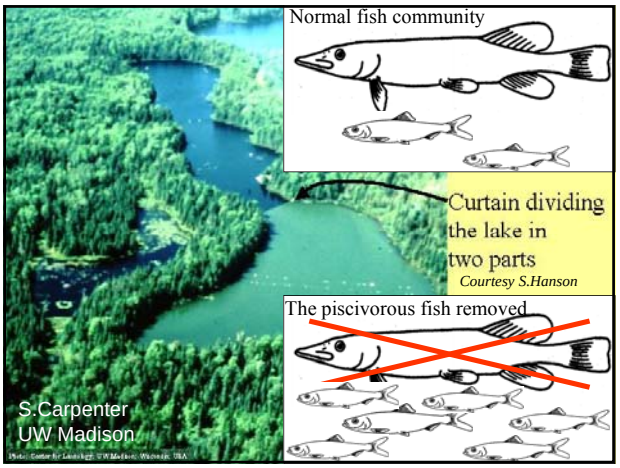
What are the reasons for the interannual variations?

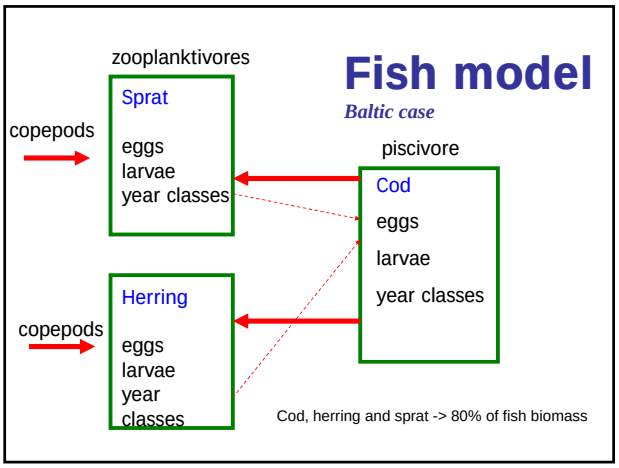


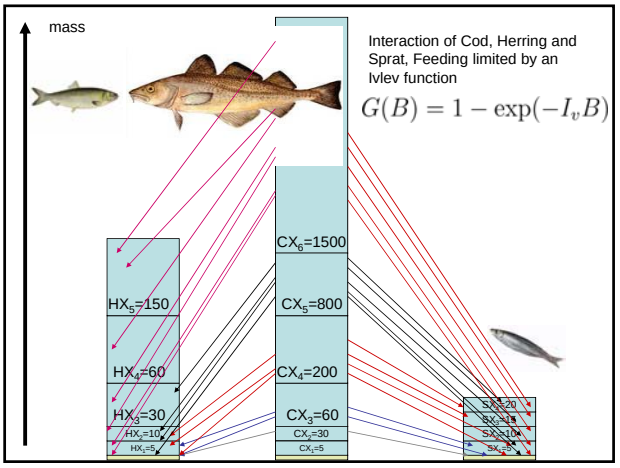


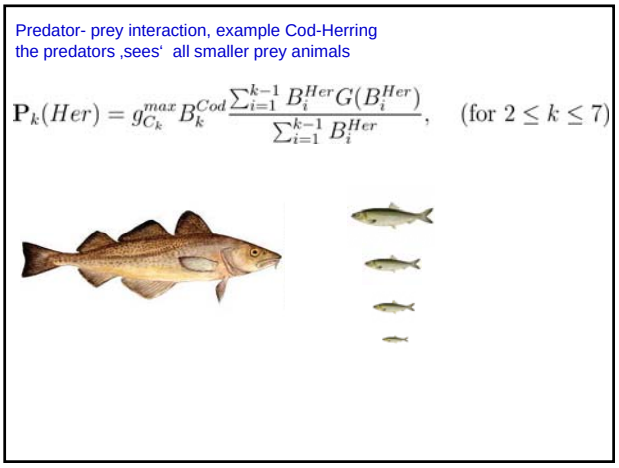
Bottom up?

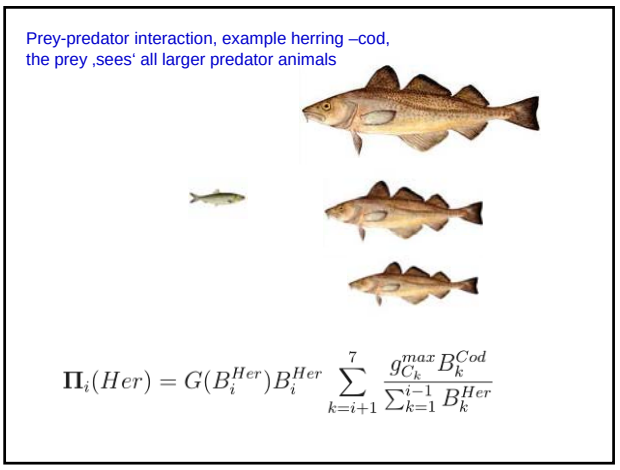
Nutrient loads











Further dynamic ingredients:

Metabolism:
respirations- and excretion rates transferring part of the ingested food (or bodymass) to nutrients and detritus
→*(rating: good, quantification of parameters can be improved)*

Reproduction:
off-spring approach → *(rating: reasonable, but needs refinement)*

Mortality:
natural deaths and starvation rates, fishing mortalities,
→*(rating: reasonable, but difficult, partly questionable, needs further consideration)*

The result is:

Warnemuende **F**ood web **M**odel (WFM)

W.Fennel:Towards bridging biogeochemical and fish-production models, JMS,71 (2008), 171-194

WFM *(show just a few equations)*

Predator (cod):
Model-equations

$$\frac{d}{dt}B_1^{Cod} = \mathrm{os}_{C6}B_6^{Cod} + \mathrm{os}_{C7}B_7^{Cod} + (g_1^{Cod} - L_{C_1N} - L_{C_1D} - \mu_{C_1})B_1^{Cod} - \tau_{C_1}B_1^{Cod},$$

for biomass

$$\frac{d}{dt}B_i^{Cod} = \tau_{C_{i-1}}B_{i-1}^{Cod} - (L_{C_iN} + L_{C_iD})B_i^{Cod} - \tau_{C_i}B_i^{Cod} + \mathbf{P}_i,$$

$$\frac{d}{dt}B_7^{Cod} = \tau_{C_6}B_6^{Cod} - (L_{C_7N} + L_{C_7D} + \mathrm{os}_{C7} + \mathrm{F}_{C_7} + \mu_{C_7} + \mu_{C_7}^{starv})B_7^{Cod} + \mathbf{P}_7,$$

and

$$\frac{d}{dt}N_1^{Cod} = \frac{1}{m_0}\left(\mathrm{os}_{C6}B_6^{Cod} + \mathrm{os}_{C7}B_7^{Cod}\right) - \mu_{C_1}N_1^{Cod} - \tau_{C_1}\frac{B_1^{Cod}}{CX_1},$$

abundance

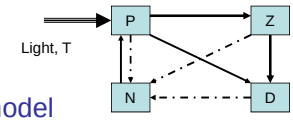
$$\frac{d}{dt}N_i^{Cod} = \tau_{C_{i-1}}\frac{B_{i-1}^{Cod}}{CX_{i-1}} - \mu_{C_i}^{*}N_i^{Cod} - \tau_{C_i}\frac{B_i^{Cod}}{CX_i},$$

$$\frac{d}{dt}N_7^{Cod} = \tau_{C_6}\frac{B_6^{Cod}}{CX_6} - (\mu_{C_7} + \mu_{C_7}^{starv} + \mathrm{F}_{C_7})N_7^{Cod}.$$

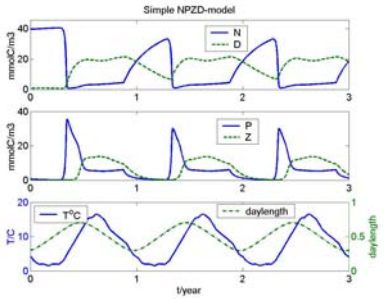
averaged individual mass m=B/N

Link to lower food web

(start with a simple toy model for the NPZD part)



Truncated model



Truncated model
$l_{ZD} = 0.03$ /d

adjusted zooplankton mortality,

Coupling the NPZD-model to fish - three channels

Respiration of fish

$$\frac{dN}{dt} = -u(N)P + l_{PN}P + l_{DN}D + l_{ZN}Z + \mathbf{L_{FN}},$$

$$\frac{dP}{dt} = u(N)P - l_{PN}P - g(P)\,Z - l_{PD}P,$$

$$\frac{dZ}{dt} = g(P)\,Z - l_{ZN}Z - l_{ZD}Z - \mathbf{G_F},$$

Feeding of fish on Z

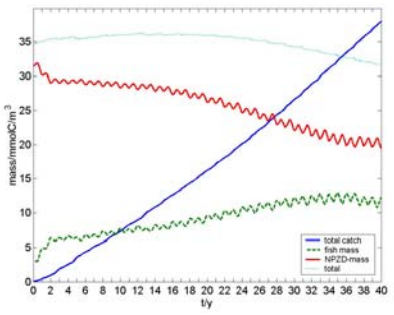
$$\frac{dD}{dt} = l_{ZD}Z + l_{PD}P - l_{DN}D + \mathbf{L_{FD}}$$

Fish mortality feeds back into D

1mmolC => 12 mgC => 100 mg = 0.1 g wetmass conversion

Constant fishing rate of cod and medium loads

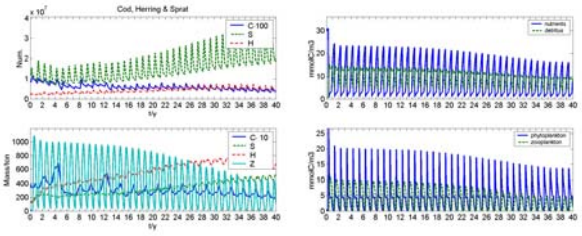
Mass balance, accumulated fish catches



Eutrophication approximately balanced by fisheries

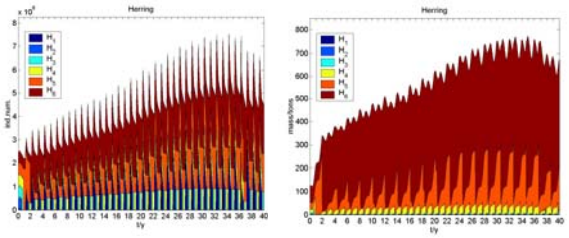
Conversion factor → 1mmolC/m³ =100 tons/km³

Fish and NPZD-part

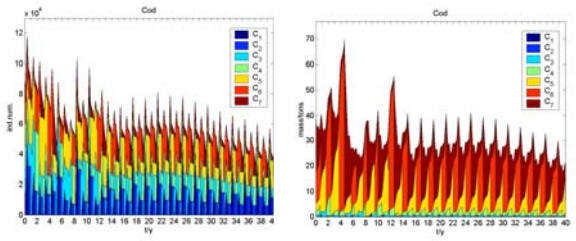


Cod stabilize while herring and sprat biomass grows,
NPZD part –indications of a cascade (?)

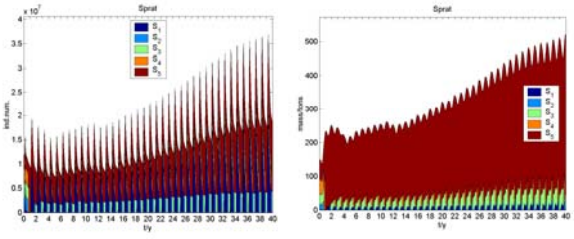
Herring mass classes: Abundance and biomass



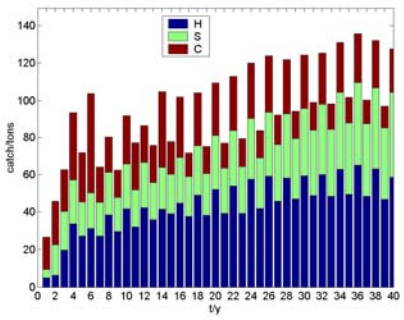
Cod mass classes: Abundance and biomass



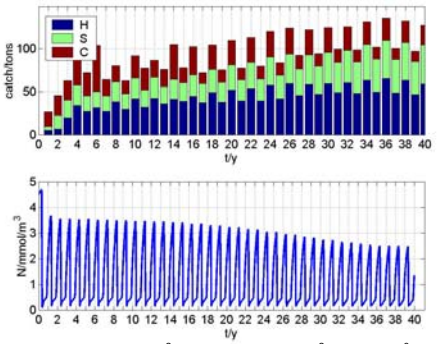
Cod mass classes: Abundance and biomass



Catches in tons/km^3 – Cod Herring and Sprat

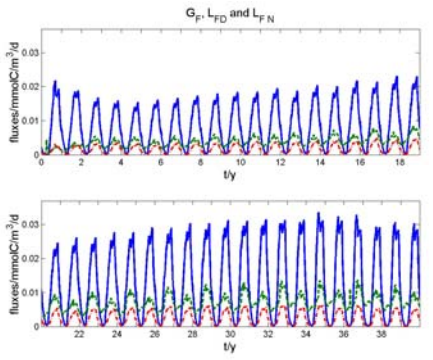


Order of magnitude is consistent !



Winter level of 3.5 mmolN/m^3 → catch 80 tons/km^3 → 1.04 10^6 tons
Winter level of 2.5 mmolN/m^3 → catch 100 tons/km^3 → 1.3 10^6 tons
(Volume of the central Baltic ~ 13 10^{3}km^3)

Fluxes between NPZD and fish model

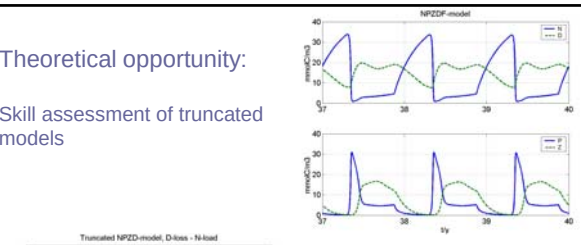


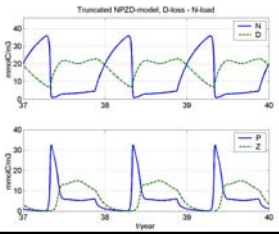
- G_F
- L_{FN}
- L_{FD}

Conversion factor → 1mmolC/m^3 =100 tons/km^3

Theoretical opportunity:

Skill assessment of truncated models





virtually identical results for:
N-load: dN/dt ~ 3 10^{-3} mmolC/m³/d,
l_Z = 2 10^{-4}/d, extra Z mortality, and
D-loss - flux into sediments:
dD/dt ~ - 1.25 10^{-3} mmolC/m³/d
or
extra Z-mortality,
l_Z = 4. 1 10^{-4}/d,
and no D-loss

Stamp:
Exp=30.15;
option_mort=1.1;
import_N=0.0063g/m³/d
(0.003 mmolC/m³/d),

Issues & challenges:

consolidation of parameter choices,

step by step increase of complexity of the NPZD component
- oxygen dynamics
- phytoplankton succession
- state resolved copepods

Higher resolution of reproduction processes (refine the off-spring approach)

Higher order interaction
- prey feed on predator eggs
- cannibalism

spatial explicit model
- migration from spawning to nursery region etc.
- behavior (forage, environmental preferences, etc)

New generations of marine ecosystem models

That integrate physics geochemistry and biology will be available within a few years

Prediction of future scenarios
→ Climate changes
→ Anthopogenic impacts (eutropication and fishery)

Thanks