Top-down control of biodiversity

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Phytoplankton diversity in ecosystem models

Ecosystem stability and functioning are influenced by community composition and biodiversity. Ecosystem models have tried to resolve diversity by including multiple nutrients and different phytoplankton functional types. These bottom-up approaches seem to considerably underestimate observed phytoplankton diversity. Here we investigate the effects of top-down control by zooplankton grazing on diversity.

Zooplankton grazing in models
- each zoo has a different preference for each phyto type (size, edibility, nutritional value, ...)
  a) constant preferences: independent of phyto type concentration (no switching)
  b) variable selectivity calculated from preferences and concentration: zoo prefer to graze most abundant types (active switching)
- experimental observations of active switching exist for microzooplankton and copepods
- our interpretation: switching as parameterization of the zooplankton community response:
  one resource type increases ⇒ predator specialized on that resource increases; and vice versa

The model

- Darwin & MITgcm 3D coupled physical-biogeochemical
- NPZD-type, 10 year simulations
- 78 phytoplankton types with random nutrient requirements, growth and sinking parameters
- 2 zooplankton (small & large) with type II grazing (saturates with phyto concentration P)
- self-assembling phytoplankton community

This study

- no switching vs. active switching
- low and high grazing rates I

NO3, PO4, Si, Fe
NO2, NH4

78 Phyto
diff. growth, sinking

2 Zoo
small & large

DOM   POM

export
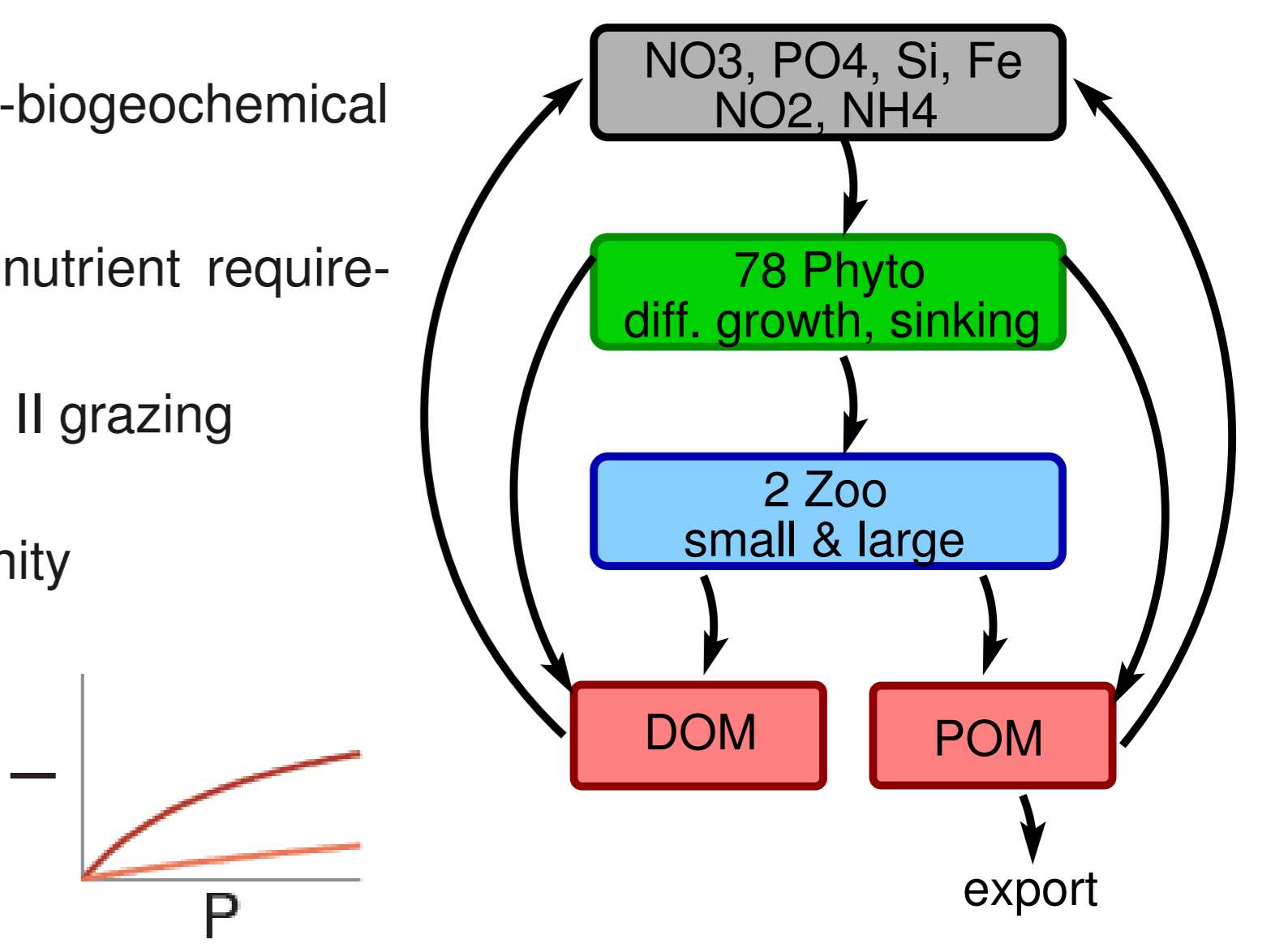
Predation increases diversity

- low grazing, no switching (LGNS; standard run):
  lower than observed diversity (see Simulations vs. Observations)
- with switching (LGAS):
  diversity increases by 82%
- high grazing, no switching (HGNS):
  diversity decreases
- high grazing and switching (HGAS):
  even larger diversity increase closer to observations

⇒ with switching, grazing pressure increases with concentration: stronger negative feedback by grazing than without switching (see Grazing pressure at right)

Annual average phytoplankton diversity (number of species above threshold concentration, 0-55 m) for low grazing & no switching (LGNS, standard run), low grazing & active switching (LGAS; star: NABE, dots: AMT), high grazing & no switching (HGNS), high grazing & active switching (HGAS).
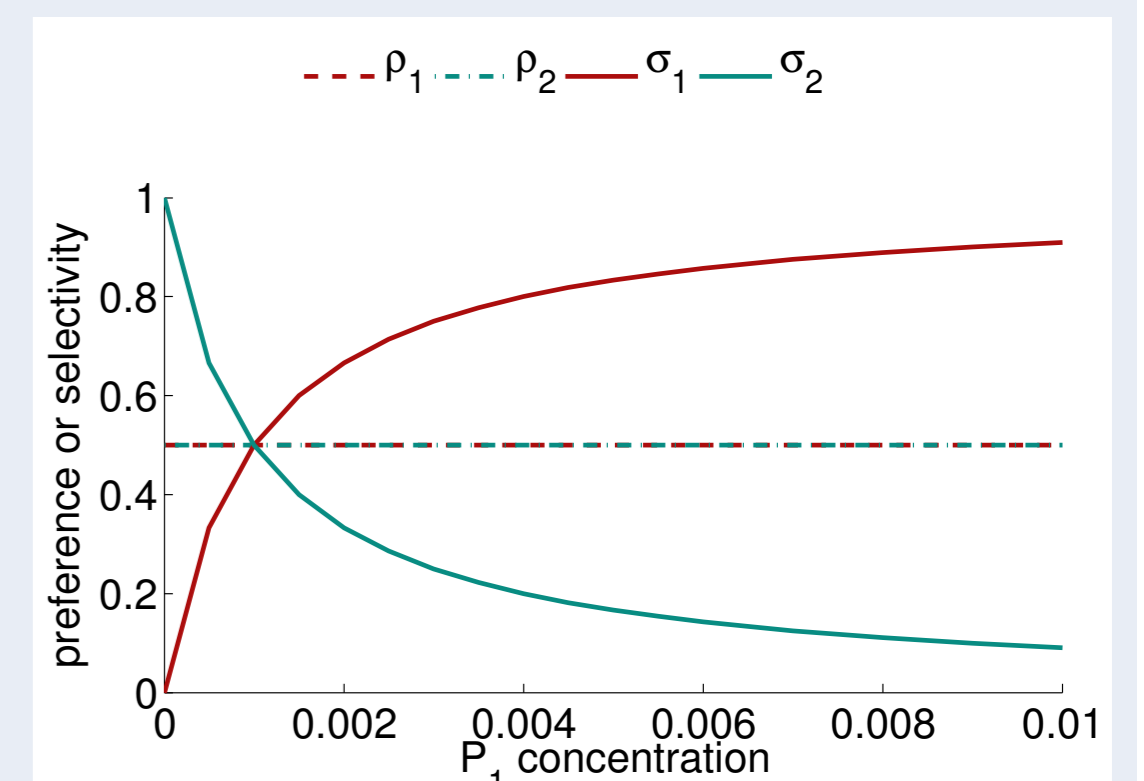

Phytoplankton diversity (number of species)

0 6 12 18 24 30 36 42 48 54
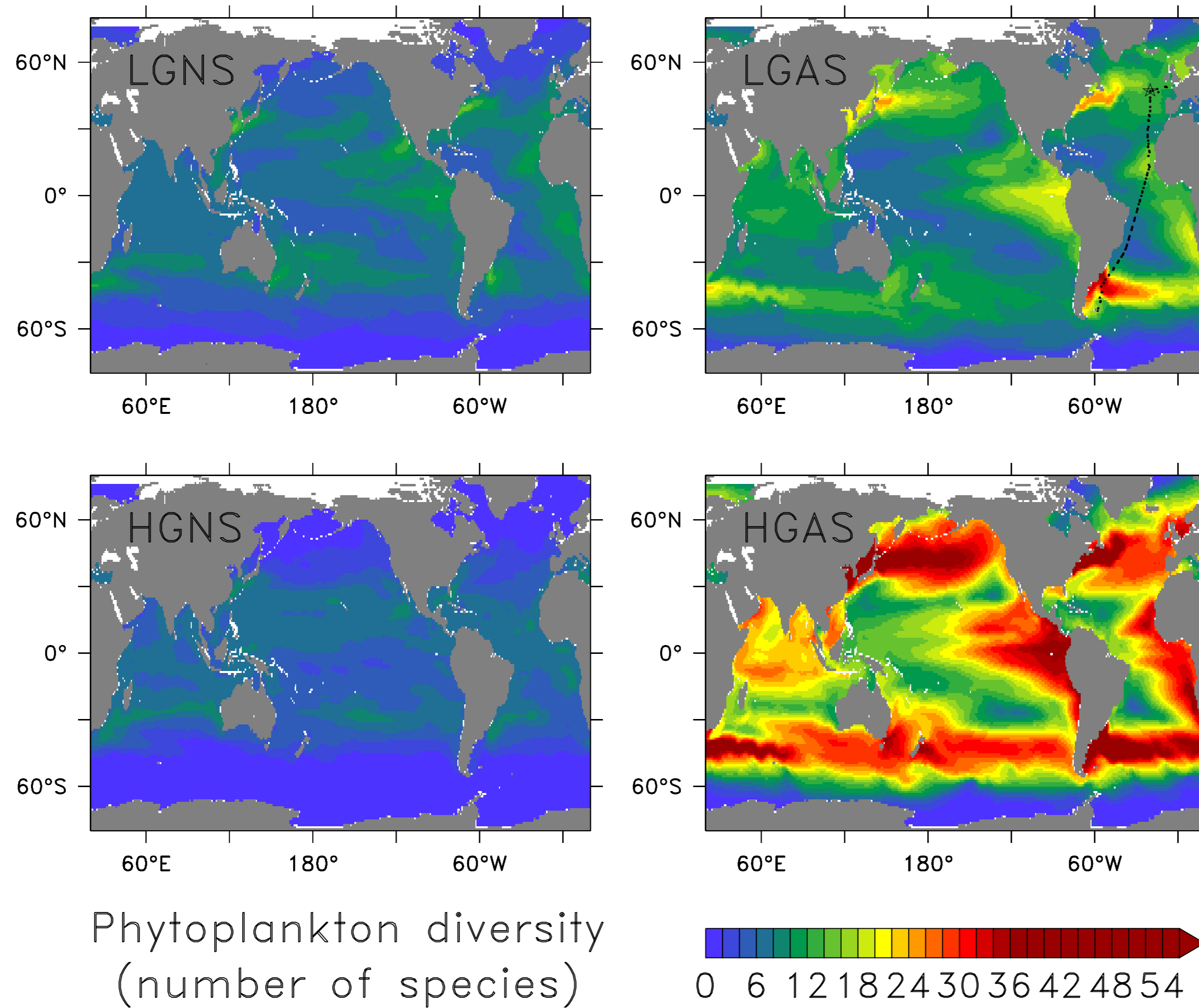
Grazing pressure in a 2-phytoplankton system

$r = 2$ phyto types with equal preferences: $\rho_1 = \rho_2 = 0.5$
concentrations phyto 1 (P_1) increases, phyto 2 (P_2) constant

Preference/selectivity
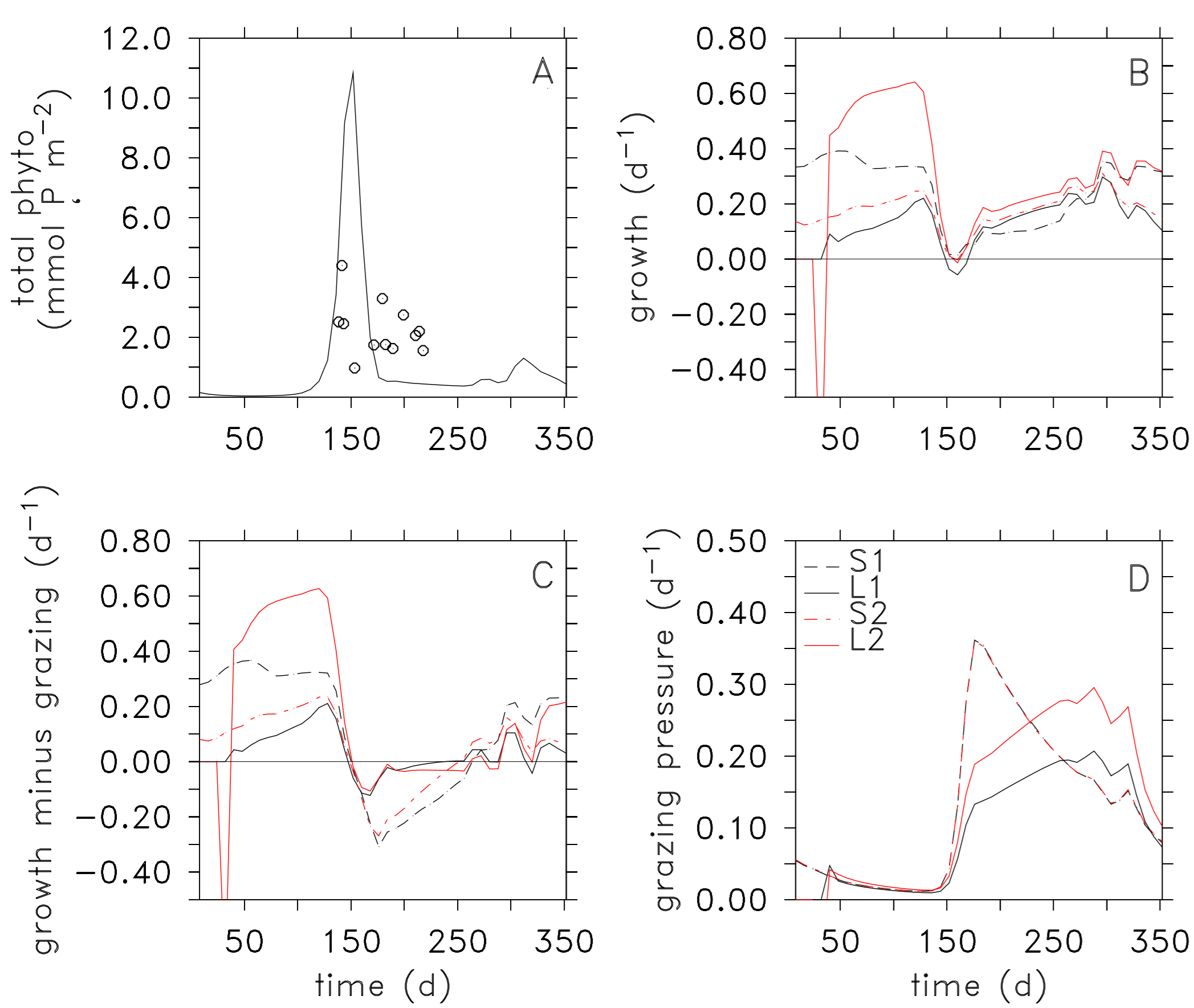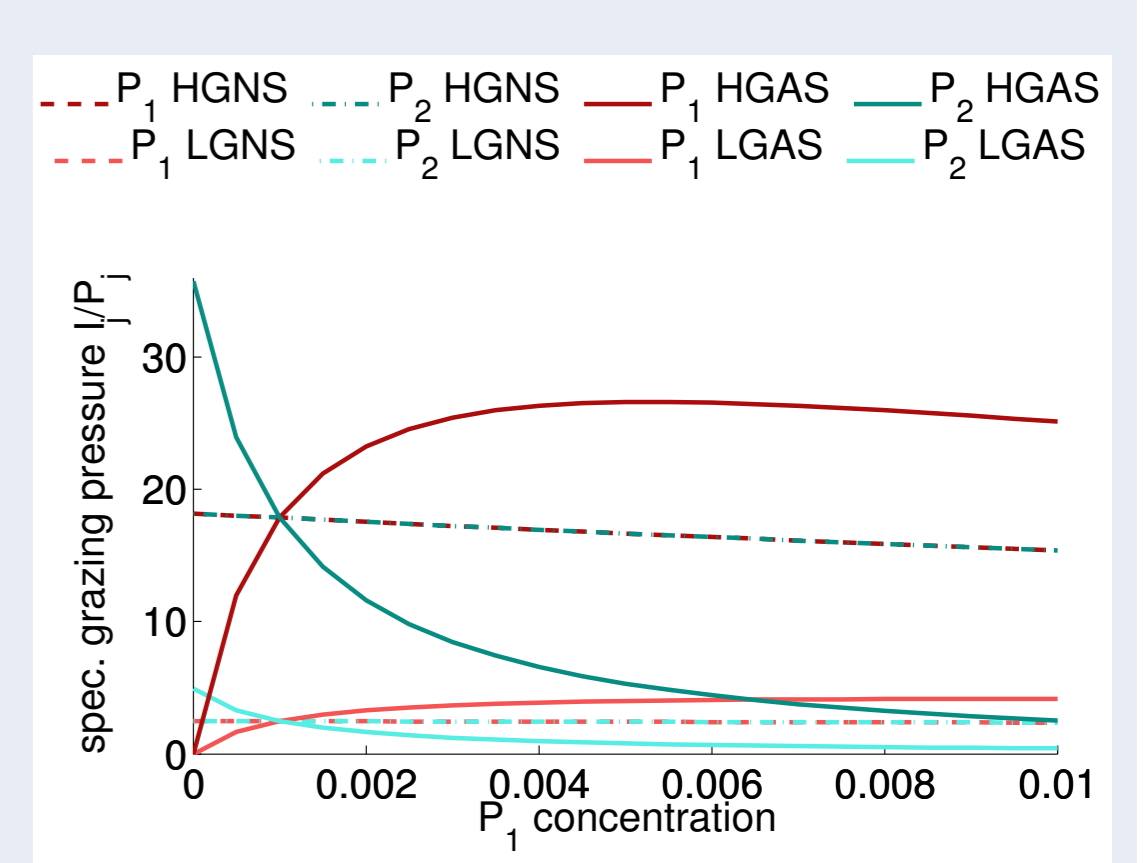- no switching:
  $\sigma_j = \rho_j = 0.5$, $j = 1, 2$
- switching: selectivity σ_j
  $\sigma_j = \frac{\rho_j P_j}{\sum_r \rho_r P_r}$
  increases for phyto 1
  decreases for phyto 2

Specific grazing pressure
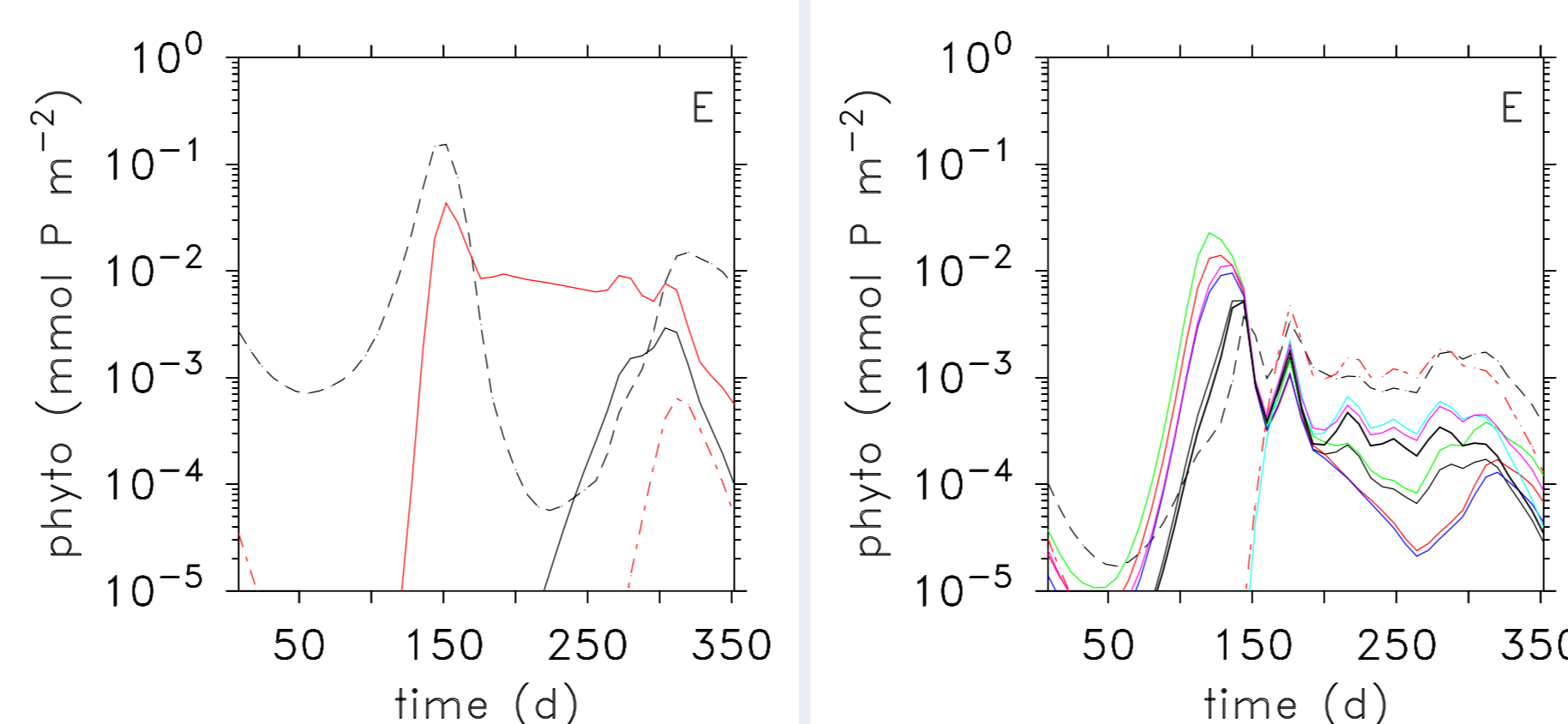$I_j/P_j = g_{max}\frac{\sigma_{jk}}{\kappa^r P + \sum_r \sigma_r P_r}$
- no switching:
  I/P decreases slightly for both phyto 1 and phyto 2
- switching:
  I/P increases for phyto 1, decreases for phyto 2
 ⇒ most abundant phyto type preferred

The seasonal cycle at NABE

no switching (LGNS)

switching (HGAS)

Phytoplankton dynamics at the North Atlantic Bloom Experiment (NABE) site for LGNS (left) and HGAS (right). (A) Average total phyto concentration (0-55 m) compared to observations (circles). Averages (0-55 m) for all phyto types present of (B) growth (nutrient uptake minus sinking minus mortality), (C) growth minus grazing, and (D) total grazing pressure by both zoo types, (E) concentration.

- 1 bloom peak instead of 2 observed (A) with 1 large (L2) and 1 small (S1) phyto type
- types with highest growth (B) and winter biomass (E) dominate
- grazing pressure between types differs only in magnitude (different, but constant preferences), increases simultaneously for all types (D)
- thus growth minus grazing also decreases simultaneously (C)

- 2 bloom peaks as in the observations (A), with high diversity (E)
- growth minus grazing decreases at different times for phyto types of 1. and 2. peak (C)
- types with high growth (B) and high winter biomass (E) dominate 1. peak
- types with low growth (B) and lower grazing pressure than other types form 2. peak
⇒ phytoplankton succession
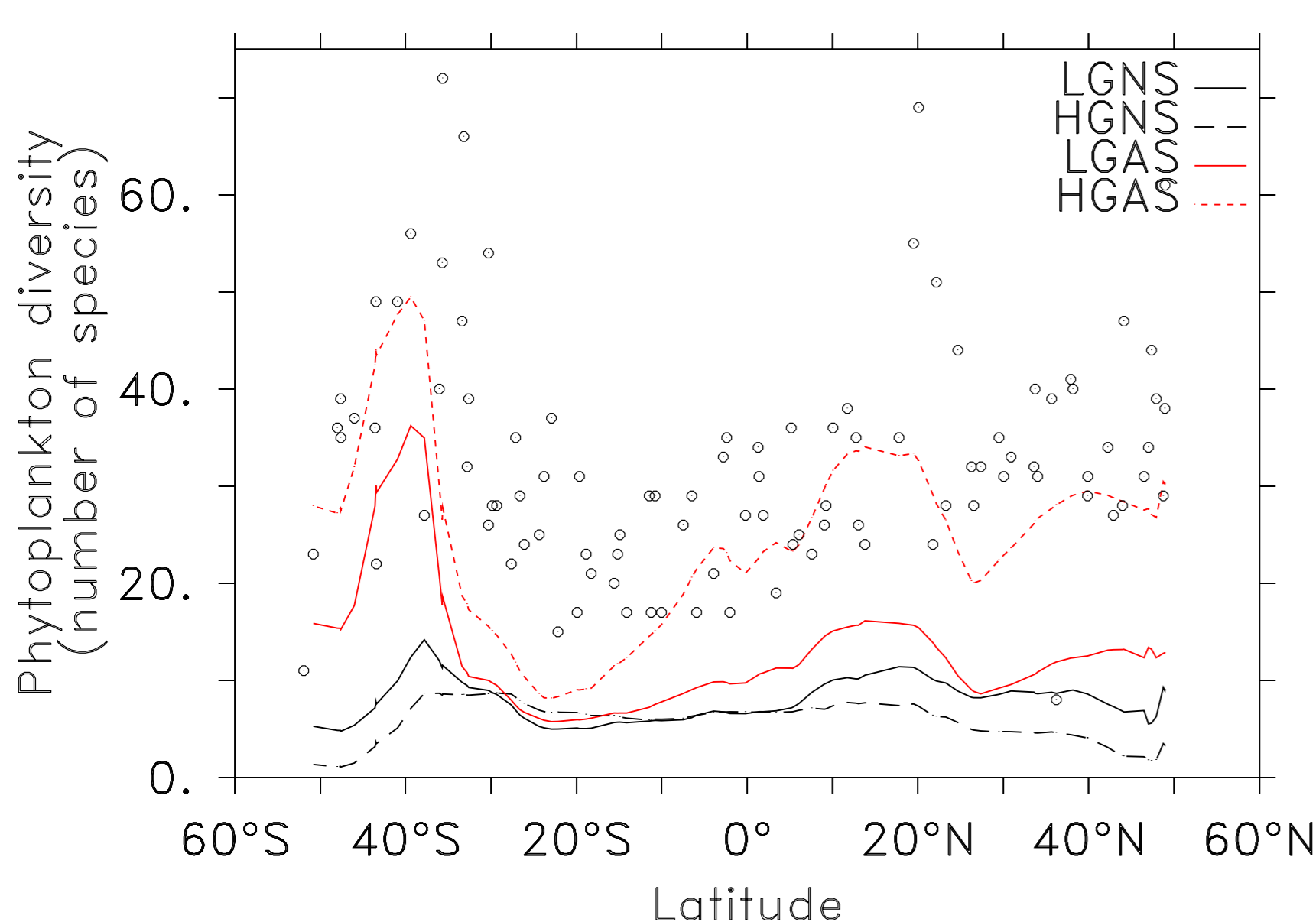
Simulations vs. Observations along the AMT

- observations: highest diversity at mid latitudes
- LGAS, HGAS: diversity pattern: maximum at mid latitudes, lower at low/high latitudes
- LGNS, HGNS: diversity pattern less pronounced
⇒ results with switching (LGAS, HGAS) fit the observed range and latitudinal pattern better than with no switching (LGNS, HGNS)

Simulated annual average diversity (number of species) in the surface layer along the Atlantic Meridional Transect (AMT) compared to observations (circles; Cermeño et al. 2008) for LGNS, HGNS, LGAS and HGAS.

Summary & Outlook

Effects of predation on phytoplankton diversity in ecosystem models:
- predation increases diversity when a zooplankton community response is included e.g. by active switching (zooplankton have variable, concentration-dependent selectivity for different phyto types)

With switching:
- simulated diversity agrees better with observed latitudinal diversity pattern
- more realistic bloom dynamics at NABE
- succession and coexistence of different phyto types

What's next:
assess the role of phytoplankton diversity for the functioning of the marine ecosystem under environmental change