Responses to climate change of coupled 1-D mixed layer / planktonic ecosystem models

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Introduction

How marine planktonic ecosystems might respond to a changing climate is important to the carbon cycle because marine plankton affect the transformations and transport of carbon between the surface ocean and the ocean interior, thereby influencing atmospheric CO_2 concentrations. We have conducted simulations of two possible changes associated with the climate: increasing ocean temperatures by 2°C, and changing the supply of iron to phytoplankton in the subarctic Pacific. The simulations have been performed with a series of 1-dimensional mixed layer / planktonic ecosystem models of increasing complexity.

A four-component ecosystem model has been coupled to a 1-dimensional mixed layer model (Mellor-Yamada level 2.5). The ecosystem model contained dissolved inorganic nitrogen ***N***, phytoplankton ***P*,** microzooplankton ***Z***, and sinking organic particles ***D***. Iron limitation was formulated as a simple constant limiting factor on maximum uptake. The model was run with annual wind and solar heating from Ocean Station P (50°N, 145°W) and has been evaluated against extensive observations (*Denman, 1997; Denman, Peña & Haigh*, *1998*; *Denman & Peña, 1999*). For these simulations, the model was modified such that all growth, grazing and mortality rates were made temperature-dependent according to Q_{10} factors: e.g. for maximum phytoplankton growth rate $\mathbf{n_m}$, at temperature ***T+DT***,

$$\mathbf{n_m}(T+DT) = \mathbf{n_m}(T)\, Q_{10}^{\,0.1DT}$$

Q_{10} was set to 2 for phytoplankton (*Eppley, 1972)*, and 3 for microzooplankton (*Huntley and Lopez, 1992)*. In the model the action of bacteria is represented through the remineralization flux and we set the Q_{10} for bacteria to 3, although there is a broad range (at least 1 - 10) in the published literature.. Two climate change simulations were run: a warming run with a 2°C temperature offset; and a run with iron limitation removed. We used the same values for the model parameters as in the standard 'iron limitation' simulation in *Denman and Peña, 1999.* In the simulation where iron limitation was removed, we increased the nitrogen input at the bottom of the model domain (simulating Ekman upwelling) to maintain a repeating annual cycle in ***N***.

Results from the Standard Model

In the warming run (2°C offset), only small changes were observed: biomass of ***P, Z*** and ***D*** changed by less than 10%, recycling increased by 25% because of the higher Q_{10}

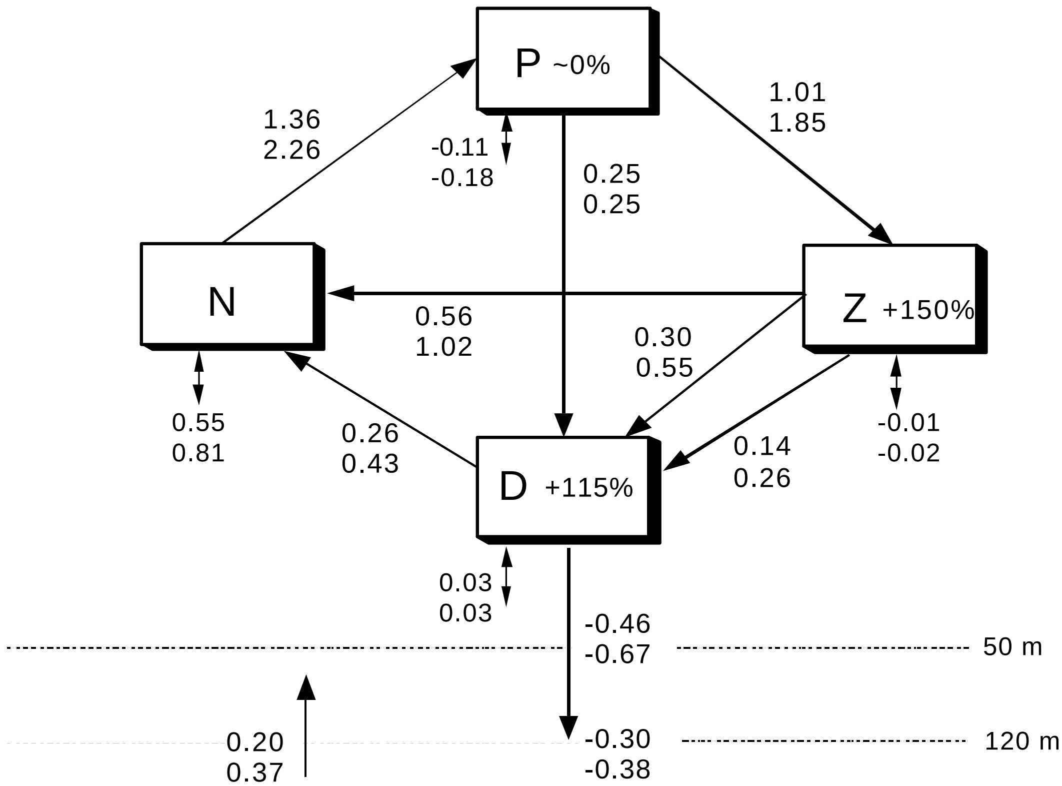


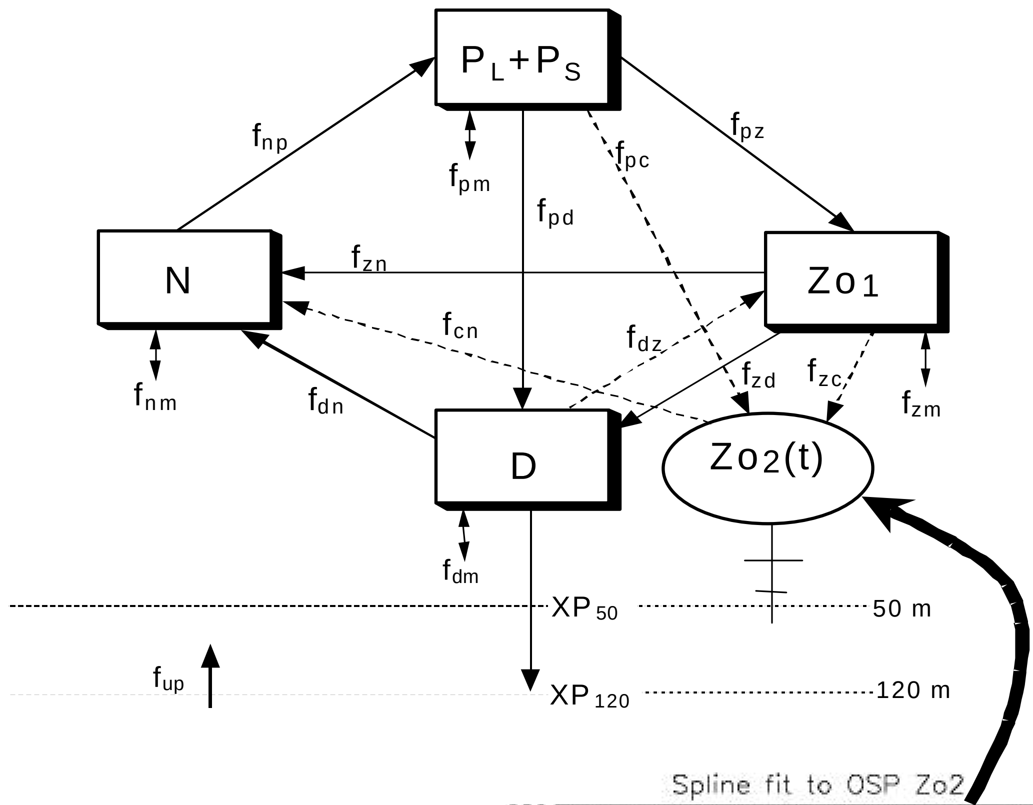
Figure 1. Results of the simulation removing iron limitation in the 'Standard Model'. Annual fluxes are in units of mol-N m^{-2} y^{-1}. Upper numbers represent the original iron limited simulation, lower numbers represent the simulation without iron limitation. Percent changes in pool sizes (*P*, *Z*, and *D*) are for time of summer zooplankton maximum.

for bacteria/remineralization, and export flux of ***D*** decreased by 13%. However, the simulation removing iron limitation produced significant changes (Figure 1). In particular, primary production increased by 66%, ***Z*** by 150% and ***D*** by 115%, remineralization by 65%, and export flux by 27%. The observation, that the annual cycle in phytoplankton biomass remained unchanged while zooplankton increased maximum biomass by 150%, was also found in an earlier version of this model (*Denman, Peña and Haigh, 1998*) with two different formulations of the mortality of the microzooplankton. The obvious question then is the following: Are these results robust to changes in the ecosystem model structure?

In the following section, we show results from an enhanced ecosystem model that we believe is a more realistic representation of the planktonic ecosystem in the subarctic NE Pacific Ocean.

An Enhanced Ecosystem Model

We made the following changes to the ecosystem model (shown schematically in Figure 2):



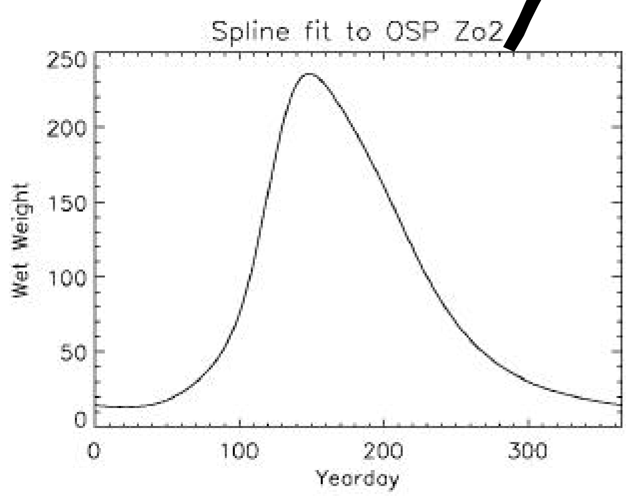


Figure 2. Schematic of the 'enhanced ecosystem model'. Phytoplankton are partitioned into large $\boldsymbol{P_L}$ (>5 µm) and small $\boldsymbol{P_S}$ cells according to the total biomass. Imposed meso-zooplankton grazing follows the average seasonal cycle from long term observations at Ocean Station P (lower right panel). Dashed lines represent additional fluxes in the enhanced ecosystem model.

(1) Impose a time-varying grazing by mesozooplankton according to the long-term 1956-80 annual cycle in mesozooplankton abundance at OSP (*Goldblatt, Mackas and Lewis, 1999*)
(2) Microzooplankton were allowed to graze on detritus ***D*** (and indirectly on bacteria). Efficiency was set such that this food made up less than 20% of the food of microzooplankton
(3) Partition the phytoplankton population into a fraction > 5µm and a fraction < 5µm according to the total biomass, as determined from recent observations from midlatitude gyres. Microzooplankton could now graze on both the small size fraction of phytoplankton and detritus. Mesozooplankton could now graze on both the large size class of phytoplankton and the microzooplankton. There was no difference in the

normalized rate of primary production between the two size fractions, but we are investigating recent works on size fractioned primary production.

Results with the Enhanced Ecosystem Model

The two climate change scenarios were rerun with the modified ecosystem model. Because the model structure was altered it was necessary to 'tune' the model again in order to recover the annual OSP nutrient cycle for the 'iron limited' standard run: for the maximum phytoplankton growth rate v_m was decreased by 25% and the half-saturation coefficient for grazing by microzooplankton k_p was increased by 88%, and the nitrogen input at the bottom of the model domain was increased to account for additional nitrogen losses to the mesozooplankton through grazing. As before, in the warming run, changes in the annual fluxes and standing stocks were minor. In all 3 runs, losses to the mesozooplankton (either lost through fecal pellets and death or diapause) were significant (29% of total nutrient uptake by phytoplankton in the 'standard' run, and 27% in the scenario where iron limitation is removed).

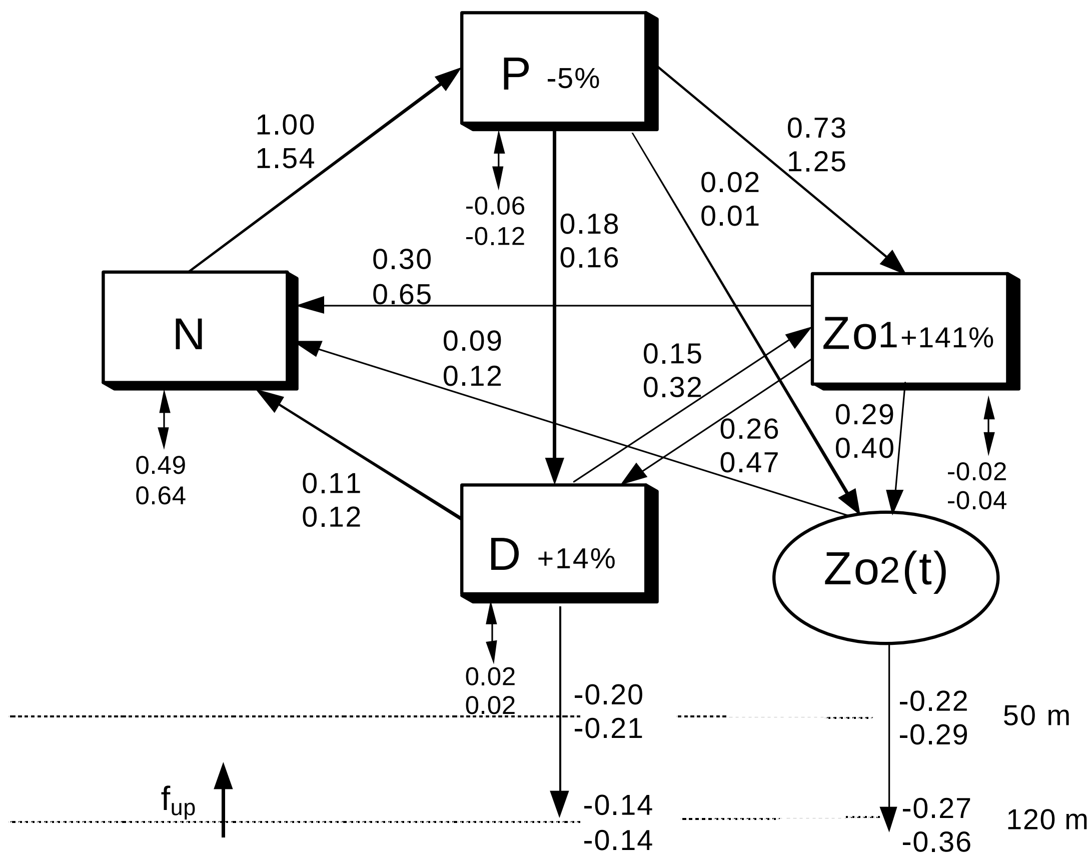


Figure 3. Results of the simulation removing iron limitation in the 'Enhanced Model'. Units and numbers same as in Figure 1.

With the removal of iron limitation (Figure 3), most changes were marginally less than in the first model: primary production increased by 54%, ***Z*** by 141%, ***D*** by 14%, remineralization by 9%, and total export flux by 23%. However, ***P*** (and its annual cycle) changed by <10%.

Summary

We have simulated potential effects of climate change on two coupled models of the planktonic ecosystem and surface mixed layer. Our results can be summarized as follows:

- Global warming simulations with 2°C offset: most rates and concentrations change by <10%; there is generally greater recycling and less carbon removal from the surface ocean.
- Removal of iron limitation can potentially increase annual primary production and maximum zooplankton standing stocks by more than a factor of 2, with little change to phytoplankton standing stocks, i.e. the increased primary production is passed on directly to the zooplankton.
- General results are reproduced with imposed grazing by mesozooplankton, grazing on detritus/bacteria by micro-zooplankton, and size partition of phytoplankton (into two classes < and > 5μm).
- The similarity of the annual cycle of phytoplankton biomass in all these simulations suggests that satellite monitoring of phytoplankton biomass as an indicator of ecosystem responses to climate change may be difficult.
- Export fluxes change by <30% for all scenarios.

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