



**Phoslock Water Solutions Ltd.**  
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## **Blue-Green Algae Management in Aquaculture**

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*This brochure describes the nutrient dynamics and growth of blue-green algae in intensive aquaculture ponds, and their impact on water quality and aquaculture production. It also describes how a novel natural product “Phoslock” successfully removes  $PO_4$  (an essential nutrient of blue-green algae) from aquaculture ponds and controls their growth by sustained limitation.*



**Phoslock – the best environmentally friendly solution for controlling blue-green algae and improving water quality in the aquaculture ponds**

### **General features of blue-green algae**

Blue-green algae, scientifically known as Cyanobacteria, are microscopic single-celled organisms that grow naturally in fresh and salt waters. They are not algae (eukaryotes), but are a type of bacteria (prokaryotes), possessing the ability to synthesize chlorophyll *a*. Therefore, they act like plants by using sunlight to manufacture carbohydrates from carbon dioxide and water, a process known as photosynthesis. Blue-green algae have vesicles or gas pockets inside vacuoles within their cells that they inflate with gas, thus able to regulate their buoyancy in response to environmental conditions. This is advantageous over other algae as they have the ability to sink and rise at their will and move to where nutrient and light levels are at their highest.

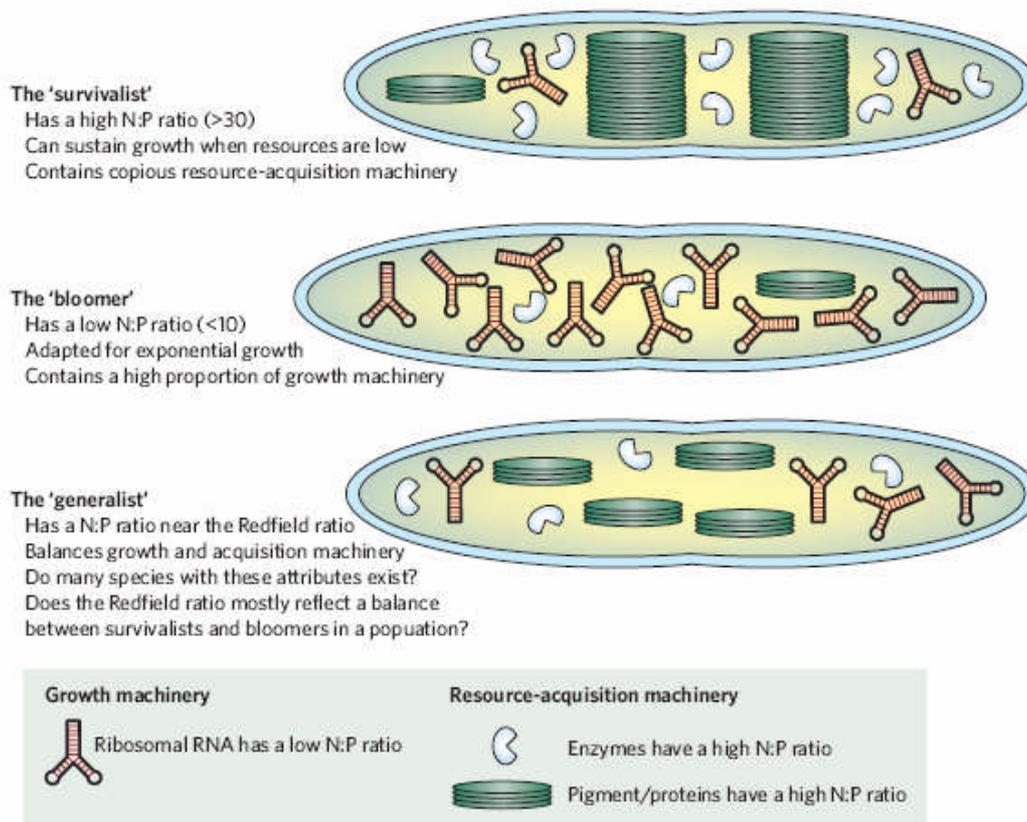
## **Nutrient requirements of phytoplankton and N:P ratio**

In addition to light and carbon, growth of phytoplankton (all photosynthetic aquatic microorganisms including algae and blue-green algae) consumes 'nutrients'. Every replication of an algal cell roughly demands the uptake and assimilation of a quota of inorganic nutrients similar to that in the mother cell. In addition to carbon, the living protoplast comprises 19 other elements. The elements/nutrients most often implicated in the constraint of algal growth are: nitrogen, phosphorus, iron, and one or two of other trace elements, together with silicon - the well known constraint on diatom skeletal growth.

Since the early twentieth century (1934) it has been recognized (primarily through the late Harvard University scientist Alfred Redfield's work on Nitrogen:Phosphorus ratios) that the elemental composition of phytoplankton was similar to that of the ocean: 16N:1P. Scientists have accepted this as a constant called the Redfield ratio. However, the canonical Redfield N:P ratio of 16 for phytoplankton is not a universal optimal value but instead represents an average for a diverse phytoplankton assemblage growing under a variety of different conditions and employing a range of growth strategies. The N:P ratio is not fixed in the environment and this is mainly due to the inflow of nutrients from anthropogenic sources such as fertilizers and runoff containing nutrient rich waste (e.g. effluent).

Different cellular components of phytoplankton cells have their own unique stoichiometric properties. Most notably, resource (light or nutrients) acquisition machinery, such as proteins and chlorophyll, is high in nitrogen but low in phosphorus, whereas growth machinery, such as ribosomal RNA, is high in both nitrogen and phosphorus. Because these components make up a large proportion of cellular material, changes in their relative proportions have a marked effect on bulk cellular C:N:P stoichiometry.

During exponential growth, bloom-forming phytoplankton optimally increase their allocation of nutrients toward production of growth machinery, reducing their N:P ratio to ~8, far below the Redfield value of 16 (Figure 1). However, when nutrients are scarce, slow-growing phytoplankton that can synthesize additional nutrients acquisition machinery are favoured. This allocation of nutrients results in optimal N:P ratios ranging from 36 – 45 (Figure 1).



**Figure 1:** Three different phytoplankton growth strategies and their resulting cellular N:P ratios (Arrigo 2005).

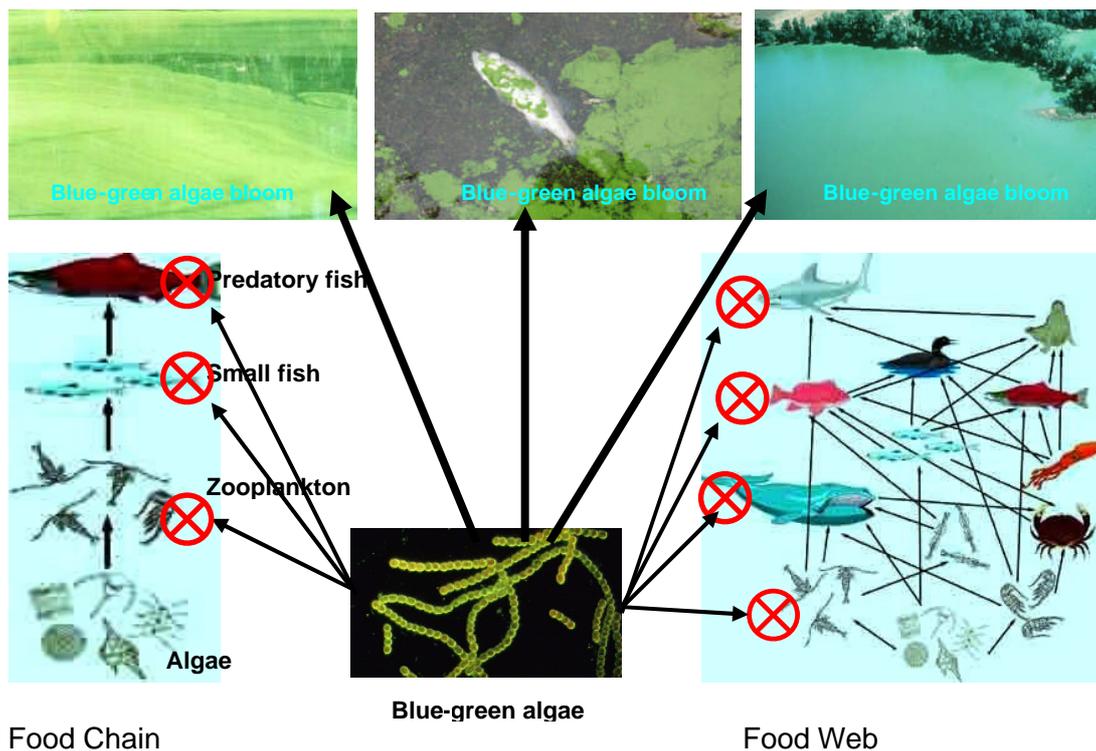
The optimal N:P ratio will vary from 8.2 to 45.0, depending on the ecological conditions. Nitrogen-fixing species (e.g. nitrogen-fixing blue-green algae) often have a higher N:P stoichiometry than non-fixing species. For example nitrogen-fixing, *Trichodesmium* blooms have N:P ratios ranging from 42 to 125. The differences in N:P ratios between phyla and super families are also significantly different. For example, green algae required N:P ~30 whereas diatom required ~10 and Dinophyceae required ~12 (Quigg *et al.* 2003) and red algae required N:P ~10 (Arrigo 2005).

## Nutrient dynamics in aquaculture ponds

In intensive aquaculture ponds, natural carrying capacities are greatly exceeded, and heavily laden artificial ecology is established among the various organisms and the environment they live. Due to the high densities of fish or prawn stock for profitable commercial aquaculture, ponds receive large nutrient inputs from uneaten fish feeds, fish excretion, and sediment mineralization/resuspension. Nutrient budget in aquaculture ponds revealed that fish could only assimilate 20 – 27% nitrogen and 8 – 24% phosphorus of the total inputs. It was reported that fish feed accounted for 90 – 98% nitrogen and 97 – 98% phosphorus of the total inputs in aquaculture ponds. The major nutrients sank into the sediment, which accounted for 54 – 77% nitrogen and 72 – 89% phosphorus of the total inputs.

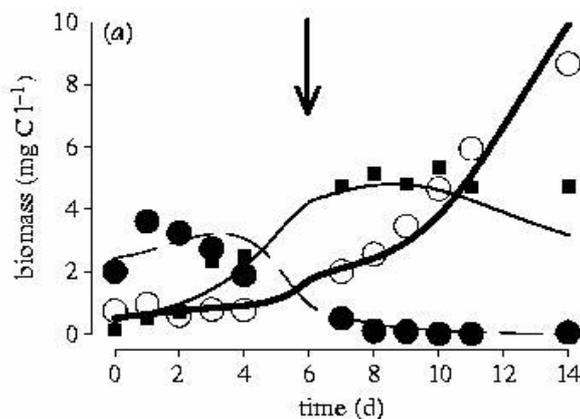
## Growth and proliferation of blue-green algae in aquaculture ponds

A large portion of nutrients from fish feed is chemically or biologically transformed and then released into the water and taken up by the algae (including blue-green algae), resulting in the excessive production of algae. Because of “static” pond systems and high amounts of nutrients added daily, algal blooms are encouraged to grow and proliferate. Blue-green algae are advantageous over other algae because of their ability to control buoyancy to access areas of increased nutrients and light. Therefore, their growth rate is much higher than other non-harmful algae in aquaculture ponds. Although phytoplankton/algae are important to the aquatic food chains because they are primary producers, blue-green algae are generally not eaten by other aquatic organisms, because they produce secondary metabolites (e.g. toxins). Therefore, blue-green algae are not an important part of the aquatic food chain and food web. Uneaten excessive blue-green algae can produce blooms in aquaculture ponds (Figure 2).



**Figure 2.** Food chain and food web in aquatic ecosystems. A food chain is the flow of energy from one organism to the next and a food web extends the food chain concept from a simple linear pathway to a complex network of interactions. Algae are the base of aquatic food chain and food web. Blue-green algae are not eaten by zooplankton or fish, because they produce toxins. Uneaten blue-green algae produce blooms in aquaculture ponds.

Blue-green algal blooms in aquaculture ponds are also promoted by zooplankton's predatory activity. The relationship between algae and their zooplanktonic predators typically involves consumption of nutrients by algae, grazing of the algae by zooplankton which in turn enhances predator biomass, controls algal growth and regenerates nutrients. However, the daily feed supply for aquaculture raises nutrient levels, but does not simply increase normal predator-prey activity; rather, harmful algal bloom events develop often with serious ecological and aesthetic implications. In the absence of the predator (zooplankton or fish), the non-harmful algal species outgrow the harmful algal species and inhibit its growth. However, in the presence of the predator (e.g. zooplankton, fish or prawns in aquaculture ponds) it completely overturns by grazing out the non-harmful species, for which it demonstrates a preference (Figure 3). The dynamics of regeneration of the limiting nutrients versus nutrient consumption by algae is critical for bloom formation, as is the role of predators that exhibit prey selectivity (eat harmless algae only). When the supply of limiting nutrients exceeds the demand, the harmful algal biomass increases but nutrient status and palatability remain depressed (Figure 3).



**Figure 3.** Simulation of interactions in algal bloom formation promoted by predator activity. Experimental data (symbols) and model output (lines) describe the predator-prey interactions. The harmful algal species (open circles, thick line) becomes unpalatable (harmful) to the predator (closed squares, thin line) when nutrient-stressed and hence not predated. The non-harmful algal species (closed circles, dashed lines) remains palatable when nutrient-stressed (Mitra & Flynn, 2006).

## Blue-green algae affect water quality and promote disease

Maintenance of appropriate water quality is essential in aquaculture farm management to ensure optimal growth and survival of aquaculture species. Poor water quality is linked with disease problems contributing to the collapse of several prawn farming industries in some South East Asian countries.

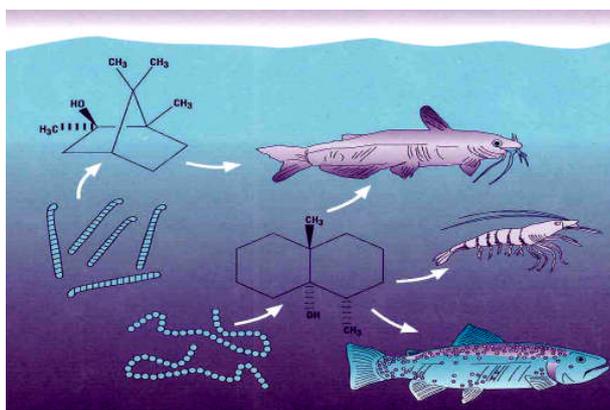
Unmanaged blue-green algal growth in aquaculture ponds cause poor water quality following algal degradation. When algae reach their maximum growth phase, they flourish for a period and then die. This is known as an algal "crash". After a crash or periodical collapse of algal populations, the decomposition of these dead algae utilizes a large amount of oxygen and can cause oxygen deficits and increased concentration of toxic ammonia. Insufficient oxygen and high ammonia concentrations may, in turn: kill aquaculture species; promote disease; and/or temporarily reduce the feeding and growth rates of fish/prawns.

## Blue-green algae produce toxins and cause stress to aquaculture species

Blue-green algae produce toxins which may cause toxic and physical stress to fish/prawns. Exposure to harmful algal neurotoxins can alter swimming and social behavior in fish and alter neuronal activity. Microcystins (a toxin produced by blue-green algae) can accumulate in the tissues of fish (particularly in the viscera - liver, kidney, etc.), and in shellfish.

## Blue-green algae produce taste and odour compounds and cause off-flavour problems

The objectionable odours or tastes detected in aquaculture products are referred to as 'off-flavour'. Off-flavour is one of the most economically significant problems encountered in catfish and prawn aquaculture. Most common "earthy" and "musty" off-flavours are caused primarily by the absorption of odorous compounds (such as geosmin (GSM) and 2-methylisoborneol (2-MIB)) from the water through skin and gills. These compounds accumulate in the fatty tissue of the aquaculture species. These odorous compounds are metabolites produced by certain species of blue-green algae. Off-flavour problems cause inconsistent product quality that may adversely affect consumer demand and ultimately, hinder industry development and decrease profits for producers and processors by increasing production costs. Up to 80% of harvestable catfish can have an off-flavour during any one year (Rimando & Schrader, 2003).



**Figure 4.** Geosmin (GSM) and 2-methylisoborneol (2-MIB) produced by certain species of blue-green algae and pass through skin and gills of aquaculture species and accumulate in the fatty tissues of fish or prawn heads (Rimando & Schrader, 2003).

"Off-flavour" is common in catfishes, but also occurs in penaeid shrimp. Off-flavour compounds are soluble in lipid and tend to concentrate in shrimp heads. Geosmin also found to be the main compound associated with the seasonal occurrence of earthy-taints in UK farmed trout.

## **Using algicides to control blue-green algae in aquaculture ponds**

Currently there is no non-toxic, sustainable method to control blue-green algae in aquaculture ponds. However, using chemical algicides (copper sulfate and certain chelated or complexed copper products) may prevent blue-green algae. But copper algicides are not suited to aquaculture. They are not selectively toxic to odour-producing blue-green algae. Copper also interacts strongly with other water quality variables, and one important consequence of those interactions is that copper products become more toxic to fish and algae as water hardness and alkalinity decrease. Copper sulfate treatments cause poor water quality. Increased aeration is required in copper treated ponds than in untreated ponds. Copper can accumulate in the sediments of treated ponds, with a relatively large fraction of the copper in the sediment initially present in a potentially bioavailable form. In addition, due to their potential adverse environmental impacts, there may be local regulations in place restricting the use of algicides.

Eradicating algal blooms may not improve the situation and could potentially make the problem worse in the near term. Treatment of ponds with algicide chemicals can result in beneficial algae also being removed. Algicides or chlorination may cause the algal cells to burst and this can cause toxins to be released into the water. In addition, when algae decompose, the phosphorus stored in the algal cells is released into the water. The released phosphorus is available to fuel new algae growth.

## **Limiting nutrients to control blue-green algae in aquaculture ponds**

The definition of a limiting nutrient is: one that is necessary for algal growth, but available in a concentration insufficient to support continued growth. Once supply of this nutrient is exhausted, algal growth ceases independently of other remaining nutrient quantities. Any nutrients, for example, nitrogen, phosphorus or certain metals can become limiting nutrients for phytoplankton growth. Limitation of nitrogen is an expensive process, which required high energy and chemical costs and specialized equipment. Certain microorganisms, including algae, are able to fix atmospheric nitrogen opportunistically. Removal of metals may disrupt the local ecology, especially that of aquatic plants.

Therefore, phosphorus limitation is the cheapest and most practical means of preventing the growth of phytoplankton, particularly toxic blue-green algae. Phosphorus is an essential requirement of living, functional algae. Phosphorus is a component of nucleic acids governing protein synthesis and of the adenosine phosphate transformations that power intracellular transport.

## **How phosphorus limitation control blue-green algae in aquaculture ponds**

In the events of phosphorus availability, phytoplankton intake excess phosphorus than their requirements which is called 'luxury uptake'. As a result, the cell may contain 8 – 16 times more phosphorus than the minimum required quota. As a consequence, it is theoretically able to sustain three or possibly four cell doublings without taking up any more phosphorus from the environment. It has been suggested that phosphorus storage in blue-green algae may be larger than in other algae providing them with a competitive advantage.

The phytoplankton biomass and the cyanobacterial component responded to phosphorus remedial action in four stages:

- 1. No biomass reduction if phosphorus in excess to requirements:** This stage occurs in nutrient rich water bodies where nutrients are never growth limiting and there is an unused fraction of the total phosphorus. In these cases there is no immediate effect on phytoplankton biomass or species composition.
- 2. Declining amount of unused phosphorus, small reduction in biomass:** This stage of recovery depends upon the behaviour of the phytoplankton in those water bodies where phytoplankton community is dominated by motile algae such as dinoflagellates and buoyant cyanobacteria. As a consequence of the reduced nutrient load, these phytoplankton move to greater depths as they seek additional nutrients.
- 3. Phytoplankton biomass falls, minimal unused phosphorus:** The phosphorus concentration continues to decline as a consequence of both the internal and external reduction of the phosphorus-loading. The overall result is a significant decrease in the phytoplankton biomass as p-limitation begins to take effect.
- 4. Further decline in biomass and changes in composition of the phytoplankton:** The fourth stage of recovery occurs once the water body reaches its new equilibrium state with a change in species composition. In this stage, the N:P ratio increase and the algal speciation shifts from toxic harmful blue-green algae to harmless beneficiary green algae because green algae required N:P ~30 whereas red algae required ~10, diatom required ~10, Dinophyceae required ~12 and blue-green algae required less than 29.

## **What is Phoslock**

Phoslock is a natural product which controls and manages blue-green algae in aquaculture ponds in environmentally friendly and sustainable way. Phoslock is produced from modified bentonite clay that was invented and developed by the CSIRO (Commonwealth Scientific and Industrial Research Organisation) Land and Water Division, Australia to significantly reduce the amount of bioavailable phosphorus (Filterable Reactive Phosphorus (FRP) or Soluble Reactive Phosphorus (SRP)) present in the water column and in the sediment pore water of a water body.

## **How does Phoslock work?**

Phoslock locks up the soluble inorganic phosphate ( $\text{PO}_4$ ) in the matrix of Phoslock clay. The phosphate is rendered bio-unavailable and cannot be used to fuel algal growth.

When applied as a slurry, Phoslock moves down through the water column and up to 95% of the Filterable Reactive Phosphorus (FRP) is rapidly removed and adsorbed onto the surface, forming an insoluble complex within the clay structure. As the Phoslock settles on the sediment-water interface it forms a 1-3 mm layer that is capable of adsorbing the FRP (on available binding sites) that is released from the sediment layer. Once the FRP is bound to Phoslock, it is no longer bioavailable for use by algae for assimilation and growth.

## **Why use Phoslock to control blue-green algae in aquaculture ponds**

The reduction of phosphate (after locking by Phoslock) in the aquaculture ponds will have a direct impact on the proliferation of blue-green algae. Reductions in phosphate will increase the N:P ratio and algal speciation will shift from toxic blue-green algae to beneficiary algae. Remaining beneficiary algae will be eaten by zooplankton, which are a natural food source for aquaculture species.

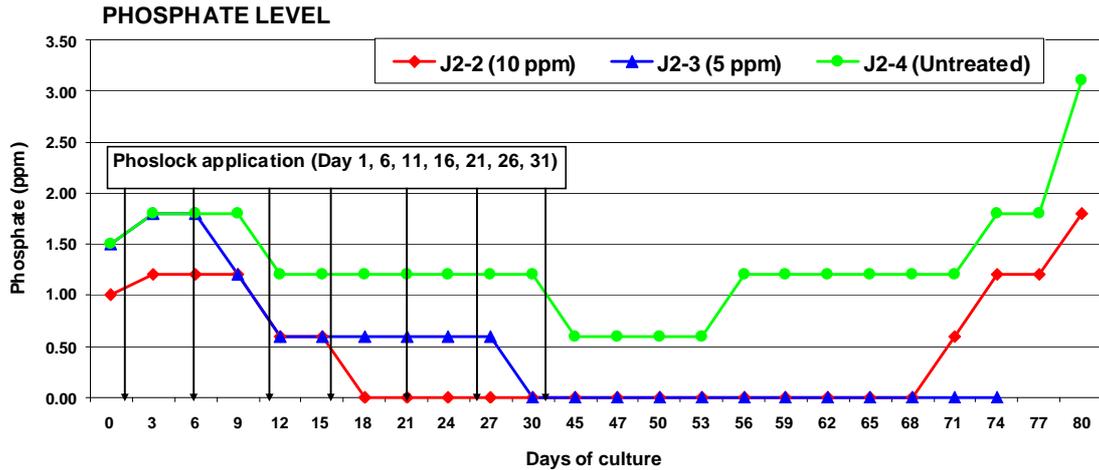
Growth and proliferation of blue green algae are not limited by the concentration of nitrogen in a water body. Some bloom forming blue-green algae are capable of fixing and storing nitrogen from the atmosphere. Their proliferation is related to the competitive advantage they have over other phytoplankton groups where excess phosphate (FRP) is available in the water. Therefore, phosphorus limitation by using 'Phoslock' is the most practical means of preventing the growth of toxic blue-green algae in intensive aquaculture ponds where nutrients regularly enter the water.

## **A successful application of Phoslock in the prawn aquaculture ponds at Malaysia**



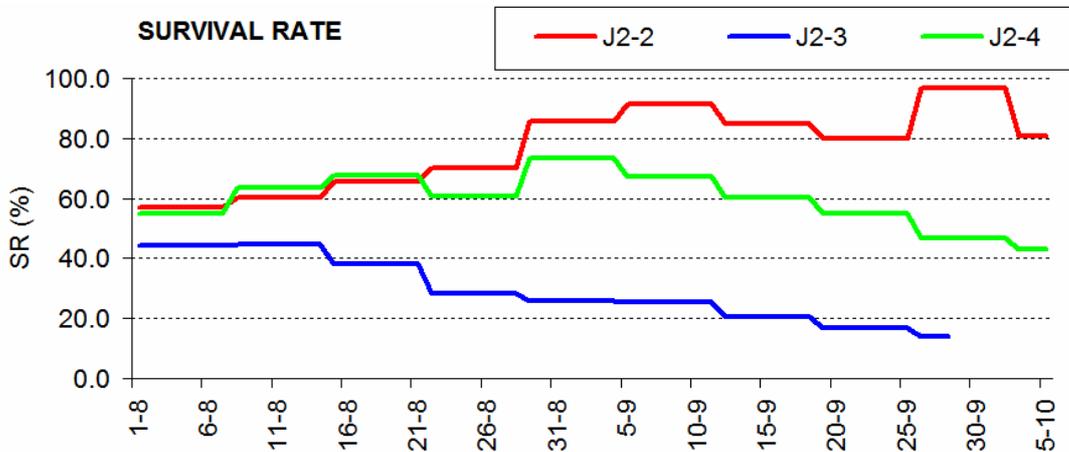
**Figure 5.** Prawn aquaculture farm in Malaysia.

Phoslock was applied in the prawn aquaculture ponds at a Malaysian aquaculture farm on a trial basis. Results demonstrated that Phoslock (both 5 ppm and 10 ppm) significantly reduced phosphate in prawn ponds (Figure 6). Phoslock (both 10 & 5 ppm) reduced phosphate concentrations to zero after a few applications. The zero concentration of  $\text{PO}_4$  was sustained for more than 30 days after the application of Phoslock stopped. It started to increase after day 68 because all of the available sites on the product were exhausted. To stop this from occurring and to combat the large amounts of  $\text{PO}_4$  accumulating in the pond, the Phoslock should have also been applied between day 31 and 68.



**Figure 6.** The concentrations of phosphate (ppm) in the Phoslock treated and untreated (control) ponds. Phoslock applied on six different days, up to day 31 of the culture period.

The Phoslock treated ponds showed improved water quality, increased prawn survival rates and increased average body weights (Figure 7). The survival rate of prawns was significantly higher in the 10 ppm Phoslock treated ponds (J2-2) compared to the untreated (J2-4) and 5 ppm (J2-3) treated ponds. It was acknowledged by the farm that the prawns in the 5 ppm pond (J2-3) had been affected by disease, hence the significantly lower survival rate.



**Figure 7.** The survival rate of prawns in the Phoslock treated and untreated (control) ponds up to day 65 of culture.

At present, there are two ongoing large scale Phoslock trials - one in Australia and one in Indonesia. Four different dose rates of Phoslock are being used in these trials and the product will be applied up to the end of the prawn grow-out season. We are expecting more comprehensive results showing Phoslock’s capability of controlling blue-green algae, improving water quality and increased prawn production from these two trials.

## Potential application of Phoslock in the catfish aquaculture ponds to control off-flavour problems

The off-flavour problem is a considerable economic burden to the U.S. catfish aquaculture industry (Channel catfish) and other aquaculture industries throughout the world. The catfish aquaculture industry is the fastest growing sector of the United States and some Asian countries such as Vietnam, China, Thailand, Malaysia, Indonesia, India and Bangladesh. In the United States catfish industry, off-flavour problems were calculated to have increased production costs by as much as US\$47 million in 1999. When catfish have an off-flavour, they can not be marketed and this results in increased production costs. Phoslock is capable of controlling the growth and proliferation of blue-green algae in catfish aquaculture ponds in a sustainable way. Controlling blue-green algal growth will reduce or eliminate the off-flavour problems from aquaculture ponds.



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