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12.823 Modeling the Biology and Physics of the Ocean

Homework #1

(1) Implementation of the Riley (1946) model showed consistency with the published results. Estimated biomass by the model had the same seasonal patterns as the observed population (Fig. 1).



Figure 1. Control run of the Riley (1946) model using the same parameter values, drivers, and initial conditions found in the paper. The black line shows the modeled phytoplankton biomass over the seasonal cycle and the blue dots show the corresponding empirical observations.

The results of the sensitivity analysis for each parameter are shown in Fig. 2. There were very large differences in the sensitivity of the model to each parameter. The model was relatively robust to changes in the respiration rate (R0) and the temperature dependence (r), but showed high sensitivity to the photosynthetic rate (p), the grazing rate (g) and the nutrient limitation (1-N) as evidenced by the strong divergence between model trajectories when these parameters were increased or decreased. The sensitivity resulted in a loss of periodicity in the seasonal cycle because trajectories tended to grow very large or decay to zero quickly. It is therefore very important to make sure that those parameters to which the model has high sensitivity are measured accurately to prevent the model from diverging from observations. Alternatively, you could fit the model to the observations to optimize your parameter values.

I also computed the average percent error over the seasonal cycle between the observations and each of the sensitivity experiments (Table 1).

*Table 1. Mean percent error over the seasonal cycle between the observations and the model when increasing or decreasing each parameter value by 20%.*

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter Value | Control Run | Decreased by 20% | Increased by 20% |
| Photosynthetic Rate (p) | 0.29 | 39.5 | 0.82 |
| Respiration Rate (R0) | 0.29 | 0.51 | 1.72 |
| Grazing Rate (g) | 0.29 | 0.32 | 1.03 |
| Nutrient Limitation (1-N) | 0.29 | 39.5 | 0.82 |



Figure 2. Sensitivity analysis showing model runs with each parameter increased (red) or decreased (blue) by 20% compared to a control run (black) using the parameter values found in Riley (1946). Note the differences in vertical scales between subplots.

The results of the sensitivity analysis show that the model is very sensitivity to a few of the parameters. The modeled phytoplankton biomass is of the same order of accuracy as the observations in some cases, but this results depends on parameter values that are optimized for a given data set or measured very accurately for a specific community and set of physical conditions. While this approach is useful for small scale local models over relatively short time periods, the high sensitivity creates problems if you were going to try to use this model to estimate phytoplankton biomass over large spatial or temporal scales, or in cases where the parameter values may be changing with time.

(2) I found the value of the grazing rate (g) that allows the model to be periodic algorithmically by changing g in small increments until the endpoints of the simulation were within a defined margin of error. Using the values for the other parameters from the paper, that means g = 0.007442, compared to a value of g = 0.0075 in Riley (1946). I also calculated the value of g that forces the seasonal cycle to be periodic when I increased each of the other parameters by 20%. The results are as follows. When p was increased, g = 0.009978. When R0 was increased, g = 0.006395. When r was increased, g = 0.006583. When (1-N) was increased, g = 0.0098.

(3) Fig. 3 shows a 10-year time series of modeled phytoplankton biomass using parameter values adjusted for periodicity and a constant seasonal cycle in the drivers. The zooplankton biomass had random perturbations added to it. The results show significant interannual variability as a result of the random zooplankton perturbations, although the long term mean appears to be fairly constant. Each year has the same qualitative seasonal cycle (large spring bloom and smaller autumn bloom) but the magnitude of these features depends on the size of the zooplankton population. The consistency of the seasonal features, however, indicates that the model’s qualitative dynamics are more sensitive to parameter values than they are to the model drivers.

Figure 3. 10-year time series of modeled phytoplankton biomass with random perturbations to the zooplankton population of 20%.