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Supplementary material

Regional shifts in phytoplankton succession and primary productivity in the San Antonio Bay System (USA) in response to diminished freshwater inflows

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Methods

Numerical modelling

To better assess the range of potential responses of phytoplankton biomass resulting from 7-day inflows in the upper SABS, the combined upper and middle SABS, and all of SABS (upper, middle and lower SABS combined), a numerical model representing a simplified plankton system was explored. In these simulations, only the mechanistic effects of hydraulic displacement and nutrient loading, and the influence of phytoplankton migration from the river, were considered. Through this theoretical exercise, we explored the potential relative influences of hydraulic displacement, nutrient loading and phytoplankton immigration during periods of high river discharge. Calibrating simulations to reproduce observed system dynamics was not the purpose here and was beyond the scope of the present research. The model followed traditional chemostat equations, but with a term included representing phytoplankton biomass in the source. The equations were as follows:

$$\frac{d\varphi}{dt} = (\mu - D)\varphi + D\varphi_S \quad \text{(S1)}$$

$$\frac{dS}{dt} = D(S_{in} - S) - Q_S \mu \varphi \quad \text{(S2)}$$

where ϕ and ϕ_S are the ambient and source phytoplankton population densities, μ is the specific growth rate, D is the daily flushing rate calculated by dividing river inflow by the volume of either the upper SABS, upper and middle SABS combined, or all of SABS, S and S_{in} are the concentrations of the growth-limiting substrate, ambient and in the source, and Q_S is the fixed cellular content of the substrate for phytoplankton. Whereas D was constant in this model for any particular simulation, μ varied and was determined using the Monod equation, as follows:

$$\mu = \mu_{\max}\left(\frac{S}{S + k_S}\right) \quad \text{(S3)}$$

where $\mu_{\max}$ is the maximum specific growth rate for the population and k_S is the half-saturation coefficient for substrate-limited population growth.

The model was parameterised using observations from our data and standard values from the literature. The maximum 7-day-averaged daily river inflow selected was 250×10^6 m^3 day^{-1}, which resulted in values for D of 20 day^{-1} for the upper SABS, 0.63 day^{-1} for the upper and middle SABS combined, and 0.39 day^{-1} for the upper, middle and lower SABS combined. An initial value for ambient S of 50 µM was used, which was representative of NO_x concentrations sometimes observed in the Guadalupe River during a time of high discharge. Values used for Q_S (0.2 µM N 10^6 $cells^{-1}$), $\mu_{\max}$ (1 day^{-1}) and k_S (0.2 µM N) were typical for many phytoplankton common to the area (Roelke *et al*. 2003). For purposes of graphical output, a N : chlorophyll-*a* ratio of 9 was used (Yentsch and Vaccaro 1958).

An analysis of model behaviour was achieved by performing multiple simulations. These included two simulations using a value of D characteristic of the upper SABS during high discharge, one with phytoplankton immigration from the river and one without; a third simulation using a value of D representative of the upper and middle SABS combined; and a fourth simulation using a value of D representative of the all of SABS (upper, middle and lower SABS combined). In these later simulations, phytoplankton source population in the river was set to zero, assuming that freshwater phytoplankton taxa originating from the river would not prosper in saltier regions of SABS. The potential effects of hydraulic displacement and nutrient loading were evaluated by comparing simulation results.

The mathematical equations were solved numerically by using ordinary differential equation-solving routines that were a part of a commercial software package (Matlab 7.14, The MathWorks, Novi, MI, USA). The routines were based on fourth-order Runge–Kutta procedures, and used a variable time step that was based on a local error tolerance set at 10^{-6}.

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