On Adding a Stage-Structured Model of Krill to NEMURO

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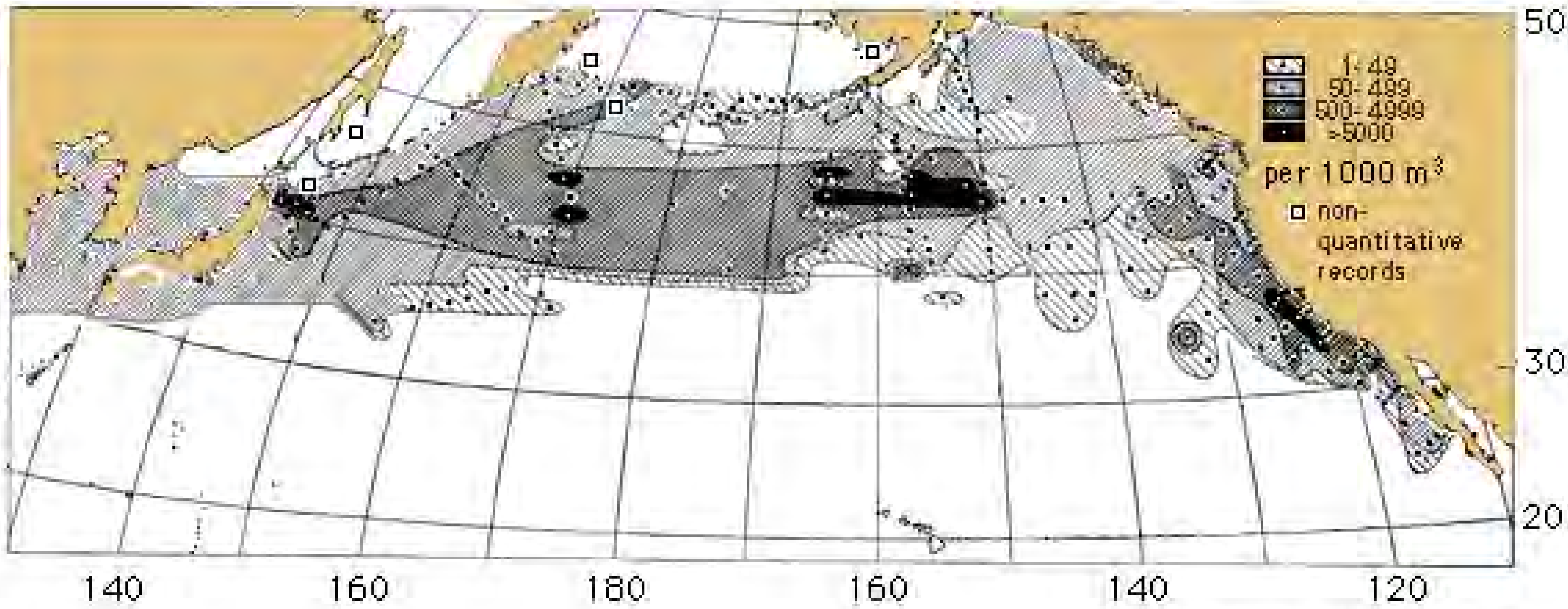
Euphausia pacifica



- Distributed around Pacific Rim and across open ocean
- Occupies a broad variety of habitats from cold subarctic waters to warm subtropical waters.
- A key species in food chains as grazer and prey for commercially-important fishes, as well as many birds and mammal species.
- How might climate change affect distribution, population dynamics and production of this species in different regions of the Pacific?

PICES FUTURE is interested in forecasts.

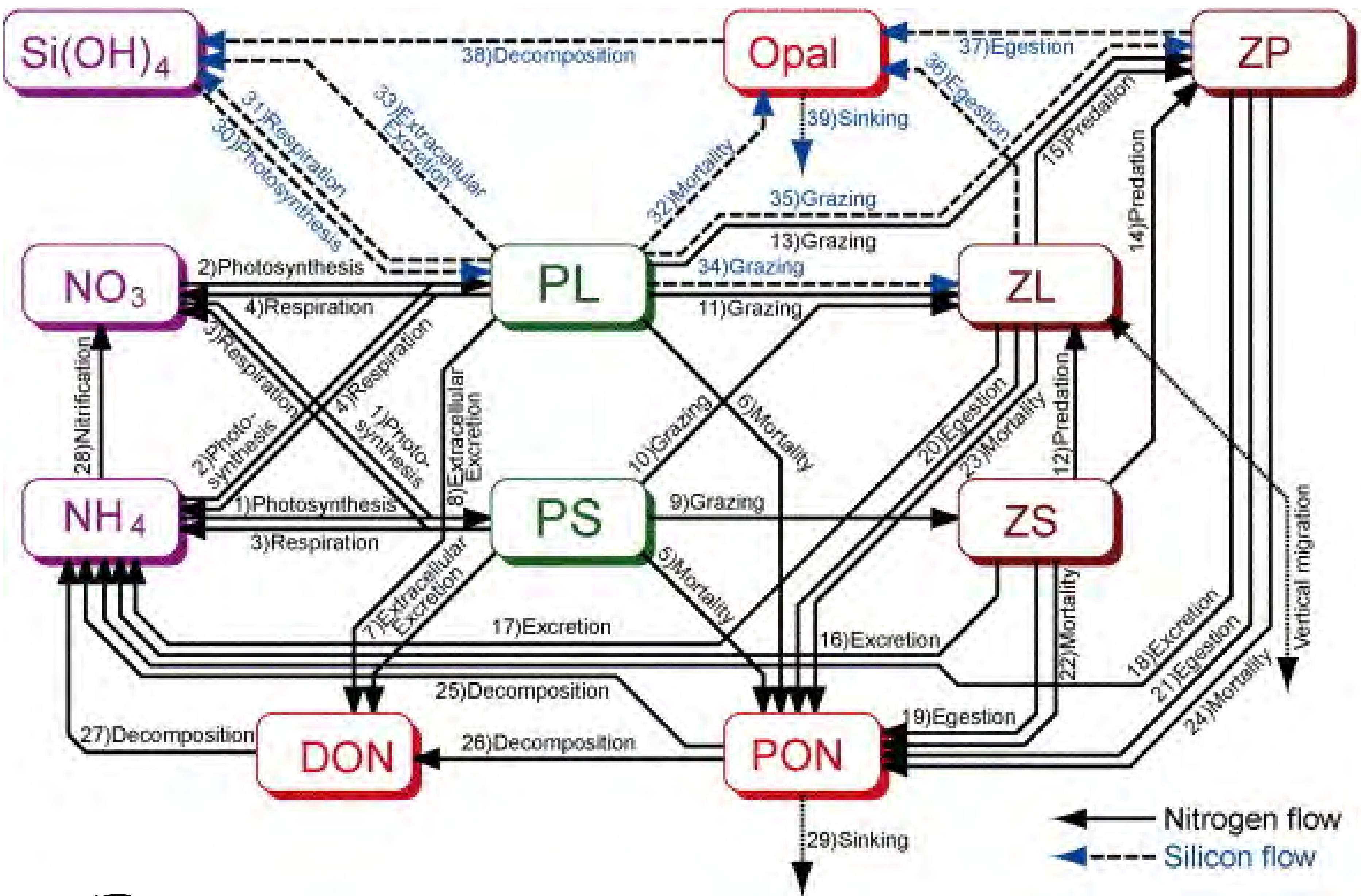
Wolfgang Fennel summarized models in the HAB topic session yesterday.

1) Forecasts means <u>models</u>.
2) "Start with simple toy models. Then move to full 3D models."

The model shown here is a toy model (0-D).

Continuous Distributions or IBMs?

Depends on the question.



NEMURO

Kishi et al. (2007; EcMod)

SOME BIOMASS

Vitals:
320 lbs, 7’6”;

Vitals:
320 lbs, 7’6”;

MORE BIOMASS

Vitals:
~320 lbs,

Vitals:
320 lbs, 7’6”;

$\stackrel{?}{=}$

Vitals:
~320 lbs,

Smaller Organisms have

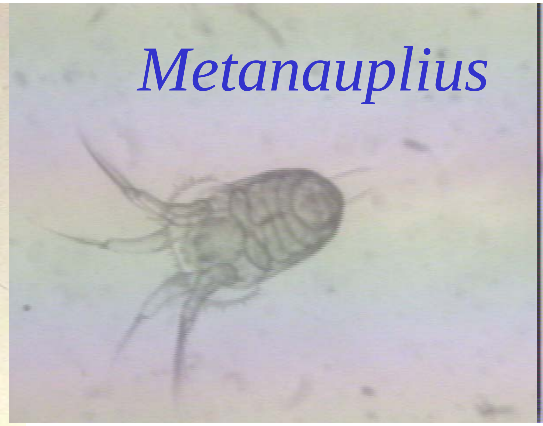
1) Higher weight specific rates (feeding, respiration, growth)
2) Different allocation to growth, maintenance and reproduction.
3) Consume different types of prey
4) Different active behaviors (migrations and movements)

than Larger Organisms

Vitals:
320 lbs, 7’6”;

Individual Size Matters!

Euphausia pacifica life stages



In Zooplankton, Individual Size

- Impacts preferred prey type (abundance/size)
- Impacts growth rate
- Impacts size-dependent mortality
- Impacts behavior
- Impacts internal pools (lipid reserves)

Stage-specific CW

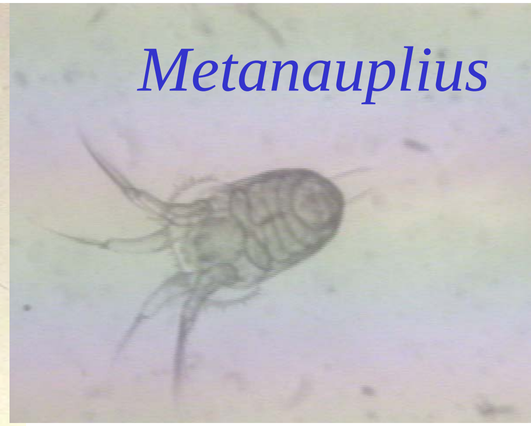
Euphausia pacifica life stages

N2

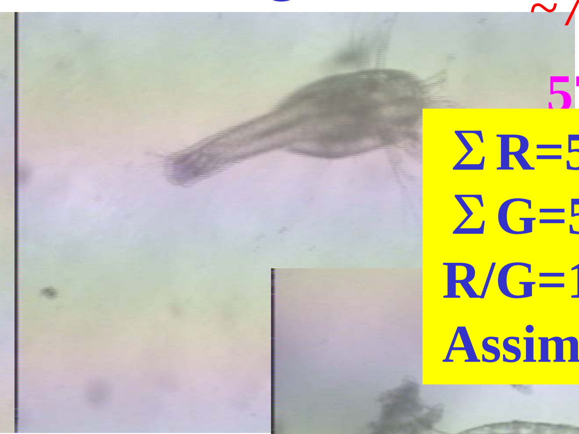
~3.2 μg ind^{-1}

1250 indiv.

Σ R=633.6 ug C d^{-1}
Σ G=425 ug C d^{-1} R/G=1.5
Assim/Wt=0.26



Metanauplius



~7 μg ind^{-1}

571 indiv.

Σ R=529.2 ug C d^{-1}
Σ G=519.6 ug C d^{-1}
R/G=1
Assim/Wt=0.26

Σ R=122.9 ug C d^{-1}
Σ G=26 ug C d^{-1} R/G=4.7
Assim/Wt=0.04

~4000 μg ind^{-1}

1 indiv.

Advantages of IBMs

1) Biology is often mechanistically explicit. (not hidden in differential equations).
2) Biological-Physical-Chemical Interactions are clearly detailed.
3) Individual is the fundamental biological unit, thus it is natural and intuitive to model at that level, rather than at the population level.
4) Allows explicit inclusion of an individual's history and behavior.
5) History-Spatial Heterogeneity interactions '*easily*' handled.

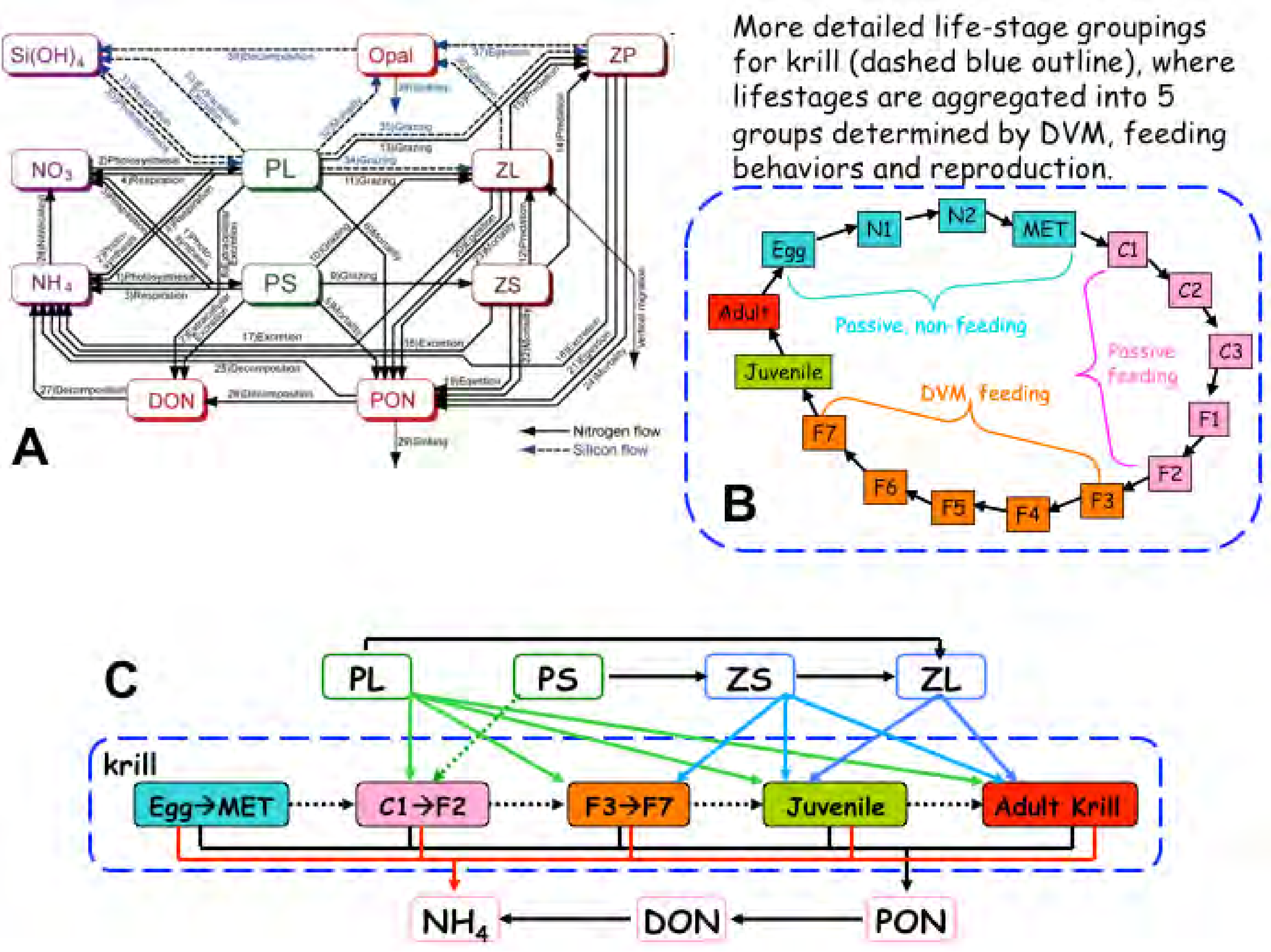
Costs Involved in IBM Approach

1) Difficult to implement feedback from IBM (Lagrangian) to underlying Eulerian model, esp. across multiple trophic levels
2) Requirement for Large Numbers of Particles
   - Difficult to simulate realistic abundances
3) Difficult (Impossible?) to simulate density dependence
4) Extensive Computation Penalty

For many research questions, we can live with these problems (or work around them).

But, when considering future climate change scenarios and responses of ecosystem structure and function, it is difficult to ignore biomass density (concentration).

Consequently, the dominance of Eulerian concentration based models in climate scenario assessment.


More detailed life-stage groupings for krill (dashed blue outline), where lifestages are aggregated into 5 groups determined by DVM, feeding behaviors and reproduction.
A
Si(OH)4
Opal
ZP
NO3
PL
ZL
NH4
PS
ZS
DON
PON
Nitrogen flow
Silicon flow
B
Egg
N1
N2
MET
C1
C2
C3
F1
F2
F3
F4
F5
F6
F7
Juvenile
Adult
Passive, non-feeding
Passive feeding
DVM, feeding
C
PL
PS
ZS
ZL
krill
Egg→MET
C1→F2
F3→F7
Juvenile
Adult Krill
NH4
DON
PON

A Stage Progression Model

E. pacifica Belehradek function for time to stage as function of temperature

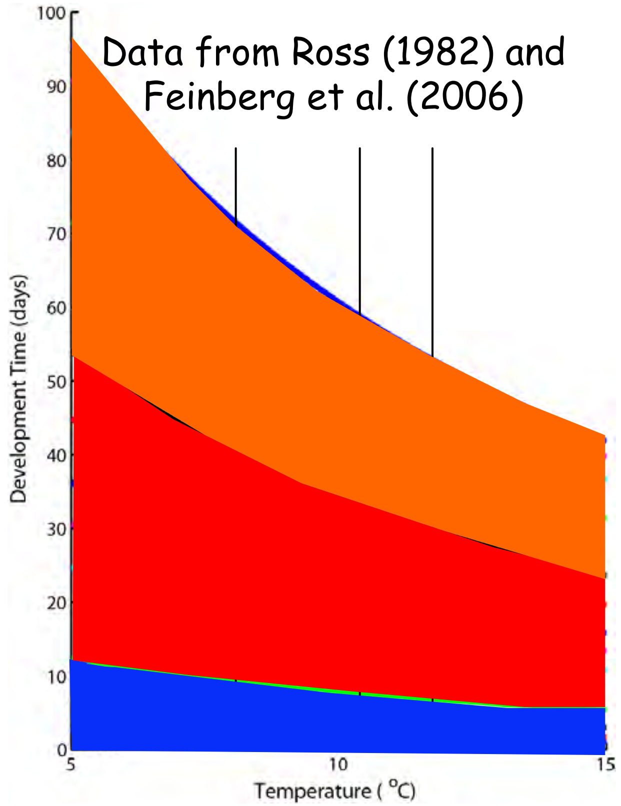
Basic Form is: $D_i = a_i (T + b)^c$

D_i is the time (days) from egg to stage i

a_i is a stage specific constant

b is a stage-independent shift in temperature

c is assumed to be -2.05 (commonly observed from experiments; determines the curvature)

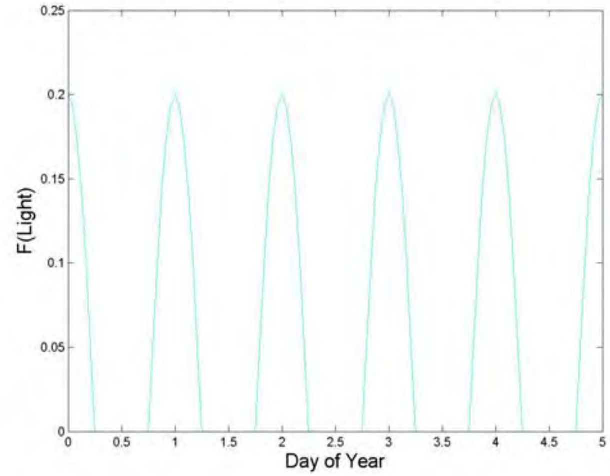


$MR_i = 1/[a_i (T + b)^c]$ ➔ Leads to numerical diffusion

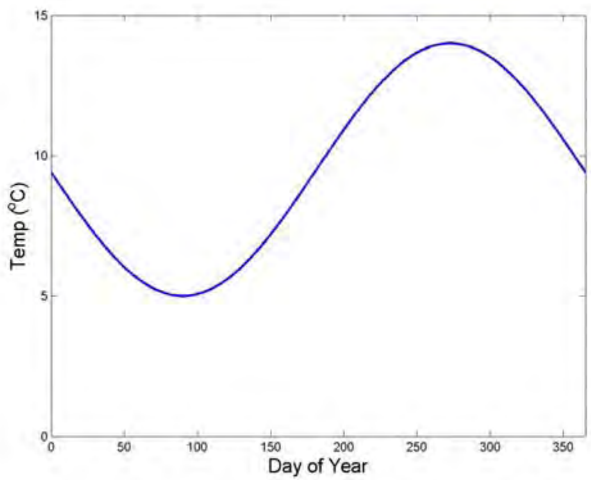
$MR\text{-}corr_i$ based on Hu et al. (2008; MEPS) algorithm that uses mean age of $state_i$ and a probability density function of transfer.

External Forcing

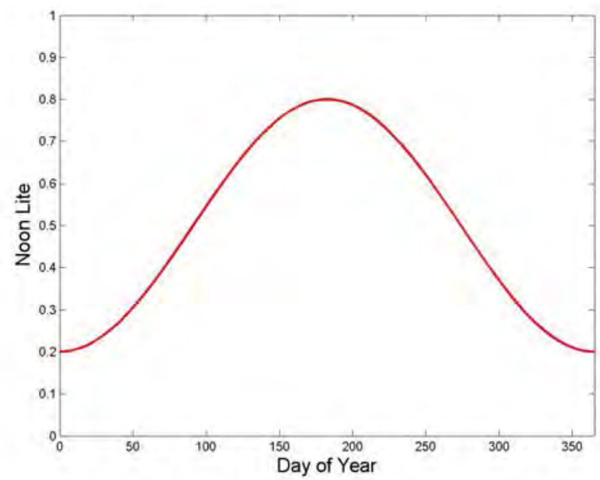
Diurnal Light Cycle

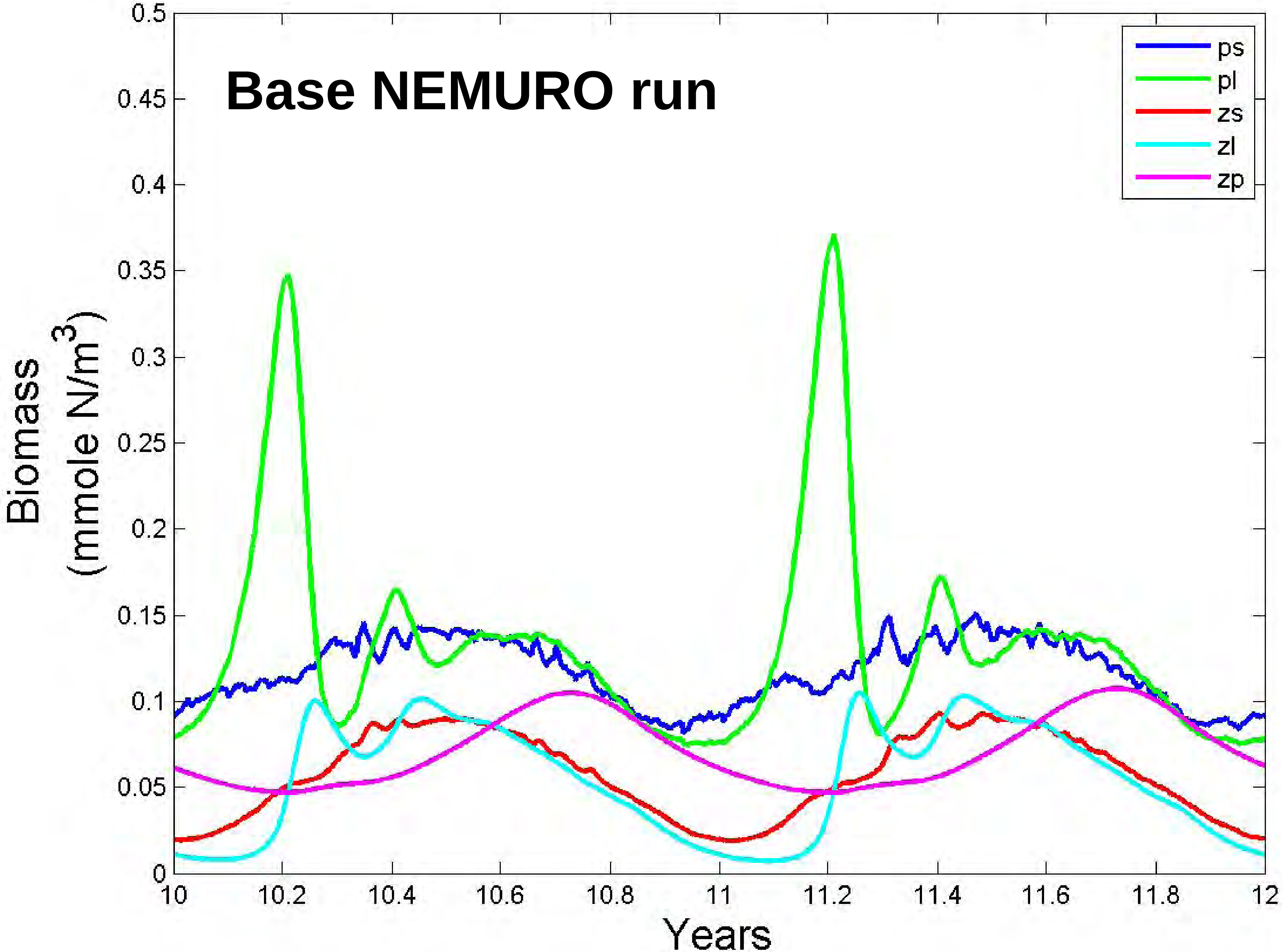


Annual Temp Cycle

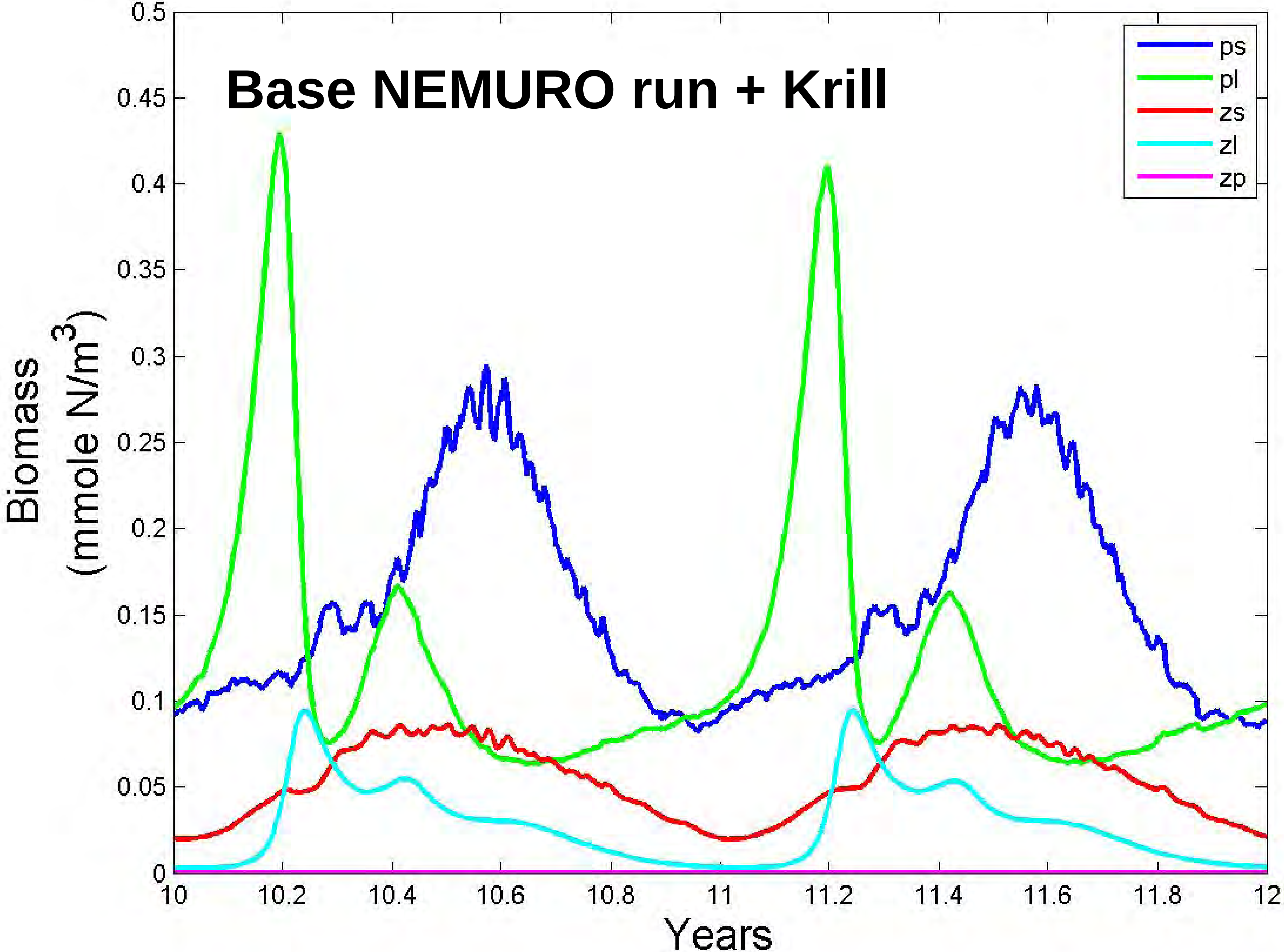


Annual Light Cycle

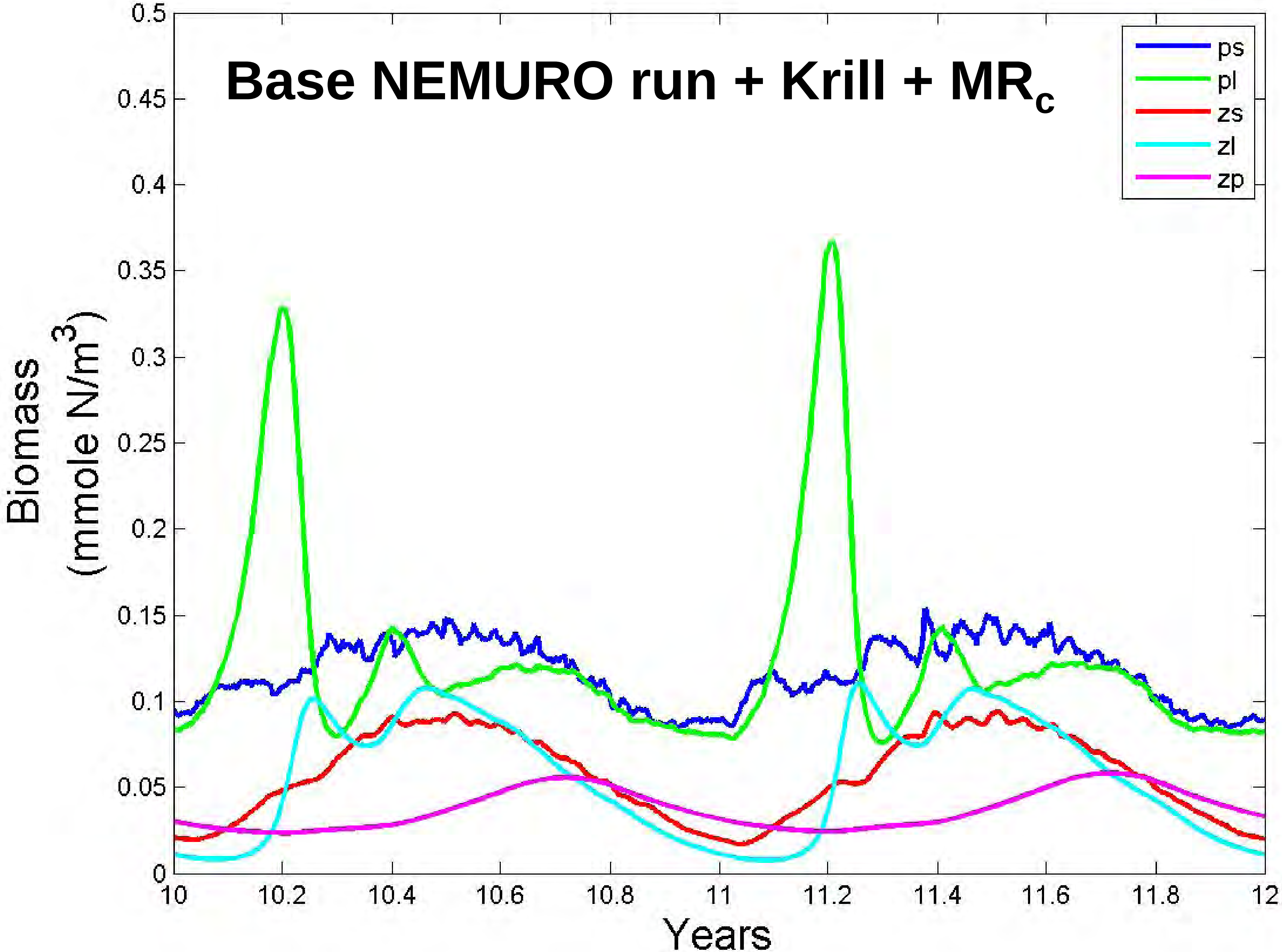




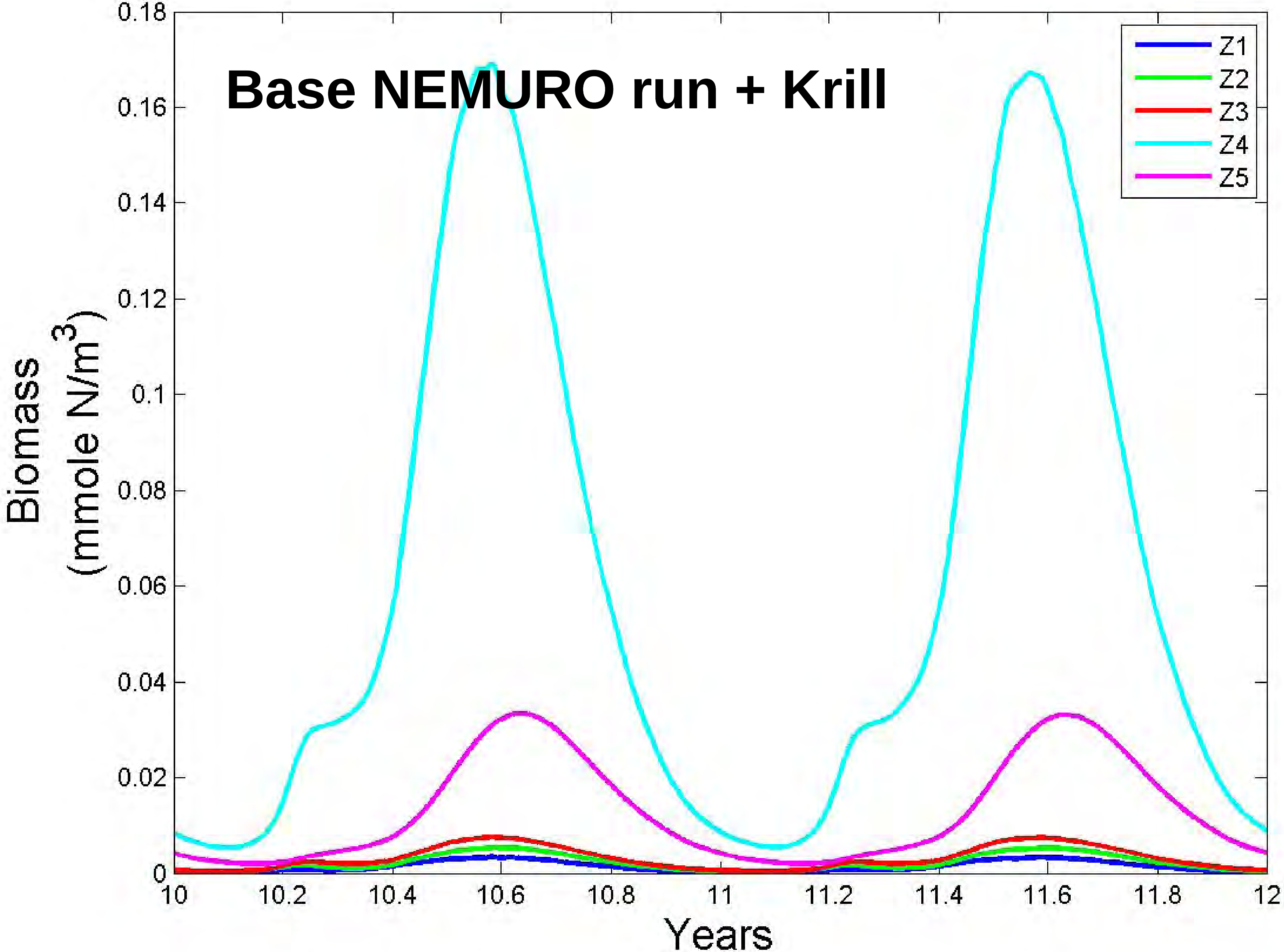
Base NEMURO run
ps
pl
zs
zl
zp
Biomass (mmole N/m3)
Years
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
10
10.2
10.4
10.6
10.8
11
11.2
11.4
11.6
11.8
12



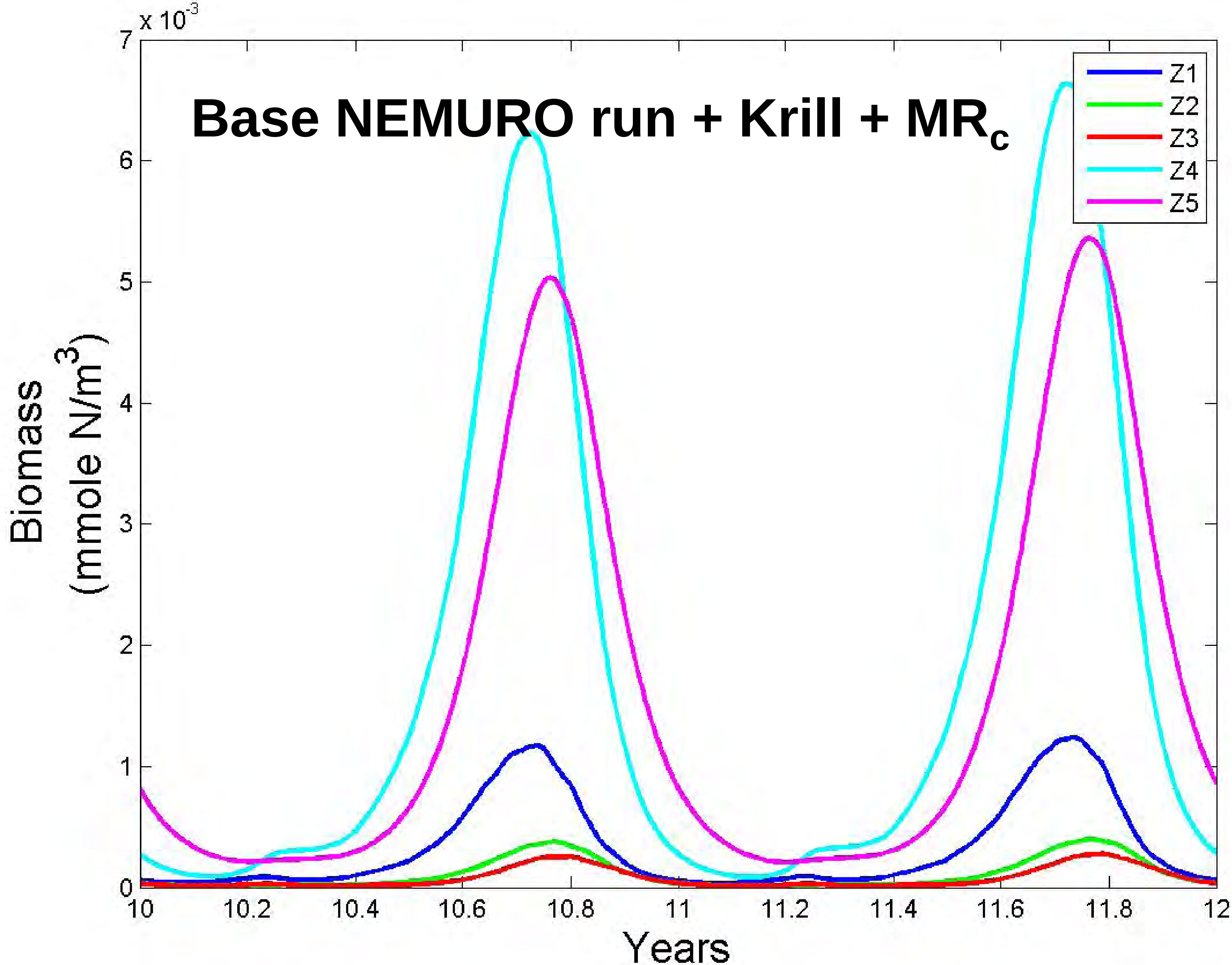
Base NEMURO run + Krill
Biomass
(mmole N/m3)
Years
ps
pl
zs
zl
zp
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
10
10.2
10.4
10.6
10.8
11
11.2
11.4
11.6
11.8
12



Base NEMURO run + Krill + MR$_c$
ps
pl
zs
zl
zp
Biomass
(mmole N/m^3)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
10
10.2
10.4
10.6
10.8
11
11.2
11.4
11.6
11.8
12
Years

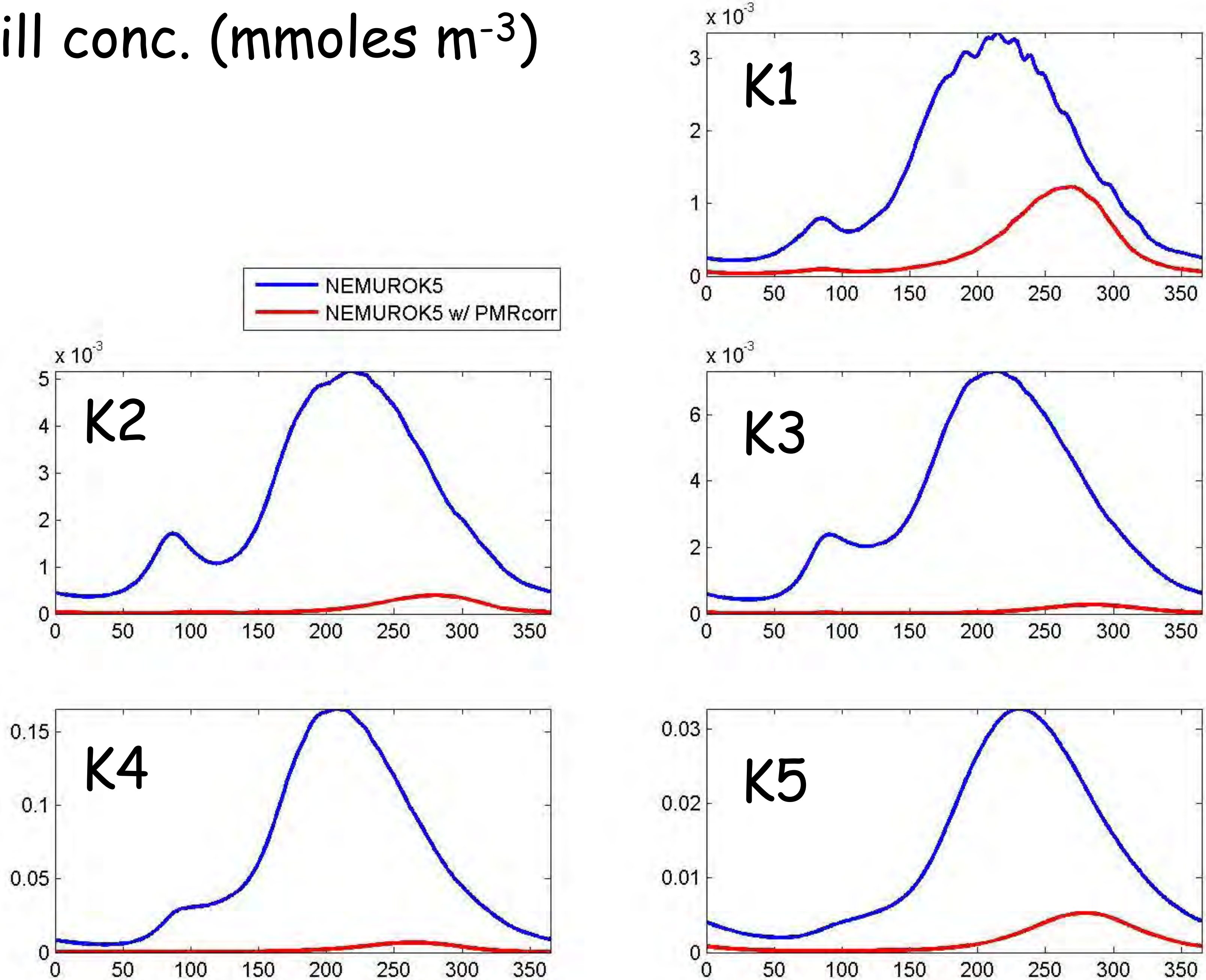


Base NEMURO run + Krill
Z1
Z2
Z3
Z4
Z5
Biomass
(mmole N/m3)
Years
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
10
10.2
10.4
10.6
10.8
11
11.2
11.4
11.6
11.8
12

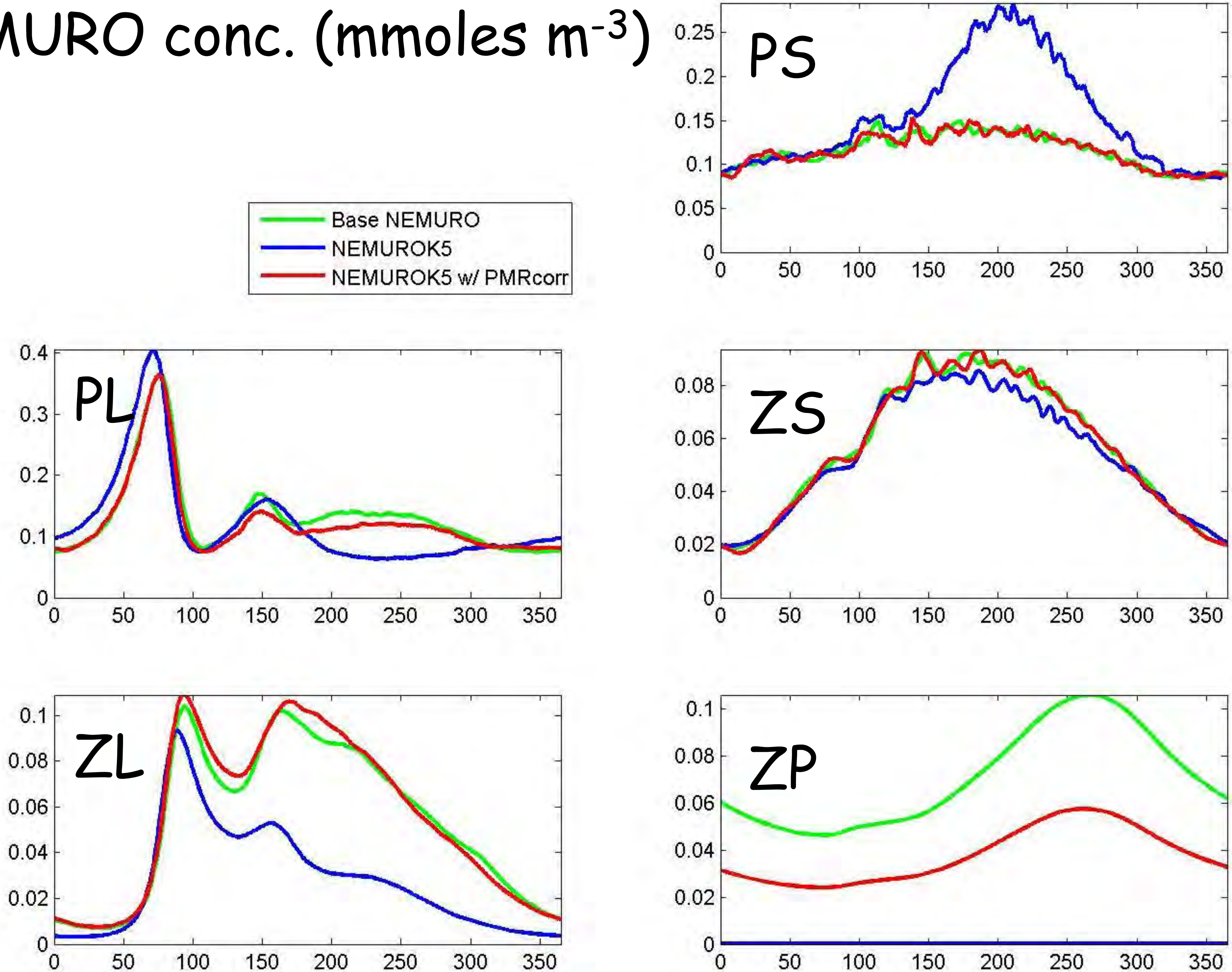


Base NEMURO run + Krill + MR_c
x 10^-3
7
6
5
4
3
2
1
0
Biomass
(mmole N/m^3)
10
10.2
10.4
10.6
10.8
11
11.2
11.4
11.6
11.8
12
Years
Z1
Z2
Z3
Z4
Z5

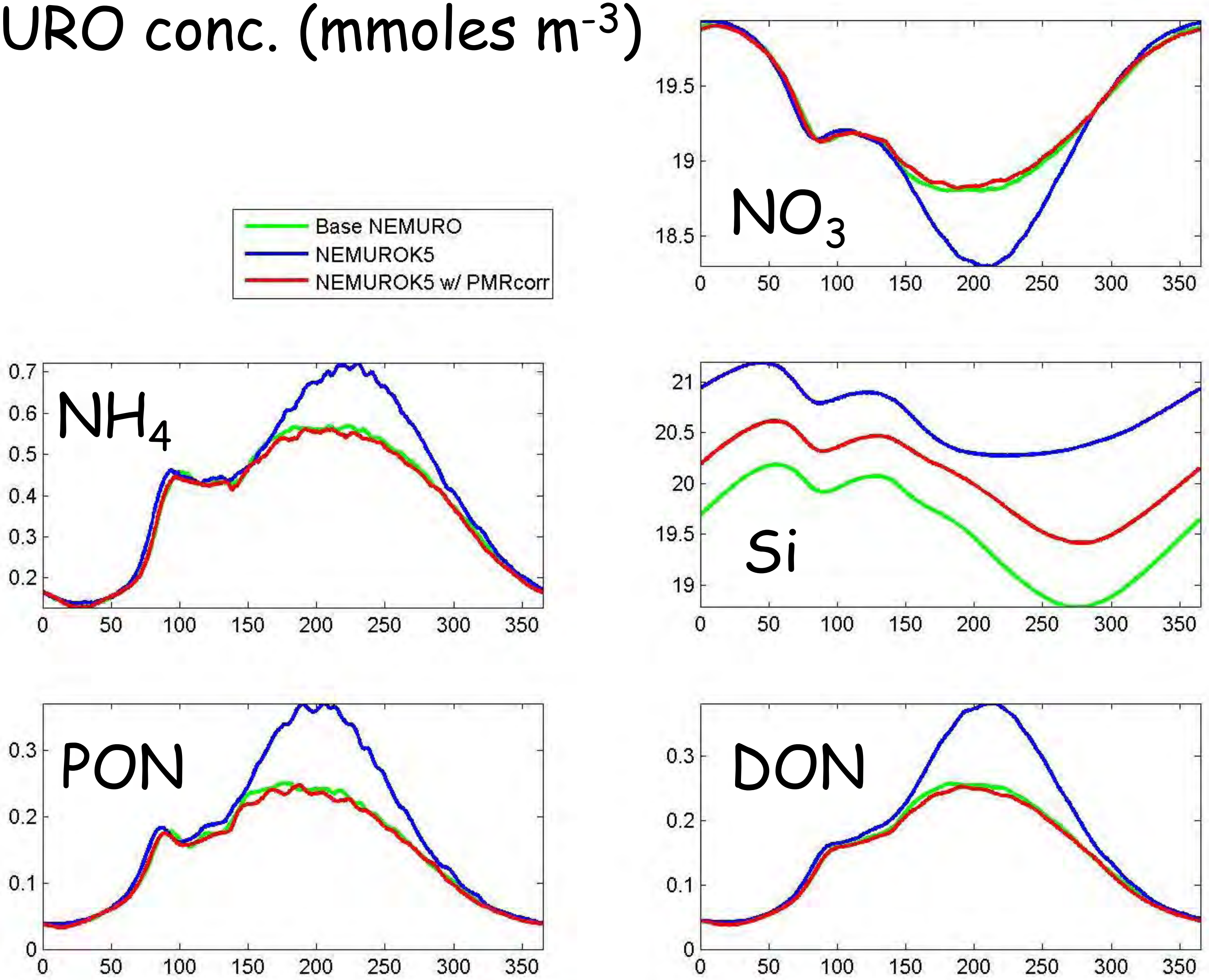
Krill conc. (mmoles m^{-3})



NEMURO conc. (mmoles m^{-3})



NEMURO conc. (mmoles m^{-3})



Summary & Preliminary Findings

1) Adding krill to NEMURO decreases ZL and ZP, the latter to extinction, and increases PS (through a trophic cascade).

2) Adding krill+MRc reduces ZP by about 50% from the base NEMURO, but has little effect on other Z's and P's in NEMURO.

3) The ZP reduction (krill+MRc) or extinction (krill) must be occurring through competition, since no life stage of krill feeds directly upon ZP.

4) Krill concentrations with MRc are much lower (~5%) of concentrations in the krill model w/o MRc. Delayed transfer from young stages of krill to older stages exposes krill to the higher mortality rates of the younger stages for a long time.

5) Timing of peak krill biomass is delayed by ~60 days in simulations with the MRc.

6) The mean age & concentration approach of Hu et al. (2008) can be applied to molting of krill in Eulerian models, and will have value also for implementing DVM behaviors (swimming speeds) in Eulerian models.

THE END