Predictability of ecosystem dynamics:

models misbehave if they miss behavior

Kai Wirtz
modeling marine ecosystem response

nutrients $\rightarrow$ phytoplankton $\rightarrow$ zooplankton

vertical mixing

temperature
predictability of marine ecosystem response

decrease in Net Primary Productivity (NPP) under climate change

\[ \Delta \text{NPP} \] MPI-ESM RCP8.5 2085-1985

nutrients → phytoplankton →
vertical mixing

temperature

gC m\(^{-2}\) yr\(^{-1}\)

Wirtz, Mathis et al *Nature Clim Change*
Phytoplankton vertical migration

Nutrients → Phytoplankton → Behavior

Light

Vertical mixing
global NPP in a warmer future ocean

decrease by 8.5 Pg-C yr$^{-1}$
(classical models)

increase by 2.3 Pg-C yr$^{-1}$
to 58.4 Pg-C yr$^{-1}$

identically forced simulation incl.
phytoplankton vertical migration
difference: $70 \times$ C-emission of Germany

underestimation of Chlorophyll-a (chl) in shallow waters
nutrients → phytoplankton → zooplankton → small fish → large fish

light • turbidity

behavior

visual (fish) predation is limited by high turbidity
CHL accumulation in shallow coasts
due to behaviorally controlled trophic cascading

remote sensing

simulation without higher near-shore zooplankton mortality
(almost all ecosystem models)
less nutrients, less phytoplankton?

decrease in nutrients (de-eutrophication after mid 90s)

dissolved inorganic nitrogen

data (AWI, Wiltshire et al 2010)

classical models hindcast
lower NPP after 1996
(e.g. Daewel & Schrum 2013)

- 50% NPP & chl
The predictability of marine ecosystem response depends on the account of **behavior** in models.

**Diagram:**

- Nutrients $\rightarrow$ phytoplankton $\rightarrow$ zooplankton $\rightarrow$ small fish $\rightarrow$ large fish

- **Behavior:**
  - light • turbidity
  - temperature

- (fish) predation increases under higher temperature

**Graph:**

- **Temperature ($^{\circ}$C):**
- **Year:**

**Equation:**

- $y = 0.037x - 63.33$
- $R^2 = 0.4332$

**Source:**

- Wiltshire et al, EstCoasts 2010
climate change: thermally intensified trophic cascading in (most) near-shore waters

data (CPR, MBA-UK)

less nutrients, more phytoplankton ...

due to behaviorally controlled trophic cascading

Chl

nitrate

- 50%

+ 2°C

data (AWI, Wiltshire et al 2010)

Wirtz 2019, Xu et al 2020
Nutrients $\rightarrow$ Phytoplankton $\rightarrow$ Zooplankton

Behavior

NPZ $\rightarrow$ NPZB models
predictability in epidemiology and social sciences

SIR models revealed only short forecast horizons in the SARS-CoV-2 pandemics

SBIR model resolves changing societal response

Susceptible → Infected → Recovered

light

temperature

Behavior
mortality
(Germany)

forecast date
(for media)

data from CSSE Johns Hopkins U

SBIR model (setup in 2020)
mobility
(Germany)

relative to Feb (%)

Jun
Sep
Dec
Mar
Jun
Sep
Dec
Mar

model
data (from Apple)

Mar
2020
2021
2022

model
data (from Apple)

Mar
2020
2021
2022

model
data (from Apple)
model tested against diverse response patterns across many regions accessible through huge open data sets
socio/eco-system responses can be reasonably predicted when combining

- mechanistic models
- critical processes driving long-term dynamics (e.g., behavior)
- data for diverse response patterns from different environments

models can behave if they are trained and know about behaviour

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