OCEANOGRAPHIC MODELLING

Balancing the books: dinoflagellate persistence in the oceanic environment

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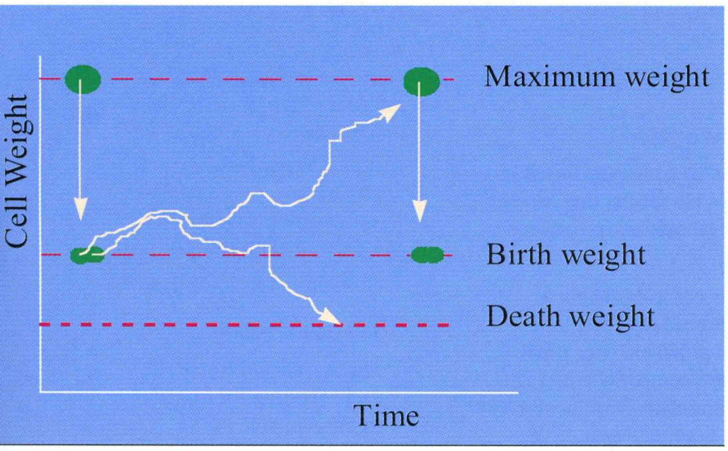
Although dinoflagellate algae are notorious for forming toxic blooms in coastal waters, the group as a whole has a tough time surviving in the ocean. Modelling has shown that if they couldn't swim, dinoflagellates probably wouldn't survive.

THE WORLD'S OCEANS are teeming with a diverse community of planktonic single-celled algae. The smallest are closely related to bacteria and are of a similar size (<2 μm). The largest are species of diatoms and dinoflagellates, which can be up to 1 mm long.

Regardless of size, all algae have the same basic requirements for life: an adequate supply of light energy for photosynthesis, suitable water temperatures and sufficient nutrients. Despite this, some species do much better than others when nutrient concentrations and/or light levels are low.

Generally, the smallest algae are best able to survive at the lowest nutrient concentrations, and are amongst the fastest growing when the environment is favourable. Of the larger algae, diatoms can also exhibit high growth rates and can grow at very low light intensities. They are also able to subsist on very low concentrations of the major nutrients (nitrogen, phosphorus). However, unlike other algae, they do require a supply of silicate. In contrast, dinoflagellates are slow growing, and require comparatively high light intensities. There is also evidence that they do not grow as well as diatoms when nutrient concentrations are low. Furthermore, it appears that (non-toxic) dinoflagellates may be the preferred prey of many zooplankton. These observations beg the question: "Why are dinoflagellates not driven to extinction by other, seemingly superior algae"?



Cellular growth rules. If a cell is lucky enough to find itself in a favourable environment (plenty of nutrients and light) it will put on weight. The cell divides into two equal "daughter" cells when the cellular weight reaches an upper threshold value. If conditions are unfavourable the cell will lose weight, and it will die should its weight fall to a lower threshold.

The good news for dinoflagellates

Dinoflagellates have three characteristics that might contribute to their success.

1. In common with many other algae, they can form resistant spores, but these are usually negatively buoyant, i.e., they gradually sink down through the water. Although shallow-water species may be able to pass through unfavourable periods as resting spores on the sea floor, the spores cannot fulfill this role in the deep ocean, where dinoflagellates are known to be abundant.
2. An increasing number of dinoflagellate species are being shown to get energy both from photosynthesis and from consuming other organisms. In other words, they show characteristics of both plants and animals! This mixed nutritional mode is termed mixotrophy (see Hall, 1998). Mixotrophy may permit continued growth even when photosynthetic activity is restricted.
3. Finally, unlike most other algae, many dinoflagellates are motile, being able to "swim" at speeds of up to 30 m per day using their whip-like "tails". This ability to move around may enable them to better regulate their environment. Dinoflagellates usually grow best near the water surface where light levels (for photosynthesis) are greatest. However, when the nutrient concentration in the surface waters becomes too low to support growth – as often happens during the summer – motile dinoflagellates can swim down to nutrient-rich, deeper waters, replenish their nutrient stores and then return to the surface waters once more.

We have investigated whether the last of these three characteristics – the ability to swim – might allow dinoflagellates to coexist with other algae, particularly diatoms, that appear to be competitively superior.

A model to predict phytoplankton survival

We have constructed a two-"species" (diatom and dinoflagellate) model of oceanic phytoplankton dynamics. Both groups are assumed to be strictly autotrophic (i.e., they gain their energy solely through photosynthesis), but the diatoms are able to photosynthesize much more rapidly whilst being much less mobile than the dinoflagellates. The figures on the right summarise part of the model, an example of an *individual-based population model* (IBPM). The great advantage of IBPMs is that they can take account of individual variability, rather than regarding the entire population as an undifferentiated group. This model represents the detailed physiological state of numerous individual algal "cells", each following a unique trajectory through the ocean (see Woods and Onken 1982). A key feature is the relationship between a cell's chosen swimming direction and its physiological state (see figure). Clearly, in reality, each cell would regulate its behaviour in response to its *own* state rather than to the population average state. This situation cannot be simulated using traditional (non-IBPM) techniques.