

Pfiesteria piscicida Population Dynamics: A Modeling Study

Xinsheng Zhang, Raleigh R. Hood, Michael R. Roman, Patricia M. Glibert, and Diane K. Stoecker
Horn Point Laboratory, University of Maryland Center for Environmental Science, Cambridge, MD, USA; zhang@hpl.umces.edu

Abstract

We developed a generalized numerical model to study *Pfiesteria* population dynamics. In addition to modeling the total biomass of *Pfiesteria*, we followed the time dependency of both individual body size and abundance of *Pfiesteria* zoospores. We created model formulations for NON-INDUCIBLE (NON-IND) and TOXIC-A *Pfiesteria* strains by specifying differences in grazing rate, kleptoplastidy, and dissolved organic nitrogen (DON) utilization. We carried out a series of modeling experiments with various sets of model parameter values and attempted to simulate the effects (e.g., turbulence, nutrient concentration and composition, microzooplankton and mesozooplankton (*Acartia*) grazing, and trophic cascade by *Acartia* grazing on microzooplankton) on *Pfiesteria* population dynamics.

Introduction

Pfiesteria piscicida is a mixotrophic, harmful algal bloom species which has a complex life cycle including flagellated, amoeboid, and encysted stages (Burkholder *et al.*, 1995; Burkholder and Glasgow, 1997). *Pfiesteria* has been implicated as the primary causative agent of many fish kills in the coastal waters of the southeastern US. However, the mechanisms that control *Pfiesteria* population dynamics are unclear. Based on our laboratory/field experimental results and literature data, we developed a generalized numerical model to study *Pfiesteria* population dynamics. The model allows us to simulate effects of physical, chemical, and biological conditions and processes on *Pfiesteria* population dynamics. We can use the model outcomes for further testing in the laboratory/field. Therefore, this model provides an important diagnostic tool in the study of *Pfiesteria*.

Model

The model is composed of *Pfiesteria* zoospores, microzooplankton, *Acartia*, dissolved inorganic nitrogen (DIN), DON, diatom, cryptophytes, and detritus (Fig. 1). We used nitrogen as the currency in our model. In addition to modeling the total biomass of *Pfiesteria*, we followed the time

dependency of *Pfiesteria* zoospores' cell size and abundance. In this model we represented these two forms of *Pfiesteria* in an idealized way. NON-IND *Pfiesteria* is kleptoplastidic, it does not utilize DON, and it has a relatively fast growth rate. In contrast, TOXIC-A is not kleptoplastidic, it utilizes DON, and it has a slower growth rate. Turbulence is one of the factors controlling the occurrence of *Pfiesteria* blooms (Burkholder and Glasgow, 1997). We derived an empirical function (not shown) of the maximum grazing rate of *Pfiesteria* to turbulence levels and incorporated this factor into the model. According to this equation, *Pfiesteria*'s grazing rate is negatively exponentially related to turbulence levels. This model is an extension of our previous *Pfiesteria* model where we developed an approach for tracking the time dependency of *Pfiesteria* zoospores' cell size and abundance during mixotrophic feeding, and a general, starvation-based mechanism for triggering encystment (Zhang *et al.*, 2003). Most of the formulations and parameter values of this model were based on Zhang *et al.* (2003).

Results and Discussion

Using this generic model, we carried out 6 modeling experiments with a 12-h light and 12-h dark cycle to simulate the effects of 1) turbulence, 2) nutrient concentration and composition, and 3) grazing on both NON-IND and TOXIC-A strains of *Pfiesteria*.

In the first model experiment we compared ecosystem responses in simulations with NON-IND vs. TOXIC-A forms of *Pfiesteria*. In both cases, *Pfiesteria* was subjected to low levels of turbulence and there was no grazing by microzooplankton and *Acartia*. The biomass of diatoms and cryptophytes was depleted quickly by NON-IND *Pfiesteria* (by day 2.5), but zoospore biomass continued to increase due to kleptoplastidy and reached a maximum in day 3.5, then began to decline due to starvation (Fig. 2A); DIN and DON concentrations remained relatively high because the biomass (uptake) of the diatoms and cryptophytes was low (Fig. 2A). In contrast, with TOXIC-A populations the biomass of diatoms and cryptophytes rapidly increased during the first 2 days, reached maxima in day 2, and slowly declined thereafter due to grazing by *Pfiesteria* (Fig. 2B); both DIN and DON concentrations were reduced to low

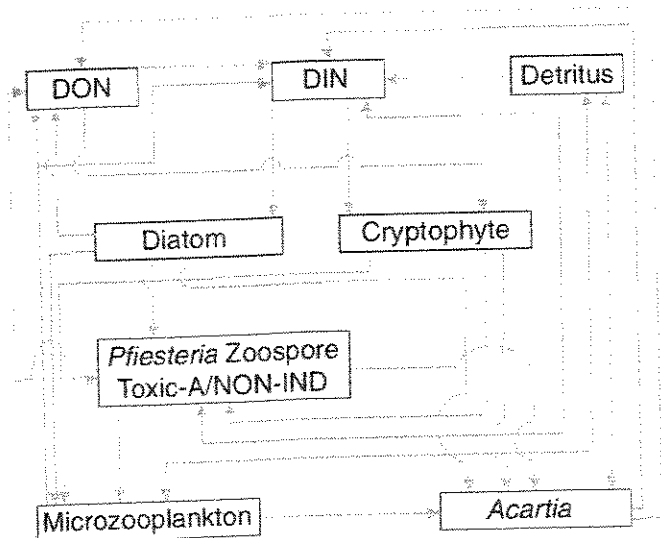


Figure 1 A schematic diagram of the generalized eight-compartment *Pfiesteria* model.

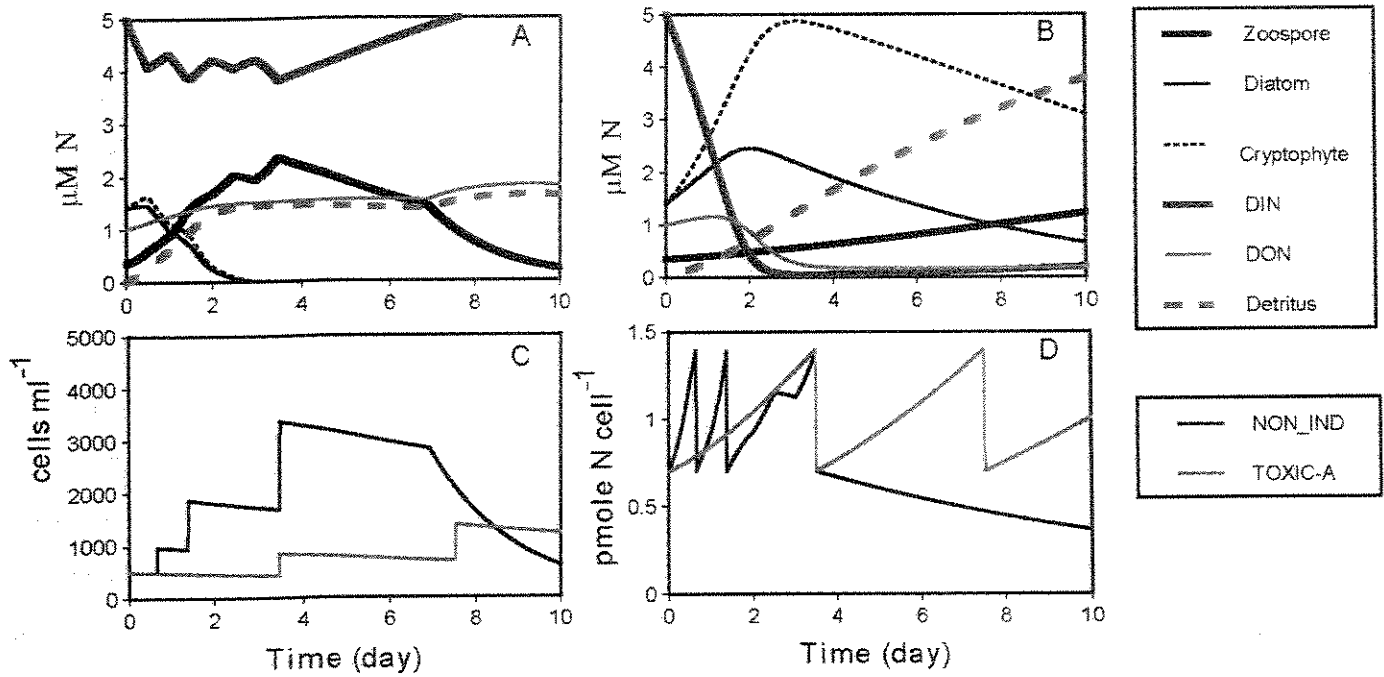


Figure 2 First modeling experiment. *Pfiesteria* zoospore biomass, diatom biomass, cryptophyte biomass, DIN concentration, DON concentration, and detritus concentration vs. time for NON-IND (A) and TOXIC-A (B). *Pfiesteria* zoospore abundance vs. time (C). *Pfiesteria* zoospore size vs. time (D).

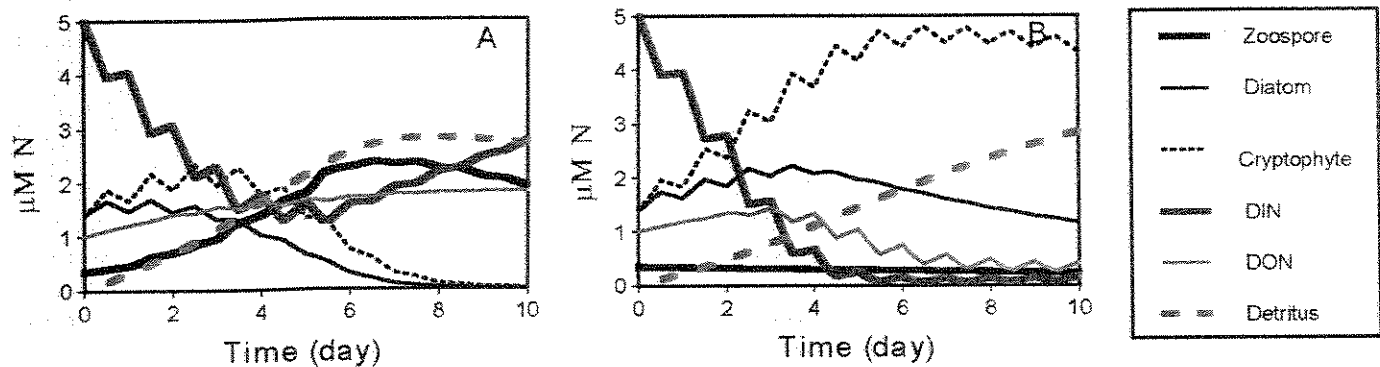


Figure 3 Second modeling experiment. All terms and conditions were the same as in the first experiment except for the higher turbulence. *Pfiesteria* zoospore biomass, diatom biomass, cryptophyte biomass, DIN concentration, DON concentration, and detritus concentration vs. time for NON-IND (A) and TOXIC-A (B).

levels due to high biomass of diatoms and cryptophytes (Fig. 2B). NON-IND zoospores divided at a faster rate than TOXIC-A cells (Fig. 2C, D). After cell division, the abundance of *Pfiesteria* zoospores doubled (Fig. 2C) and the size of *Pfiesteria* zoospores was reduced to half (Fig. 2D).

In the second experiment, we simulated the effect of increased turbulence on *Pfiesteria* population dynamics. Here, we present only the time dependency of biomass/concentration of each component for the rest of experiments and focus mainly on changes of zoospore biomass. All terms and conditions were the same as in the first experiment except for the higher turbulence. Compared to the first experiment, NON-IND zoospores grew slower and biomass did not reach a maximum until day 7 (Fig. 2A vs. Fig. 3A). TOXIC-A biomass declined throughout the model run (Fig. 2B vs. Fig. 3B). Although turbulence had a negative effect on both NON-IND and TOXIC-A strains, the model results

suggest that it is more difficult for TOXIC-A strains to live in high turbulence conditions than for NON-IND strains.

In the third experiment, we simulated the effect of nutrient concentration and composition on *Pfiesteria* population dynamics. All terms and conditions were the same as in the first experiment except for a change of nutrient concentrations from the previously high DIN and low DON condition to a low DIN and high DON condition. Compared to the first experiment, NON-IND zoospore biomass reached a lower maximum in day 3 (Fig. 2A vs. Fig. 4A), and TOXIC-A zoospores grew much faster because more DON was available for utilization/growth (Fig. 2B vs. Fig. 4B).

In the fourth experiment, we introduced the effect of microzooplankton grazing on *Pfiesteria*. All terms and conditions were otherwise the same as in the first experiment. Here, we present only the time dependency of *Pfiesteria* zoospore biomass for the rest of experiments.

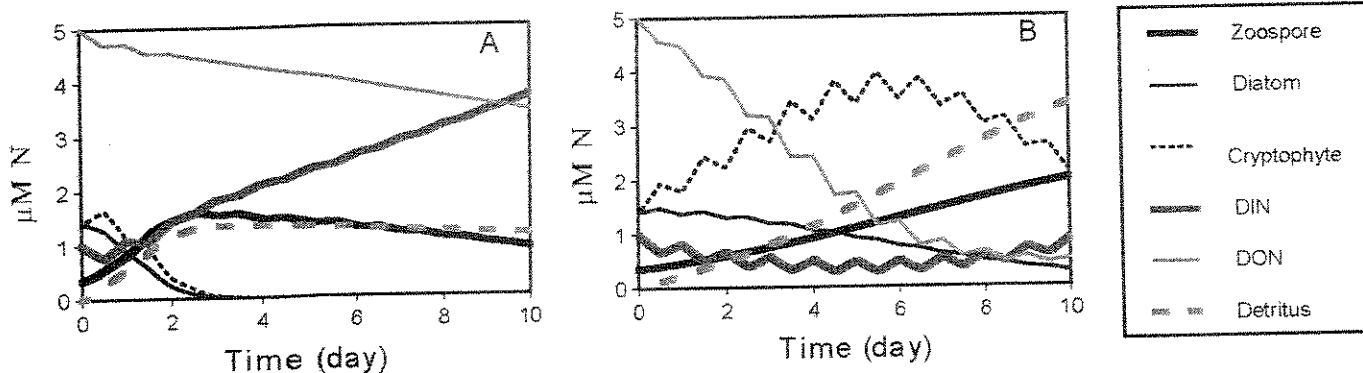


Figure 4 Third modeling experiment. All terms and conditions were the same as in the first experiment except for the change of nutrient condition from the high DIN and low DON to the low DIN and high DON. *Pfiesteria* zoospore biomass, diatom biomass, cryptophyte biomass, DIN concentration, DON concentration, and detritus concentration vs. time for NON-IND (A) and TOXIC-A (B).

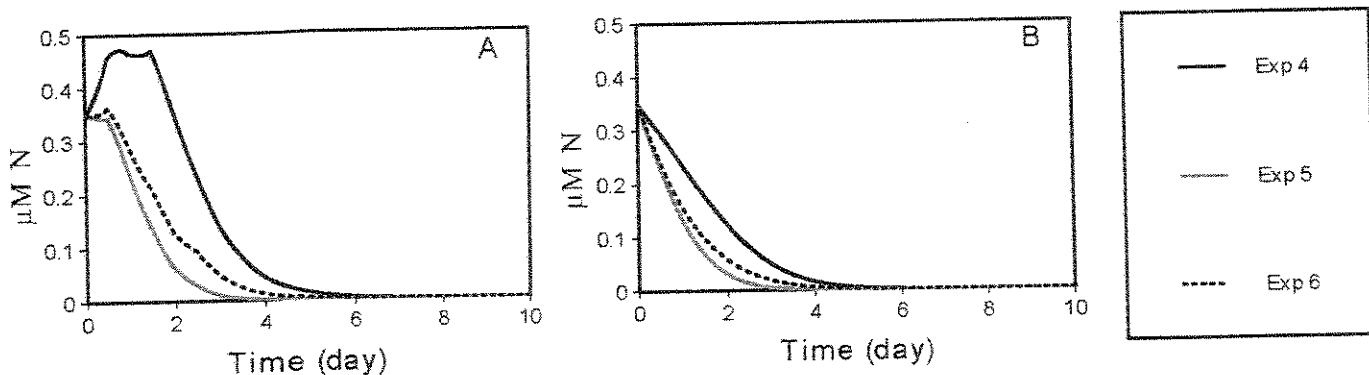


Figure 5 Modeling experiments 4–6. All terms and conditions were the same as in the first experiment except for the addition of microzooplankton grazing (Exp 4), *Acartia* grazing and the assumption that *Acartia* does not eat microzooplankton (Exp 5), deletion of the assumption that *Acartia* does not eat microzooplankton (Exp 6). *Pfiesteria* zoospore biomass versus time for NON-IND (A) and TOXIC-A (B).

Compared to the first experiment, *Pfiesteria* zoospore biomass declined much faster and was depleted in days 5–6 (Fig. 2 vs. Fig. 5). Therefore, the *Pfiesteria* population in the model was regulated by a combination of bottom-up (food) and top-down (grazing) control.

In the fifth experiment, we simulated the effect of *Acartia* grazing on *Pfiesteria*. All terms and conditions were the same as in the fourth experiment except for the addition of *Acartia* grazing and the assumption that *Acartia* does not eat microzooplankton. Compared to the fourth experiment, *Pfiesteria* zoospore biomass declined even faster and was depleted in days 3–4 (Fig. 2 vs. Fig. 5).

In the sixth experiment, we simulated the effect of trophic cascade; *i.e.*, *Acartia* grazing on microzooplankton which in turn grazes on *Pfiesteria*. All terms and conditions were the same as in the fifth experiment except for removal of the assumption that *Acartia* does not eat microzooplankton. Compared to the fifth experiment, *Pfiesteria* zoospore biomass declined slower and was depleted in days 4–5 (Fig. 2A vs. Fig. 5). Therefore, trophic cascade by *Acartia* grazing on microzooplankton have a positive effect on *Pfiesteria* growth.

Conclusions

In general, the model suggests that the TOXIC-A strain of

Pfiesteria is more vulnerable to elevated turbulence than NON-IND, but its growth is enhanced by high DON concentrations. Thus, the model predicts that toxic blooms are more likely to occur in calm, organic nutrient-rich conditions, which are often found in shallow, protected tributaries that are subject to anthropogenic effects. These results are generally consistent with observed patterns of toxic blooms in the Chesapeake Bay and the Neuse River of North Carolina (Burkholder and Glasgow, 1997; Glibert *et al.*, 2001).

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