Cycling of phosphorus in the Eastern Mediterranean (CYCLOPS)

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Contract n°	EVK3-1999-00009	Project duration:	March 2000 to June 2003
Project budget	€ 2304958	EC contribution:	€ 1786700
Website	www.earth.leeds.ac.uk/cyclops		

Objectives

To understand the processes which control primary productivity in the Eastern Mediterranean. This is particularly important because of the very low background productivity and high and changing inputs of anthropogenic pollutants to the system from both the atmosphere and from rivers and other point and non-point sources.

Results

The CYCLOPS team carried out a Lagrangian experiment involving an addition of the nutrient, phosphate. It was the first successful experiment of its kind, anywhere in the world, involving the addition of a nutrient other than iron. We added 18 tonnes of diluted and partially neutralised phosphoric acid, together with SF_6 as the inert tracer, to a 16 km^2 patch of water. This resulted in a mean initial phosphate concentration of 120 nmoles/litre. The patch, which was contained in the centre of a warm core eddy, was followed successfully for 9 days. We carried out detailed biological, chemical and physical measurements on the patch water, and also on a series of stations outside the patch. These data enabled us to monitor in detail the changes that occurred in the system in response to the phosphate addition.

In addition we carried out the most comprehensive set of co-ordinated and simultaneous modern measurements made in the Eastern Mediterranean. This included measurements of activity, biomass and species identification of bacteria, phytoplankton, micro and macro-grazers. We also measured community parameters such as photosynthesis rates, several different chlorophyll determinations and P uptake kinetics. During the project we developed, and carried out for the first time, measurements of nanomolar concentration nutrients (phosphate, nitrite and nitrate) as well as a new alkaline phosphatase method for estimating the amount of excess available nutrients present in a microbial sample. We also determined for the first time in this area the particulate C:N:P ratio and the dissolved organic C:N:P ratio. All these parameters were measured on water samples taken from both inside and outside the fertilised area.

We expected there to be an increase in phytoplankton biomass when we added P, the limiting nutrient to the system. In fact we observed a decrease in chlorophyll. Our results showed an unexpected complexity of response that we did not anticipate when we designed the project. The base of the food chain consists of heterotrophic bacteria, nano- and pico-phytoplankton. There are very few larger eukaryotic phytoplankton in these waters. When phosphate is added, it is taken up rapidly by the microbial community (as shown by the ^{33}P turnover rates combined with nanomolar phosphate measurements, and an increase in particulate phosphate). The bacteria show a significant increase in activity but not in biomass. The dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) that they are able to access from the water column sustain this increase. The DON, which was seen to decrease, provided them with the N source they need for growth. By contrast, the phytoplankton took up P but did not grow. However, when they were supplied with dissolved inorganic nitrogen, in the form of ammonia within the microcosm, rapid growth occurred. The induced changes caused an increase in grazers and in grazing rates, which caused the bacterial biomass to remain stable and caused a decrease in the phytoplankton chlorophyll. It is concluded that the bacteria are P limited and are able to access N from the DON pool. The phytoplankton are N&P co-limited. Microbial grazers are present within the system and seem to be 'hungry' and able to take advantage rapidly of short term changes in the food supply.

The system is ultra-oligotrophic with very low levels of chlorophyll and primary productivity. The primary producers are extremely small, dominantly in the nano- and picoplankton range. The levels of dissolved inorganic nutrients within the system are very low (generally below the detection limits even of the nanomolar technology). However the levels of DOC, DON and DOP are relatively high. We found that the system is P starved with no reservoirs of non-labile P present.

A total nutrient budget was carried out for the entire basin. This showed that there was a major imbalance in the nutrient input with an N:P ratio in the inputs of ~50:1. The largest input source was atmospheric input which represented 70% of the N and 30% of the Labile P. It was suggested that the reason why the basin was p limited was because more N was supplied than P. It retains this high N:P ratio because of the unique antiestuarine circulation which causes the system to be ultra-oligotrophic which results in very low accumulation of organic matter in the sediments and water column. The result is that the normal processes of biologically controlled buffering cannot occur in this system. There is no evidence or need for N fixation to occur.

Potential importance and relevance to end users:

Our work confirms the ultra-oligotrophic nature of the system. This is despite the major input of nutrients from the population in the catchment and the annual influx of tourists. This is because of the unique anti-estuarine circulation of the basin, which results in a large net export of nutrients through the straits of Sicily.

The major input of nutrients to the system is from the atmosphere. The flux is dominantly N, mainly anthropogenic from Europe (NOx from cars and NH_3 from agriculture). As a result, the regulations to control nutrient input from point sources have a limited effect on the nutrient status of the system as a whole. The input of atmospheric N is likely to be increasing as the general influx of atmospheric nitrogen increases. However, this has a relatively minor effect on the overall productivity of the system, since the system is P limited and most of the P is natural input via Saharan dust.

Previous attempts to calculate the fish biomass from primary productivity measurements using conventional food chain calculations resulted in a problem. There seemed to be too much fish biomass for the primary productivity measured. Our results may suggest a reason for this. It seems that relatively large micro-grazers, and even macro-grazers, are consuming bacteria and other primary producers. If this is true then the efficiency losses through the system will be much lower than expected, which would explain the relatively high fish yields for relatively low primary productivity.

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